Differential adoption of digital technology in the Canadian agriculture and mining sectors

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Abstract:

The development and adoption of interconnected, digital control systems (i.e. Internet of Things) is posited to be on the cusp of radically reshaping the economic space in the goods producing economy. We can report that the hypothesized transformation is proceeding, but that different industries and different parts of the same industry are progressing at different paces. Our work on agriculture has revealed that the digital play is coming at and is embedded within the industry at almost all levels. Individual farmers, the existing global production network and the global innovation network are now endogenously developing, assessing and adapting new digital applications while the ICT and venture capital sectors are looking at the agriculture and food industry from afar and judging it is worth further investment. The Canadian mining sector, also a large contributor to Canadian GDP and exports, is much less engaged with the digital opportunity. Few Canadian ventures have identified or are working on digital applications to mining. We investigate the differential scope and scale of the transformations through the lens of industrial structure and firm strategy. While the agricultural industry is inherently and fundamentally engaged in heavy competition with the global market, most Canadian mining ventures act more like rent seeking oligopolies or regional monopolies, largely standing back from the dynamic global innovation network and delaying adaptation to the resulting transformation in the global production network. Public policy at the moment does not seem to be a barrier; instead, industrial structure and firm strategy seem to be the most significant barriers to engagement.

Key Words:

Digital transformation; agriculture; mining; adaptive behaviour; Canada; industrial structure; firm strategy

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1. Introduction

Digital applications, and the emergence of the integrated, automated and interconnected internet of things, initially was focused on creating new innovation and production spaces, either offering new programs or services or setting up new entrants to compete directly with existing, less digitally intensive production and marketing systems. While that activity was exciting to many, it offered prospects for only marginal increases in productivity and output, as the scope of application was a small part of the overall economy. There is increasing evidence that the pre-digital producers are now exploring if, how and where they might adapt and adopt this new technological opportunity to the existing global production system. This adaptive behaviour warrants further exploration.

The history of technological change is rich with stories of technological revolutions that threaten what Schumpeter called 'gales of creative destruction' as new market entrants with what look to be quantitatively and qualitatively superior technologies, products or business models overwhelm the existing production systems and make those firms and production methods obsolete. Adoption theory and most firm case studies show that incumbent market players are seldom indifferent to their fate—market leading firms often respond to technological challenges by enhancing internal R&D, by acquiring the innovations produced by others or by buying out new market entrants and either mothballing or absorbing their innovations into their operations. Generally we would expect to see this adaptive behaviour by the existing production system in response to the digital challenge.

The responses of the Canadian agricultural and mining sectors offer an interesting comparative case study of the adaptive behaviour of incumbent firms. This paper explores the divergence in their response. Section 2 discusses the theory and literature of adaptive responses to new technologies. Section 3 investigates the underlying context for application of digital technologies to the Canadian agricultural and mining industries. Section 4 reviews the evidence of uptake and use of digital applications in the two sectors. Section 5 explores three possible explanations for the observed divergence in responses: industry structure, firm strategy and policy supports. Section 6 addresses two overarching questions: how does diffusion of digital technology contribute to the dynamism and competitiveness of Canadian industry and do the changes affect the share of the global production network that Canada captures?

2. Adaptive responses to new technologies

There are two dominant views of how the market responds to the challenge of new technologies. Economists assert there is a well-motivated and routine approach that managers and owners use to select technologies to use. The business school rejoinder is that the standard model may work for iterative technologies, but it fails to capture the challenge of developing or adopting transformative technologies.

The economics literature suggests that the decision to adopt a new technology or innovation is determined by three important factors: recognition of competitive stance among firms in an industry and awareness concerning the existence of an alternative innovation following market conditions; motivation and/or incentive to explore the alternative and the resource availability to implement the decision (Chen, 1996). Rogers (2003) posits that the decision to adopt a new technology involves five stages, including knowledge (awareness), persuasion (potentially by gaining sufficient information on the characteristics, benefits and costs of a new technology), decision, implementation and confirmation. The adoption process starts with getting information about (awareness of) the new technology. This may be through media advertising, marketing or direct engagement with innovation in research, production or social networks. This is followed by a careful review of the perceived attributes of the technology and the potential benefits and costs of acquiring the technology. After examining the characteristics and weighing the benefits, costs and trade-offs associated with the new technology, a firm will make the decision to either adopt or reject the technology. Some factors including public response, the time of introducing the technology, location (region) of introduction and the influence networks where technical leaders drive opinions all could trigger rejection or acceptance. First adopters will usually need to invest time and resources in adapting and fine tuning the innovation to the production system and to reduce uncertainty about the impacts of the technology. At this stage, there is usually continued evaluation of the technology to ensure that it meets expectations. This can lead to re-invention (i.e., modification of the technology for compatibility to suit needs). It should be noted that the potential adopter continuously seeks more information about the technology, and therefore incurs transaction (search and negotiation) costs. Adoption decisions made prior to implementation stage of the adoption decision process can be driven by subjective judgement. After implementation and re-invention, the implementer seeks for facts and/or evidence, considering attributes of the technology (subjective judgement) to support his/her adoption decision. If the implementer is satisfied, he/she would objectively adopt the technology. There could be continuous use of the technology depending on the outcome. Alternatively, the technology may be discontinued if there is a new (higher) version for replacement or if the technology no longer meets expectations (perceived relative advantage).

A common result of technology adoption studies in the literature (e.g. Bohlen and Beal, 1955; Griliches, 1957; Hildebrand and Partenheimer, 1958; Mansfield, 1961; 1963) is that adoption often follows an S-shaped (sigmoid or ogive) curve, suggesting that adoption of a new technology starts slowly at first with few adopters, while the number of adopters increases (gets to the peak) as the knowledge about the technology spreads; and then slows down as the optimum number of potential end users adopt the technology. Despite the perceived benefits of a new technology, some agents will not adopt owing to reasons including: attributes of the technology (e.g. relative advantage of the technology, complexity, compatibility, divisibility), consumer opposition, firm size, costs (fixed and variable costs of investment) relative to benefits, profitability, socio-economic characteristics of decision makers and location (as the impact of some technologies could vary from one region to another). Mansfield's (1961) adoption model attributed the s-shape to inter-firm (or industry) differences and hypothesized that "the probability that a firm will introduce a new technique is an increasing function of the proportion of firms already using it, … but a decreasing function of the size of the investment required" (p. 672-763). On the other hand, Stoneman (1981) in his "Bayesian theory of learning" model of adoption interprets the s-shape as the 'intra-firm' diffusion path, and hypothesizes that a firm changes its level or rate of adoption of a new technology as it learns more and accordingly adjusts its expectations.

The business school literature does not dispute the economic model, but is concerned it has limited application. Bower and Christenson (1995) assert that 'one of the most consistent patterns in business is the failure of leading companies to stay at the top of their industries when technologies or markets change' (43). They cite the example of late or poor responses by Goodyear and Firestone to the radial-tire market, Xerox's failure to exploit their innovations in the small copier market, letting Canon gain a lead, Bucyrus-Erie allowing Caterpillar and Deere to take over the mechanical excavator market and Sears giving way to Wal-Mart. The focus of their work is on offering advice on how leading firms might remain on the cutting edge of the technology in their sector. Each of their iconic examples represents a case of transformative technology, product or business model that had a profound effect on the market and that the dominant firm let get away from them. Bower and Christenson (1995, 45) offer one possible explanation of this outcome: 'disruptive technologies introduce a very different package of attributes from the one mainstream customers historically value, and they often perform far worse along one or two dimensions that are particularly important to those customers. As a rule, mainstream customers are unwilling to use a disruptive product in applications they know and understand. At first, then, disruptive technologies tend to be used and valued only in new markets or new applications; in fact, they generally make possible the emergence of new markets.'

The image of firms and sometimes whole industries missing the boat on some major technological change dominates much of the research on new technologies. While those examples of strategic failure offer some insights into the technological innovation challenge, the more important question is why and how the majority of firms sustain themselves in the face of such challenges. To unpack this problem we need to go beyond the hagiography of firm success and failure and look deeper into the dynamics with production networks that operate locally and connect globally.

Many assert that the Internet of Things will be one of those transformative changes that challenges firms to adapt. While it is true that some specific firms choose to forgo being early innovators and thereby shrink in relative size and importance in their markets, the more enduring but less observed and studied phenomena is that those firms that generate the bulk of any sector's GDP and jobs for the most part muddle through, adapting and adopting technology just fast and far enough to remain competitive. Even with the iconic examples above, most of the laggard firms still operate and command a large if not dominant market share in their sector. From a research perspective, there is much to be learned by examining how all firms, and not just the leading firms (or leading firms that are lagging), adapt and adopt to transformative innovation.

Bower and Christenson (1995) argue that 'using the rational, analytical investment processes that most well-managed companies have developed, it is nearly impossible to build a cogent case for diverting resources from known customer needs in established markets to markets and customers that seem insignificant or do not yet exist' (ibid 45). Rosenberg (1994, 53) concurs, concluding that 'innovation, the central feature of capitalist reality, is not a product of a decision-making process that can be described or analyzed as "rational".' He credits Schumpeter with previously asserting that:

> the assumption that business behavior is ideally rational and prompt… works tolerably well only within the precincts of tried experience and familiar motive. It breaks down as soon as we leave those precincts and allow the business community under study to be faced by … new possibilities of business action which are as yet untried and about which the most complete command of routine teaches nothing (ibid, 98-9).

This paper explores the adoption of digital technologies in the Canadian agricultural and mining sectors through these two lenses of the rational economic actor and the disrupted decision maker forced to make decisions under conditions of profound uncertainty.

3. The agricultural and mining sectors in Canada

Agriculture and mining are two historically and currently important sectors in Canada.

Canada is one of the world's strongest and most competitive agricultural producers. Canada is one of the top five global players in the world's agri-food industry. Canada's agriculture and food sector contributes $100+ billion to the national GDP, employs 2.1 million people (12% of total Canadian employment) and generates about $55 billion in gross exports annually. Canada is the world's fourth largest exporter of foods, exporting more protein per capita than any other major exporter (AAFC 2015).

Mining is similarly important, albeit in different areas of the country. Indeed 'extraction' activities are so important the statistics are often but not consistently reported separately as basically *oil and gas* and *minerals and metals*. Canada's value of mineral production was $42.8 billion in 2015 and the industry contributed $56 billion to Canada's Gross Domestic Product (GDP) in 2015 and directly employed more than 373,000 workers across the country in mineral extraction, smelting, fabrication and manufacturing, and indirectly employed an additional 190,000. The CCA report on industrial R&D (2013) reported that mining and quarrying, oil and gas extraction, one of only four industries in Canada that ranked as significantly large within the OECD (i.e., at least 1.25 times the OECD average), was roughly 330 per cent the size of the OECD average. Canada ranks in the top five countries in the global production of 13 major ***minerals and metals***, including: first in potash; second in uranium, nickel and niobium; third in cobalt, aluminum and platinum; fourth in salt, sulphur and tungsten; and fifth in diamonds, graphite and gold. Workers in the industry enjoyed the highest wages of all industrial sectors and the mining is the largest private sector employer of Aboriginal peoples in Canada on a proportional basis. In addition to the core industry, Canada has one of the largest mining supply sectors globally with more than 3,700 companies supplying engineering, geotechnical, environmental, financial and other services to mining operations. About 57% of the world's public mining companies are listed on the TSX and TSX-Venture Exchanges and together the two exchanges accounted for 53% of the equity capital raised globally for mining in 2015, totalling $6.8 billion (Mining Association of Canada 2017).

Table 1: Percent Distribution of GDP by industry and province, 2014.

Industry	Canada	AB	SK	MB
All industries	100	100	100	100
Agriculture & FFH	1.7	2.0	11.0	4.2
Mining, quarrying, oil & gas	8.2	23.1	24.2	4.1
Utilities	2.5	1.6	1.9	2.3
Construction	7.2	10.9	7.6	6.5
Manufacturing	10.4	7.3	6.4	11.3
Services	69.9	55.1	48.9	71.7

Source: Statistics Canada.

Agriculture and mining are differentially located in Western Canada. Saskatchewan, in particular, has the highest share of its GDP derived from agriculture and mining, is the centre of a globally competitive dry-land grains research community and is home to the head offices of Canadas' potash and uranium industries, two of Canada's leading mining sub-sectors (table 1).

While both sectors have higher productivity in Canada than the US (CCA 2013), they face a range of competitive challenges. Overall, both sectors face pressures sustaining multi-factor productivity. Agriculture has and continues to face a long-term secular cost-price squeeze, as real output prices have not kept up with inputs costs. Hence, rising productivity is a necessary condition for short and medium term success, as gains in capital and labour productivity offset the squeeze on profits. Mining, as well as oil and gas extraction, in contrast, faces resource exhaustion, with easily and cheaply accessible deposits having to be replaced by more expensive ore bodies. This leads to declining capital and labour productivity, which for much of the past 15 years has been offset by buoyant markets (at least partly due to China's apparently insatiable demand for primary inputs). Now, with Chinese growth moderating, most commodity prices are off their peaks, firms are being squeezed in ways that may lead them to work to find ways to improve their capital and labour productivity.

Table 2: Productivity Growth (annual average 1997-2007)

Sector	**Canada**	**AB**	**SASK**	**MB**
Economy-Wide Market Sector				
Multifactor Productivity	-0.24	-2.22	-1.17	0.46
Labour productivity	1.29	0.57	1.79	1.88
Capital Productivity	-0.47	-4.22	-2.46	-0.62
Agriculture & FFF – MFP				
Multifactor Productivity	2.44	4.07	1.01	2.87
Labour productivity	4.55	8.75	5.46	5.59
Capital Productivity	1.91	2.80	0.08	2.51
Mining and Oil & Gas Extraction				
Multifactor Productivity	-4.64	-6.10	-6.36	-1.11
Labour productivity	-1.56	-2.98	-4.52	2.05
Capital Productivity	-5.10	-6.90	-6.57	-2.72

Source: http://www.csls.ca/reports/csls2011-03.pdf

4. Digital engagement in the agricultural and mining sectors

The digital opportunity is for the most part not reflected in the data in table 2. The data is lagging the adoption of the technology. So it is necessary to look elsewhere for a sense of the scale of digital opportunities and uptake and use of the various applications.

McKinsey Global Institute (2013) estimates that the IoT—combined with mobile internet, 3D printing, automation of knowledge work, advanced robotics, next-generation genomics, cloud technology, autonomous vehicles and various specific applications to energy and materials—will directly generate more than $125 trillion gross value by 2025 (Table 3). To put that into perspective, the World Bank estimates current annual global gross world product (the sum of all national domestic product (GDPs) in 2014 was $78 trillion (World Bank, n.d.).

McKinsey identified 12 digital technologies that would have potential application across the economy. Eight of the 12, projected to generate in aggregate about 75% of the value of digital applications, are applicable to some part of the agri-food global production network while 10 of the 12 worth about $120T could find a fit in mining.

Table 3: The scale and scope of the digital opportunity and its potential application in agriculture and mining

	Projected value ($T)	Application in agriculture	Application in mining
Internet of Things	40	X	X
Mobile internet	26	X	X
3D printing	11		X
Automation of knowledge work	9	X	X
Advanced Robotics	8	X	X
Next-generation genomics	8	X	X
Cloud Technology	5	X	X
Autonomous and near autonomous vehicles	4	x	X
Advanced oil & gas exploration and recovery	4		
Renewable energy	4	x	X
Energy storage	3		X
Advanced materials	1		

Source: McKinsey Global Institute (2013). (Highlights reflect areas with direct economic input-output relationships with agricultural or mining sectors)

With this as context, it is worth asking about the efforts of firms in the two sectors to respond to this technological opportunity so far. Across the whole economy, about 51% of all firms and 85% of large firms (>500 employees) have invested in ICT in the past three years. The main investments were for hardware, followed by off the shelf software, network operating systems and customized software. The primary part of the agricultural sector underperformed on all available measures, while the larger mining firms invested more than most large firms in Canada but smaller ventures were lagging somewhat. This data should be taken as only one part of the story, as the survey only really captures the direct investments in ICTs and fails to capture the embedded ICT value in inputs and processes bought in.

Table 4: Survey of digital technology and Internet use, capital expenditures on types of Information and Communication Technologies (ICTs), by North American Industry Classification System (NAICS) and size of enterprise

Type of capital expenditure on ICT	Size of enterprise	Private sector	Agriculture	Mining, quarrying, oil & gas extraction
Any capital expenditures on ICT in the past three years	Total	51.3	**36.7**	46.4
	Large	85.5	**83.1**	**96.1**
	Medium	76.5	**73.0**	75.5
	Small	48.2	**34.0**	41.2
Computer hardware	Total	47.4	**34.3**	42.1
	Large	84.7	**59.1**	**95.7**
	Medium	73.8	**69.6**	74.7
	Small	44.2	**31.8**	36.5
Customized software	Large	52.5	**33.8**	23.3
Network Operating Systems/Equipment	Total	18.3	**13.9**	**26.1**
	Large	65.7	**66.3**	**87.6**
Off-the-shelf software	Total	32.0	**27.1**	22.9
	Large	62.6	**50.6**	**90.7**

Source: Stats Can 358-0201.

Of course the global production network for agriculture and mining are not fully captured by the narrow NAICS classification of those two industries. Table 5 breaks out a range of other three and four digit sectors to investigate their investments in and use of various ICT applications. Looking at Table 5, one can see that many of the upstream inputs to both the agriculture and mining sectors (such as scientific R&D, chemicals, and various upstream business services) are relatively heavily engaged in the use of new technology, while many of the downstream activities of common interest (especially truck transportation, which is important for both sectors) are not overly invested in applying digital applications. Overall, data processing, which will be vital to exploiting the data rich environment of the internet of things, is a relatively weak investment category across most sectors.

Table 5: Survey of digital technology and Internet use, capital expenditures on types of Information and Communication Technologies (ICTs), by North American Industry Classification System (NAICS) and size of enterprise

Type of ICT service expense	Any outlays on ICT in past 3 years	Software as a service	Web site design or hosting	Data processing services	Database services
Private sector	*51.5*	*18.3*	*31.4*	*7.5*	*17.8*
Mining, quarrying & oil & gas extraction	*51.6*	*25.7*	*93.4*	*1.6*	*13.1*
Agriculture (& FFH) [11] (1)	*29.9*	*3.3*	*19.3*	*6.1*	*11.9*
Global Production Network					
Scientific R&D services [5417]	66.4	25.9	38.8	8.2	21.6
Chemical manufacturing [325]	79.1	17.5	61.1	x	x
Machinery & equip wholesale-dist [417]	74.2	31.4	48.9	9.2	26.1
Insurance and related activities [524]	75.9	19.4	47.7	16.2	43.2
Management, S&T consulting [5416]	47.3	16.9	22.3	4.8	15.5
Securities & commodity contracts [523]	28.0	12.3	16.0	3.6	12.9
Farm product wholesale-distrib. [411]	23.7	2.0	18.5	3.5	7.7
Truck transportation [484]	24.9	6.6	7.1	0.7	6.6
Food manufacturing [311]	58.7	14.8	33.7	10.5	22.7
Accounting, tax prep, books (5412]	58.4	21.0	22.2	0.7	11.1

Source: Stats Can 358-0201

While the data is only partial, our work on agriculture (25 surveys and the 2016 GEM analysis) has revealed that the digital play is coming at and is embedded within the industry at almost all levels. ***The pace of change in the agricultural space is presently faster than research allows.*** At the beginning of the research project the general assessment of the large capital (digitally embedded) equipment was "not yet". The mood appears already to be changing. Individual farmers, the existing global production network and the global innovation network are now aggressively assessing and adapting new digital applications. Most commercial farmers now use at least one and most many digital applications (e.g. self-guiding seeding and harvest equipment, digital planning and recording of fields and animals and/or digital management or data analytics of inventories and markets). A recent Internet based survey (Steel 2017) reported that 49% of farmers reported using precision agriculture tools on the entire farm and another 37% reported using it on part of the farm. Only 11% had not tried using any of the tools. Given that the survey was not based on a random sample, it should be viewed as representing a snapshot of the practices of early and middle adopters in the sector. An average 63% of the acreage cultivated by the farmers surveyed was soil sampled, of which about 70% was geotagged with GPS coordinates, which means about 40% of their total acreage was ready for more intensive data capture and analysis. Almost all farmers surveyed (98%) reported using GPS guidance systems for their operations. Between 85% and 96% of the fertilizer, spray and seed was applied with GPS guidance. 70% of chemical was applied using automatic section control to manage applications, while 37% of fertilizer and 26% of seed was applied using ASC. About half of producers use prescription maps and/or variable rate technology to determine rates of application of fertilizer (49%), seeds (24%), chemicals (11%) and irrigation (5%). Almost 40% used remote imagery in-season to monitor their crops, 28% from satellite systems and 19% captured by drones. More than 85% of the combines used some form of real-time monitoring. About two-thirds of farmers reported using temperature and moisture sensors to monitor grain stored in bins. Virtually all producers in the survey reported using a mix of desktop, laptop, table and smartphones for farm business management. While most farms reported they managed their farm data, they shared that task with farm/crop consultants (31%), crop input dealers (6%), equipment dealers (4%) and accountants (5%).

The rest of the agri-food production network is equally engaged. The large multinational seed and farm machinery companies all have invested heavily in applications and existing digital firms, while the ICT and venture capital sector directed at digital applications are looking at the industry from afar and judging it is worth further investment. A large number of new entrepreneurs are contesting the market with digital applications for farm management and marketing. The non-agricultural ICT and venture capital industry is also searching for applications of their skills in the farm and food space, both in the upstream breeding industry (e.g. data rich breeding models, including automated phenotyping and genotyping) and in downstream farm and food apps. The AgFunder (2017) AgTech Investing Report, compiled from SEC filings and media reports, shows investment in food and agriculture technology start-ups was $2.36 billion in 2014, $4.6 billion in 2015, and $3.2 billion in 2016, for a 3 year total in excess of $10 billion. About $1 billion in 2016 was directed at digital applications. Overall, about half the flow of funds was in the US. India, Canada, UK and Israel France closed out the top five by number of deals. But for so much of the agriculture market — which represents about 10 percent of global GDP— there is still a wide funding gap that other sectors are not experiencing: only about 3.5 percent of total VC funding was directed to agriculture.

The evidence of value change is accumulating rapidly. Whether and how Canadian firms will exploit this transformed value is less clear. Most of the multinationals are non-Canadian and do much of their research and data management elsewhere, which risks value migration. But translating that research to use requires local partnerships in research systems and production networks. There are also a significant number of Canadian-based entrepreneurial start-ups. Based on assessments of other technological transformations in agriculture, we can conclude that at least a portion of the value of the new technologies will be shared with producers (Alston et al. 1999; Gusta, et al 2010).

Mining presents a bit more of a challenge. The mining, quarrying, oil and gas sector is often aggregated into a single NAICS code, but there is significant heterogeneity within and among the different commodity spaces, partly depending on whether they use open cut mining techniques, drilling and slurry extraction or long-wall, deep rock mining (table 6). No major mineral or energy (except natural gas) is mined or extracted using only one of the three methods. As traditional deposits or reserves are exhausted, some sectors are moving between different mining technologies. For example, oil, which was traditionally drilled and extracted as crude, is increasingly being mined in Canada in open cut operations where bitumen is extracted and further refined elsewhere. Potash which started largely as long-wall mining deep underground has been further mined through solution mines and now, in 2017, the first open pit mine is opening in Eritrea. Uranium is both open cut and long-wall mined, and there is some discussion about adapting horizontal drilling and slurry technologies to exploit some of the richest and deepest deposits in Northern Saskatchewan.

Table 6: Approximate distribution of mining and extraction techniques for global extraction of energy and mineral resources

	Drilling	Long-wall	Open cut
Oil	70%	0	<30%
Natural gas	100%	0	0
Iron Ore	0%	20%	80%
Coal	0	40%	60%
Diamonds	0	10%	90%
Potash	25%	70%	5%
Uranium	0	65%	30%
Gold	0	35%	65%
Other metals (e.g. copper, zinc)	0	70%	30%

The digital opportunities in the mining and energy space will vary by the type of extraction used. Drilling involves extensive geomatics and engineering physics, as directional drilling and fracking, leaching and various slurry techniques are used to extract the commodity from locked-in pocket in the overburden. Long-wall mining involves a similar mix of geomatics and engineering, but the logistics of mining involves machinery, only some of which with current technologies is being automated. Open cut operations are perhaps the most amenable to automated machinery, especially with autonomous vehicles, to make extraction cheaper, safer and more predictable (see HAL 2015 for study on geomatics in Canada).

By some estimates the global mining software and technology industry is now US$16.3 billion (2010) and forecast to rise to $26.1 billion by 2018 (Lee and Prowse 2014). Embedded in those numbers is a small but growing global investment in autonomous equipment in mining totalling about US$360 million annually, which represents about 60 autonomous units annually. This compares to a $3.6 trillion global industry, with about $2.7 trillion from mineral fuels. Table 7 reports the recent Canadian investment in R&D in the broad sector, which represents only about 1.3% of the $127 billion gross sales from the industry. A recent MaRS study reports that Australia has invested more than four times as much in research and development than Canadian firms, which has led to a growing gap in research competitiveness and technology uptake over the last decade between Australia, the widely acknowledged leader, and Canada (ibid).

Table 7: Research and development performed by business enterprises in the mining, quarrying, oil and gas extraction sector

	2009	2010	2011	2012	2013
Total R&D expenditures ($M)	**929**	**981**	**1,387**	**1,608**	**1,645**
Current expenditures ($M)	823	868	1,175	1,012	1,138
Capital expenditures ($M)	106	113	212	596	508
Total R&D personnel (FTE)	**1,873**	**2,044**	**2,089**	**1,896**	**1,897**
Professionals (FTE)	1,006	1,249	1,403	1,268	1,158
Technicians (FTE)	740	688	584	438	436
Other support staff (FTE)	127	107	101	189	303

Source: Statistics Canada, CANSIM, table 358-0024 and Catalogue no. 88-202-XIE, http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/econ151c-eng.htm.

While industry is not obviously an aggressive investor, there is some positive news. The CCA study on industrial R&D report in 2013 reported that Canada had a strong capacity in university and laboratory based research and that a relatively large portion of those publications were either undertaken by or in partnership with industry. The industry share of total publications was 33% in mining and metallurgy; 17% in geological and geomatics engineering and 13% in geology.

But in terms of actual adoption of digital applications, the Canadian industry is lagging. The MaRS study of mining and the IoT concluded that "Without a doubt, there are strong cases that support the adoption of the IoT in mining. While the benefits appear to strongly favour IoT adoption, we need to consider that the question of adoption tends to vary from company to company, and that the mining sector as a whole lags behind other sectors of the enterprise market (e.g., manufacturing)… Almost all of the stakeholders we spoke with acknowledged that mining companies are as a group risk-averse and very cautious when it comes to adopting new technology" (Lee and Prowse 2014, 18). The use of autonomous haul trucks appears to be one signal of adoption of IoT applications (Brundrett 2014). Currently there are about five major manufacturers of these machines, and four of the five appear to be aggressively converting their machines to be autonomous. Each of the major suppliers has developed a strategic alliance with some part of the mining sector. Komatsu aligned with Rio Tinto in 2008 to automate a number of heavy haul trucks and Rio Tinto has purchased more than 63 for its iron ore mines in the Pilbara in WA. By some reports Komastu has no spare 'autonomous capacity' to direct sales to other customers. Rio is also trialing autonomous ore trains (2015) and robotic drills (2017). BHP Billiton aligned with Caterpillar (which acquired Belay) (2011), Hitachi is aligned with Stanwell Coal (2013) and Belaz is aligned with Russian mining operators. Volvo, which acquired Trex, and Liebheen are reporting experiments with automated heavy haul trucks but have not signalled any strategic partnerships. The CBC (2016) reported that Suncor has some experimental Komatsu equipment on site at its heavy oil properties in Alberta but there are no other obvious trials in Canada with autonomous vehicles.

There is no unambiguously obvious reason for the differential uptake and use of digital technologies in these two important, globally competitive Canadian industries. The next section explores three theoretically postulated explanations.

5. Why is there a gap in adoption in some sectors and subsectors?

Theory suggests there could be three main reason which individually or collectively could lead to differential adaption and adoption of digital technologies in agriculture and mining. First, industrial structure, both in terms of the corporate concentration and in terms of the built capacity, could be either a pathway or barrier to adoption. Second, firms within each sector may have specific strategic or tactical preferences that influence the rate of uptake and use. Finally, there may be a lack of supports for entrepreneurial effort to translate ideas into products and services appropriate to the sectoral needs. This section explores the evidence for each factor.

5.1 Industry structure:

As far back as Schumpeter (1934) scholars have observed that the structure of an industry can have a significant influence on how firms engage with or respond to innovation pressures. Theory suggests that there is not a simple trade-off between competition and innovation. Schumpeter aptly pointed out that perfectly competitive enterprises seldom could justify the investments in research and commercialization unless they had some hope of gaining some market power by which they might drive a wedge between their marginal cost and demand in order to recoup a return on their investments. Yet, when it came to adoption of new technology, perfectly competitive firms are usually on a technology treadmill, whereby they need to operate at or near the production possibilities frontier to survive, and hence will be aggressive adaptors and adopters of technology. At the other end of the competition scale, pure monopolies similarly have limited interest in aggressive innovation, as any resulting creative destruction would effectively come from their profits and capital base; moreover, as monopolies they have less incentive to aggressively adapt and adopt technologies if their market is relatively secure. Hence, one might expect to find the most aggressive research among firms that exhibit some market power, be it monopolistic competition or some measure of oligopoly, while adoption is most likely to advance quickly among those facing the full brunt of competition.

Table 8 provides a brief overview of the competitive structure of the global production networks that Canadian agriculture and mining occupy. Agriculture is fundamentally grounded in a large and highly competitive community of owner-operated farms, that are perpetually squeezed by declining real output prices and rising input costs. Producers aggressively adopt new technologies. The input and output sectors are more organized and exhibit some market power, but except in a few regulated spaces such as rail transport, few of the industrial segments or firms in those segments have much sustained market power. Their markets are eminently contestable. Hence, the sector as a whole is open to change and aggressively invests in research.

The mining industry is much less buffeted by market pressures. While individual firms might complain that their prices are volatile, it is less due to other firms capturing part of their market and more because of price cycles that all producers face. While Canada's mining sector looks oligopolistic, which might suggest it is open to investing in research, it actually exhibits many monopolistic attributes. Neither of those sectors and the firms in them have any substantial investments in research divisions in Canada, reducing their capacity to absorb technological innovations from outside their enterprises. Meanwhile, the sectors are highly organized, which minimizes their local competition. All of the current potash producers market all of their offshore sales through Canpotex, a de-facto cartel; competition among the firms is limited to the North American market. Meanwhile the only uranium producing firms are partners on all the current mines in Saskatchewan, so in effect they have cartelized the production in Canada. Uranium producers have also come to an accommodation with First Nations communities in the North, exchanging jobs in trucking and services for social license to operate; moving to automation would destabilize these important relationships. In both cases, the sectors, and firms in them, have little built capacity, incentive or interest in aggressively destabilizing their production systems.

Table 8: Industrial structure of enterprises operating in the agriculture and mining sectors in Saskatchewan

	Agriculture			**Mining**		
	Sub-sector	***# firms***	***C4***	***Sub-sector***	***# firms***	***C4***
Inputs	Seeds	>50	5-80%	Machinery	<10	>50%
	Patented Chemicals	~5	>70%	Geomatics in Western Canada	~525	<10%
	Machinery	~10	60%			
	IT firms	>100	>10%	IT firms	>100	<10%
Primary producers	Farmers	28,642	<1%	Potash mining	13	100%
				Uranium mining	30	100%
Marketing	Licensed grain cos	~160	>75%	Potash	4	100%
	Grain processors	~30	<25%	Uranium	2	100%
Transportation	Custom trucking	>250	<10%	Trucking	~10	>70%
	Rail (incl. shortline)	15	~100%	Rail	2	100%

5.2 Firm strategy:

The two sectors exhibit a different mix of firms that have varying strategies. While agricultural sector firms report major barriers across the landscape (table 9) and report lower than average investments in ICT applications (Table 5), the overwhelming evidence from surveys and reports is that the industry is innovating, adapting and adopting new digital technologies aggressively.

Table 9: Barriers to adoption of ICT by factor, firm size and selected sector, 2012

	Firm size	Private sector	Agriculture	Mining, quarrying, oil & gas
Cost of technology & implementation too high	Large	40	72.9	8.6
Employee resistance to new technology	Total	9.6	11.5	17.6
Lack of technical expertise & skilled personnel in-house	Total	29.5	54.5	12.6
	Large	18.4	--	6.8
New systems incompatible with existing systems	Large	18	61.8	5.5
Security and/or privacy concerns	Total	18.7	30.9	6.9
Unaware of new technologies	Total	16.4	20.1	5.8

In contrast, the mining sector reports few barriers, except employee resistance to new technology (see Thomson 2016 for a study on the impact of digital technologies on mining in Saskatchewan). Firms report that there are no extraordinary barriers to adoption, and in fact there is evidence of many firms testing out new technologies, but as a whole, while agriculture seems to be adapting, the mining sector has not engaged in sustained innovation (table 10).

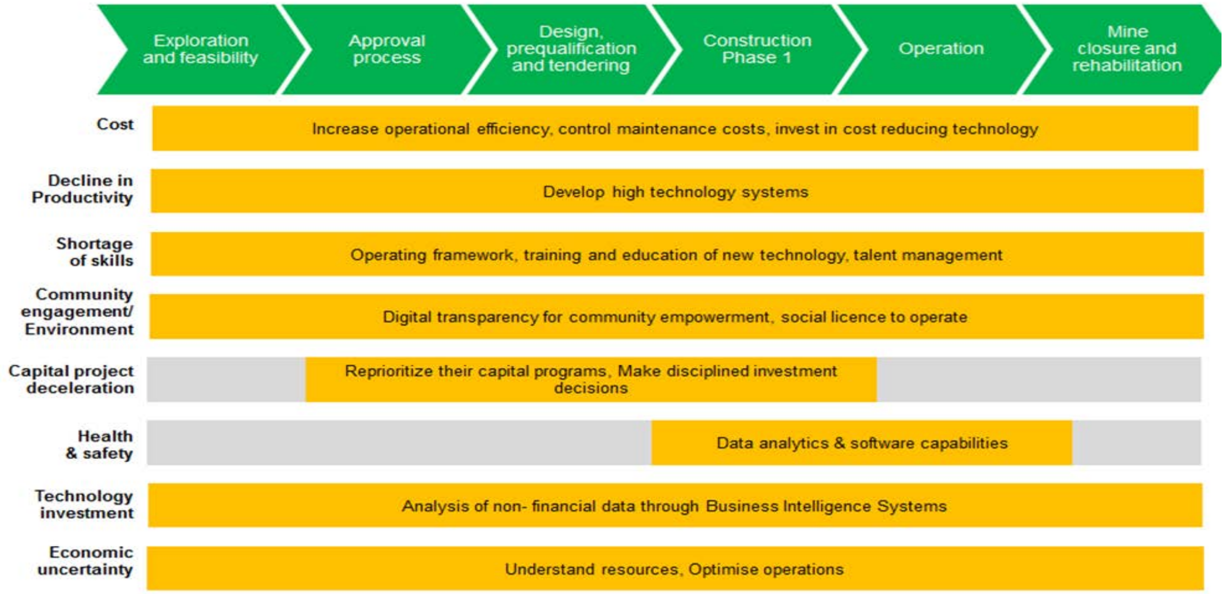
Table 10: Firms reporting different innovations, 2007-09 (percent of all firms surveyed)

	Goods innovation	Services innovation	Process innovation	Organizational innovation	Market innovation
Mining & related acts.	23.5	6.3	14.6	39.5	19.8
Oil, gas & drilling	6.4	0	8.7	20.9	2.9
Manufacturing	42.6	21.7	15.7	44.9	20.4
Food manufacturing	36.5	14.4	17.7	38.3	20.2
Services	25.3	27.7	14.7	30.9	31.3

SOURCE: Industry Canada 2009.

The developments in Australia show how far away the Canadian sector is from the technology frontier. The state of the art of firm and sectoral engagement is Australia, according to most observers. Deloitte undertook a detailed roadmap for the both the mining and energy sectors, developing detailed sets of drivers and assessments. Figure 1 illustrates one of the many templates they have developed and that seem to be driving both firm and sectoral strategies. One observation from reviewing the efforts and prognostications of Australian miners is that the IoT will fundamentally disrupt the management of global mining. Some of the firms are looking at linking all of their automated ventures across regions, products and markets to optimize a range of values in real time. Firms assert they could sharply lower their carbon foot prints, more fully arbitrage among and within mineral and energy subsectors and optimize profits across their entire portfolio of investments. Currently, planning and management make relatively lumpy decisions based on data that lags the market by hours, days, weeks, months and sometimes years. Tightening the information flow and using it in real-time (perhaps even automated) management could have profound effects on where value is generated and who benefits. Apart from a MaRS report on the deficiencies in the sector (Lee and Prowse 2014), there is no evidence of similar thinking or planning for the future use of this suite of technologies.

Fig 1: Business drivers and technology requirements – Mining



Source: Deloitte 2013.

5.3 Policy and program support:

A third possibility is that there is latent supply and demand for new technologies but that the market cannot unaided put the two halves together. In those cases, public policy and program support could be instrumental. We tested that proposition through the Global Entrepreneurial Monitor, which was directed in 2015 and 2016 to target the ICT actors in the agricultural and mining space in Saskatchewan.

When we analyzed the results we came up with an interesting and perhaps counterintuitive result, but one that does not lead one to accept this potential factor as important. The GEM survey tests a range of factors that are hypothesized to affect the entrepreneurial and innovation performance of an economy, including finance, government policy and programming, education and training, R&D transfer efforts, infrastructure, market structure, cultural and social norms and social entrepreneurship. Most GEM analyses tend to focus on weaknesses in programming, aggregating the opinions of all respondents, which are drawn both from the user and supplier domains. While we don’t have results of our 2016 survey yet, our 2015 survey targeted at the agricultural sector revealed that, when we disaggregated the responses by whether the respondent was a supplier or user of the entrepreneurial programming, generally those directly involved in supplying a factor (e.g. financiers connected to finance and public servants connected to policy and programming) were less positive about the quantity, quality and impact than entrepreneurs who used the program or service. The preliminary results suggest that while experts may be dissatisfied by the state of their offerings, the potential users are relatively content. In short, there does not seem to be a compelling reason to conclude that the programs designed to support entrepreneurial activity are a barrier to impact (Wixted 2016).

In short, familiarity appears to breed contempt of policies, programs and instruments. We intend to extend this analysis using the results of the 2016 GEM survey which targeted ICT actors in the mining sector. We will then undertake a series of surveys to test to determine how much over-confidence among users and/or the Dunning-Kruger Effect among expert suppliers and lay users might contribute to the divergence of opinions.

5.4 Summary of impacts

Table 11 summarizes our somewhat counterintuitive findings. While agriculture is relatively poorly prepared for the IoT, is a modest investor in research to adapt it and faces significant technical barriers, the nature of the marketplace and production system has incentivized firms both inside and outside the industry to adapt, adopt and use the technology. In contrast, mining, which appears on the face of it to be well prepared and faces few technical barriers, is weakly involved in research and has exhibited little interest in adapting, adopting and using the technology in existing mining operations. The only significant difference between the two sectors is the industrial structure and firm strategies—relatively stable and non-competitive conditions allow miners to abstain while the dynamics of the agricultural and food sector are driving forward investment and use.

Table 11: Relative engagement with the digital opportunity in the agricultural and mining sectors

	Preparedness	Research and Investment	Technical Barriers	Adoption and use
Agriculture				
Upstream	Above average	Moderate	Above average	Strong
Primary sector	Below average	Weak	Above average	Strong
Downstream	Below average	Weak	Above average	Moderate
Mining				
Upstream	Above average	Weak	Below average	Weak
Primary sector	Average	Weak	Below average	Weak
Downstream	Above average	Weak	Below average	Weak

6. Conclusion:

While the key to successfully navigating the transition to an Internet of Things world is adapting the technologies to our existing production system, we are unable to say with any confidence that that transition will prove possible or fruitful. The evidence from the agricultural system is that it is ready, willing and able to adapt, and perhaps actually might be a principal actor in the transformation. In contrast, the mining industry is holding back, watching and observing. It is unclear which strategy will have the greatest effect on long-term competitiveness.

Our evidence does provide a base for addressing two core questions that drive concerns about the digital transformation: How does the diffusion of digital technology contribute to the overall dynamism and competitiveness of Canadian agriculture and mining? And, does it change value capture in our portion of the global production network? The answer to the first question is that it variably affects the dynamics and competitiveness of Canadian industry. The competitive structure and the inexorable pressure of the cost-price squeeze is driving aggressive engagement, innovation and adoption in farming and in its related and supporting industries. Mining seems to be holding back. Theory and evidence suggests that those sectors and firms able to engage early will likely gain some innovator and early adopter benefits (especially farmers) but those who hang back risk losing market position. The impact of new drilling technologies on the global oil industry is a salutary lesson for those who think a large endowment of resources is enough to sustain a dominant market position (Vara 2017). As for value capture, except in pockets in the agri-food space, most of the research and technological development is happening abroad. As those technologies reach scale, they will capture a portion of the value chain. At least in the primary industries where there is limited capacity to differentiate output, this is a zero sum proposition, so any value capture by others is a loss to the existing actors in the global production network.

The lesson from this work is not that there is anything fundamentally wrong about the technologies, their potential value or the economic or policy context. Rather, there is a lack of firm and sectoral leadership to take advantage of this opportunity.

At one level, this paper dampens both the enthusiasm and angst about Canada's engagement with the IoT. Many of the developments we are able to measure are really only 'standard' innovations. The radial, disruptive and transformative changes are all somewhat in the future. In mining, the application of autonomous machines and IoT data management signals more is coming. Metals and non-renewable energy is no longer operating in even a semi-stable environment. In decades past minerals and energy miners were only really in competition with each other. Now the rollout of IoT technologies across the economy could fundamentally alter the demand conditions in primary sectors. One small example is that if autonomous cars proceed as forecast, they have the potential to reduce the need for personally owned vehicles by 60%. This would dramatically shift demand for metals. In other cases technologies long deemed unviable have made huge gains in recent years—solar energy is now approaching the same cost structure as coal, an idea than even a few years ago was deemed far future stuff. Therefore, we are not dealing with one technological instability – technology uptake by sectors well removed from the core industries explored in this paper could have multiple simultaneous effects on the structure and location of the value chain. The economics adage "ceteris paribus" (aka ***all other things being equal) is a*** fundamental of social science research but it looks increasing under challenge as even a working hypothesis for this area of investigation..

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