

**CREATING AN INNOVATION OPPORTUNITY SPACE FOR  
BROADACRE SMART FARMING: A CASE STUDY OF AUTONOMOUS  
FARM EQUIPMENT**

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By

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## **ABSTRACT**

Advances in digital technologies are transforming the agriculture and agri-food system. The technological changes are represented in many forms, ranging from software-based prescriptions for optimal rate application of farm inputs, advanced imagery of fields and plants collected by sensors, satellites and drones, to new forms of human-to-machine interactions and machine learning. This thesis is a case study of one type of a smart farming innovation, a field robot, originating from a small-to-medium sized enterprise (SME) that designs and manufactures machinery used in broadacre, conservation tillage farming. The innovation, known as DOT™, is an entrepreneur's response to problems in the agriculture industry, and a solution to a critical constraint of labour shortages in the sector. By gathering qualitative data through interviews, news items and academic publications, observing the farming community's engagement with digital technology innovation at farm show, and applying the Innovation Opportunity Space (IOS) analytical framework, this study identified that an autonomous DOT™ offers a solution for farming problems. Other firms are incorporating the DOT™ technology into their manufacturing operations through licensing agreements and early farmer adoption is positive. The process of innovation was based on synthesis of tacit knowledge (experience-based knowledge of farming and agribusiness) and codified knowledge (drawing on computer programming), while public policy facilitated the hiring of trained university students who remain with the SME as advocates for smart farming. There remain some gaps: public policy for safe deployment of smart farming innovation is lagging behind invention and commercialization; new business models for manufacture and commercialization of high-tech equipment are just emerging and data ownership and control remains unresolved; and evidence of the value of smart farming technologies to farmers and the larger social system remains scant.

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## LIST OF ABBREVIATIONS

Abbreviation	Term
AAEA	American Agriculture Editors Association
AAFC	Agriculture and Agri-Food Canada
AB	Alberta
ac	acre
ADT	Ag Data Transparency
AFB	American Farm Bureau
AIC	Agriculture Institute of Canada
AIS	Agriculture Innovation Systems
AMC	Agricultural Manufacturers Canada
API	application programming interface
B	billion
BUS	binary unit system
CA	conservation agriculture
CA\$	Canadian dollars
CAHRC	Canadian Agricultural Human Resource Council
CAN	controlled area network
CAP	Canadian Agricultural Partnership
CAP	Common Agriculture Policy (European Union)
CCMTA	Canadian Council of Motor Transport Administrator
CDO	Creating Digital Opportunities
CFS	Committee of Food Security
CGIAR	Consultative Group for International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIT	Corporate Income Tax
DMCA	<i>United States Digital Millennium Copyright Act</i>
DNI	Department of National Intelligence
DNS	Department of National Security
DSL	digital subscriber line
EU	European Union
EULA	End User License Agreements
FAIR	Findable, Accessible, Interoperable and Reusable
FAO	Food and Agriculture Organization
FCC	Farm Credit Canada
GDP	Gross Domestic Product
GDPR	<i>General Data Protection Regulation</i>
GIS	geographic information system
GPS	global positioning system
ha	hectare
HMI	human to machine interaction
Hp	horsepower
HS	harmonized standard
HSC	harmonized standard code
ICT	information and communications technology

Abbreviation	Term
IDC	International Digital Council
IEEE	Institute of Electrical and Electronics Engineers
IoFF	Internet of Farm and Food
IOS	innovation opportunity space
IoT	internet of things
IP	intellectual property
IRAP	Industrial Research Assistance Program
ISO	International Organization for Standardization
IT	information technology
ITC	International Trade Center
Kbps	kilobits per second
km-2	square kilometer
LAN	local area network
LTE	long-term evolution
LTE WAN	long-term evolution wide area network (wireless broadband)
M	million
m-2	square meter
M2M	machine to machine interaction
Mbps	bits per second
n.d.	no date
NRC	National Research Council
NT	No-till
OECD	Organization for Economic Co-operation and Development
OEM	Original equipment manufacturer
p.comm.	personal communication
PFRA	Prairie Farm Rehabilitation Agency
PIPEDA	<i>Personal Information Protection Electronics Document Act</i>
R&D	research and development
RI/ RRI	responsible innovation, responsible research and innovation
RTK	real time kinetic
SAID	Saskatchewan Advantage Innovation Fund
SK	Saskatchewan
<i>smart</i>	self-monitoring, analysis, and reporting technology
SME	small-to-medium-size enterprise
T	trillion
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
US\$	United States dollars
USA	United States of America
USDA	United States Department of Agriculture
VC	Venture capital
VR/ VRT	Variable-rate or Variable-rate technology
WTO	World Trade Organization
YEP	Youth Employment Program
ZT	zero-tillage

# 1. INTRODUCTION

The digitization of agriculture is setting the stage for rapid changes in farming. The changes have been called Agriculture 4.0, described as the “fusion of precision agriculture with the Internet of farming” and the connection of farm activities with Cloud-based systems (Zambon et al. 2019, 9). Other names are the Digital Revolution, Precision Farming, or Decision Agriculture (Klerkx et al. 2019). An innovation named DOT™ is representative of this transformative force and technological innovation.

Within Agriculture 4.0 is the idea of ‘smart farming’. In North America, smart farming is conceptualized as the integration of new technological solutions into farming practices to help farmers manage their operations more reliably and efficiently, using precision agriculture (Cosgrove 2017 in AgFunder 2017). Smart farming involves advances in sensors, satellite systems, connectivity and information and communications technologies (ICT), data storage and analytics, and other technologies (e.g. unmanned aerial vehicles or drones, blockchain, robots) and uses the Industrial Internet, Cloud Computing and artificial intelligence (e.g. machine learning). Zambon et al. (2019) view smart farming as a worldwide network with uniquely addressable objects that are interconnected through standard communication protocol. Its key attributes are interconnectivity, object-related services, heterogeneity, dynamic changes and high scalability. These virtual object structures encompass intelligent resources, devices, products or machines (software and hardware), data transfer and infrastructure, data analysis and people, processes, and systems (Ibid, 4). Wolfert and colleagues (2017) note the Internet of Things (IoT) further propels smart farming, emphasizing it ‘goes beyond the farm gate’.

Smart farming offers opportunities for Canadian agriculture but each new technology must be studied closely to ensure it makes economic sense and creates sustainable socially and environmentally responsible farming. One of these opportunities is the manufacture of autonomous agriculture equipment.

The idea of DOT™ was initially conceived in 2014, demonstrated in 2017 at an outdoor farm show in Langham, Saskatchewan (SK) and is now commercially available. DOT™, pictured below in Figure 1.1, is a field robot with smart technology - *self-monitoring, analysis, and reporting technology* (NetLingo n.d).

DOT™ makes for an excellent case study of smart farming because it is an example of bringing together multiple types of resources used in developing and commercializing an

Agriculture 4.0 innovation and directly solving a farm-level problem; it eliminates the need for a tractor driver, therefore addressing the severe and persistent problem of labour shortages on grain and oilseed farms in western Canada (CAHRC 2019). Moreover, DOT™ challenges a century-old tradition in farming by eliminating the need for a tractor to pull farm implements. Instead, DOT™ is a propulsion system for agriculture equipment. It is a Power Platform™ that may be paired with different Dot-Ready™ farm implements such as a planter (seeder) or sprayer, illustrated in Figures 1.2a and 1.2b, respectively. The innovation is rugged, designed for use in the extreme climates of the western Canadian prairies, enables autonomous farming in broadacre agriculture conservation agriculture production systems. DOT™ is ‘Farming Reimagined’ (Norbert Beaujot, inventor of DOT™ 2017).

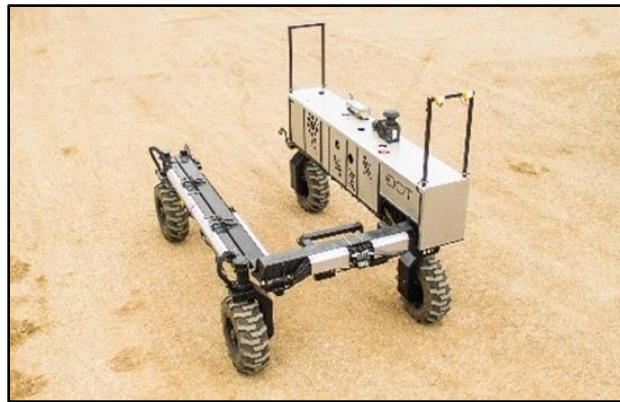


Figure 1.1: DOT Power Platform™ Source: Dot Technology Corp., 2018.



Figure 1.2a: DOT™ paired with a seeder. Source: Dot Technology Corp., 2018



Figure 1.2b: DOT™ paired with a sprayer. Source: Pattison Liquid Systems, 2018

The case study of DOT™ is also interesting in that the innovation is made by a small-to-medium-size enterprise (SME) and has the potential to disrupt the markets for tractors, which in North America are dominated by global agribusinesses equipment manufacturers such as Deere and Company (John Deere™ equipment). Zambon et al. (2019) argue that smart farming innovation by an SME is limited by its research and development (R&D) capacity to incorporate the latest digital technologies into the products. This research project challenges Zambon et al.'s conjecture and uses the case study of DOT™ to explore the role of entrepreneurs and SMEs in the democratization of technology as suggested by Yahya (2018).

The development of DOT™ began with an entrepreneur and pioneer in equipment manufacturing and owner of an SME reflecting on a better way to farm on the prairies of western Canada. A farm-level problem was identified and the SME created an equipment-based solution. DOT™ utilizes digital technologies similar to those used in autonomous vehicles, and it is designed and manufactured by a family-owned and managed, private corporation that employs approximately 80 to 100 staff located in the rural municipality of Edenwold, Saskatchewan (SeedMaster 2018 a,b). In March 2020, Raven Industries acquired ownership of DOT™, however, manufacturing will remain at the Edenwold location (Wade Roby, Executive Director Raven Autonomy in Raine and Booker 2020).

New agricultural technology must show the potential of farm-level value and be accepted by the farming community. The initial presentation of DOT™ occurred at the July Ag in Motion outdoor farm show in Langham, SK, July, 2017 (Rance 2017). The audience consisted of local farmers and their families, agriculture marketing and R&D industry representatives along with a few senior federal and provincial government officials with science, innovation, economic development and agriculture portfolios. The crowd of several thousand people witnessed a short field demonstration of DOT™ operating under both remote control and autonomous mode, while powering a seeder. The seeder was quickly un-paired and interchanged with a (swath) roller, and then the process was repeated with a grain cart. The innovation was politely received, and many show attendees personally greeted the well-known, local inventor.

Upon conclusion of the farm show, the farm media event organizer, Glacier Media, surveyed approximately 400 subscribers to gauge their acceptance of autonomous equipment, document their concerns and perceived benefits of the technology represented by DOT™. Three-quarters of the survey participants indicated they would be ready to use an autonomous agriculture

vehicle in three to five years (Lyseng 2017b; Glacier Media 2017). Respondents indicated that the main benefit of autonomous equipment is time saving, and the future of using robots on their farms will be contingent on continuing rural labor shortages. In addition, cultural factors such as a change in the lifestyle of farming and safety were identified as the leading farm level concerns regarding autonomous equipment. Specific barriers are the (high) cost, perceptions of the technology being too complicated, and access to easy and timely technical support. However, these constraints did not deter early adopters who placed deposits guaranteeing purchase of a DOT™ unit, and by the end of March 2018, production through to the end of 2020 was sold out. By spring 2019, ten DOT Power Platforms™ were used on approximately 16,000 acres of fields for seeding, spraying and fertilizing crop operations in the Canadian Prairie Provinces and in the American state of Arizona (Relf-Eckstein 2019).

The problem-solving aspect of smart farming innovations are key to recognizing the value of smart farming at the farm gate, however, DOT™ has several other attributes which may bring value beyond the farm gate. For example, DOT™ creates new opportunities for employment among youth with skills in computer programming. Dot Technology Corp., manufacturer of DOT™, introduced a licensing business model for equipment manufacturers that empowers them to convert an existing line of farm implements into autonomous agriculture equipment without incurring the initial research costs of developing a commercial field-scale robot that is suited to use in broadacre farming. The time for the conversion is rapid, ranging from four to eight months. In addition, DOT™ offers the prospect of reducing fuel usage, thus conferring environmental benefits from fewer emissions. When compared to a traditional tractor-based pull-type system, the inventor of DOT™ estimates that a fully ballasted tractor requires between 20 and 30% more horsepower than a DOT™ unit, the tractor thus using between 20 and 30% more fuel. Other aspects of agriculture sustainability such as improved soil health may be possible with DOT™. A 400 hp tractor weighs approximately 18,100 kilograms (kgs). In comparison, a DOT™ unit weighs 5,570 kgs. With less weight travelling in the fields, there is potential for reducing soil compaction, a serious problem caused by heavy field equipment that restricts the activity of roots and earthworms, alters soil structure and water infiltration, and negatively impacts crop yield.

The development of smart agriculture equipment is a new phenomenon, and except for scientific publications from engineering, computer programming researchers, there is a gap in the policy and social sciences scholarship when viewed from the lens of equipment manufacturers.

According to Bellon Maurel and Huyghe (2017) the use of new technologies in agriculture equipment is an important aspect of innovation. Industry sources support Bellon Maurel and Huyghe's idea. The venture capital platform, AgFunder, tracks investments in new technology, reporting that machinery-based applications of digital technologies are leading the way for what's next in ag-tech (Rogers 2018a). Recognition of farm-level problems and the potential of autonomous systems to solve these problems is also a neglected area of smart farming innovation literature, and furthermore, there is an absence of evidence-based research on the creation and use of smart agriculture equipment in commercial settings.

Opportunities and challenges for smart farming innovation in Canada will be addressed through the following three research questions.

1. How does smart farming address problems at the farm level while also supporting sustainable intensification of agriculture and delivering public good benefits?
2. How are smart farming innovations such as DOT™ enabled or limited by public policy, or advancing in the absence of state or industry-made governance models?
3. What are the potential risks associated with an autonomous farming innovation developed by an SME?

The thesis takes a single case study approach to these questions (Yin,2009) using DOT™ as the case. The boundaries for the case study of DOT™ are defined by the following parameters:

1. Broadacre farming on the western Canadian Prairies;
2. Agricultural equipment and associated farm inputs;
3. Advanced equipment manufacturing capacity in Canada and Saskatchewan;
4. Smart farming technologies bundled in agricultural equipment; and
5. The timeframe of data collection, July 2017 to July 2019.

Smart farming is a relatively new concept and is an example of new patterns of innovation which involve many actors and interactions. Developing an appropriate research strategy for the case study of DOT™, was a challenge. Entrepreneurs, such as the inventor of DOT™, are creating new ways of accessing resources and generating novel business models that defy traditional classifications, measurement, and evaluation of output and outcomes used in conventional approaches to study innovation. The Innovation Opportunity Space (IOS) is a new analytical framework, developed by Flowers, Meyer, and Kuusisto (2017) in response to a need for a new way to think about the breadth and depth of twenty-first century innovations. The framework is inclusive of the technology, the entrepreneurs, public and private sector actors, and the 'open' user community. The developers of the IOS used the framework in a series of case studies including



Kickstarter, Airbnb, Uber, open data projects, and a community forestry strategy used in Finland. A key attribute of the IOS is a starting point that is “not the idea of a market for a commercial product” (Flowers et al. 2017, 62). Instead, the ‘jump-off point’ for examining an innovation is a neutral initial frame of reference the authors call “*the space* [own emphasis] into which an innovation will be introduced and how value is created from innovation activities” (Ibid, 9). The authors argue an opportunity space need not emerge due to economic factors, it may:

1. “emerge due to a technological or other change;
2. be latent but unrecognized and have only emerged due to a reframing of the context;
3. exist and be widely recognized but effectively closed off due to regulations, market structure, inadequate technology, or a lack of market readiness” (Ibid, 58).

Some of the features of the case studies presented by the IOS authors had similarities with DOT™ (e.g., the new business model for commercialization of autonomous agricultural equipment). Consequently, the case study of DOT™ seemed well suited for use of IOS analytical framework. Following the approach taken by the IOS authors, the evidence for the case study of DOT™ is collected from multiple sources and is structured and analyzed as four aspects of the DOT™ IOS– the Architecture of the IOS, i.e. the norms, rules and standards, the Actors involved in the IOS and their related Activities, and the Aftershock, the impact and outcomes of the actions taken by the actors in the IOS.

The case study will provide evidence to advance policy-making in the province of Saskatchewan. It will open the debate on smart farming innovation ‘opportunities’ in agriculture equipment and further discuss the associated broader considerations for society, which suggest smart farming innovation, especially digital technologies bundled in agriculture equipment, warrant the attention of policy-makers.

### **1.1 Agriculture innovation in western Canada**

The following research draws on existing scientific knowledge from observations and evidence of a successful innovation system processes that profoundly impacted prairie agriculture. This evidence is applied to test a theory of smart farming innovation and presents the main

argument for the case study based on what is known about sustained change in farming behaviour and agriculture on the prairies.

### **1.1.1 Historical context – innovation must bring dollars and cents to the farmer**

In the 1990s, prairie agriculture shifted from the use of technologies and farming behaviours for constant tilling of the land and grain-fallow rotation for water conservation and weed control to the use of conservation (zero) tillage technologies and crop diversification. The process of change took many years and involved a systems-level effort. The transformation and radical change in farming behaviours offers the opportunity to apply ‘lessons learned’ about advancing innovation in western Canada (Gray 2010). The change from continuous to zero tillage involved local invention and innovation, experience and knowledge sharing among farmers and individuals across the research community and industry. The outcome was a durable (sustainable) shift in agriculture. Canadian manufacturers became world leaders in conservation tillage equipment, and prairie farmers and researchers are recognized for their deep understanding of the challenges and benefits of sustainable conservation agriculture.

The transformation of dryland, broadacre farming on the prairies started with the identification of a problem by farmers, government extension specialists, and researchers, followed with advocacy for the cause by members of the government elite, Senators and the Standing Committee on Agriculture (Senate of Canada 1985). The norm for farming using the system of continuous tillage practices was recommended to the early settlers as a practice to control weeds and conserve water (Shephard 2011), leaving the land lie fallow (uncropped) for one in three years per cycle (Carlyle 1977). After several decades of this farming tradition, soil organic matter had decreased dramatically, and as drought conditions and high winds had accelerated erosion, soil health in Canada deteriorated to a critical level. By the 1980s, the agriculture system was no longer sustainable.

Policy-makers allocated resources to establish base line data on the scope and scale of the problem (AAFC 1995), financially supporting and coordinating efforts made by research scientists, industry innovators and farm groups in order to assess and demonstrate new technologies to farmers (Lindwall and Sonnta, 2010). A main driver of the widespread adoption of conservation agriculture was the availability of new farm equipment with air seeding technology developed in Western Canada (Gray 2010). Other drivers included lower glyphosate (herbicide) costs, research and extension in the form of conservation tillage field days for farmers, public

access to the knowledge of costs and benefits of the new technology and several policy factors that were key to the radical shift in farmer behaviour (Gray 2010). The latest census data documented that 87% of total acres of land area in the three prairie provinces of Alberta, Saskatchewan, and Manitoba was prepared for seeding using no-tillage (NT) or minimum/zero tillage (ZT) systems (Statistics 2016, Table 32-10-0408-01). As a nation, Canada is ranked in the top five countries in the world where farmers demonstrate long-term and widespread adoption of conservation agriculture (CA) innovations, providing an environmental benefit associated with the change in farming practices that is increasingly recognized (Kassam et al. 2015).

But first and foremost, Gray (2010) argues that conservation agriculture farming brought ‘dollars and cents’ value to the farmer. These practice shifts presented a new problem space for smart farming innovation, following from Ruttan’s (1997) conjecture on invention – that invention should generate a new, useful, and non-obvious thing.

Based on a reflexive stance, the benefit of evidence-based knowledge of keys to success for innovation in prairie farming, this case study of smart farming, therefore, presents the following theory:

*Smart farming innovations must first solve a farm-level problem and deliver economic value to farmers. Only after this condition is met will smart farming innovation shape a new ag-tech culture in the broader farming community, and then sustain Agriculture 4.0 innovation to deliver value beyond the farm gate.*

This theory will be tested using data gathered from interviews with the developers of DOT™, document analysis of farm media and other market articles, and researcher observations at farm shows.

### ***1.1.2 The policy challenge of governance supporting, not driving, innovation***

Boosting innovation in agriculture is viewed as key to productivity growth in Canada (Economic Council of Canada 2017). In addition to being world leading producers and exporters of oilseeds and grains (Agriculture and Agri-Food Canada 2017a), the nation has a vibrant machinery manufacturing sector. According to Global Affairs Canada (2017), Canada ranks among the world’s top machinery manufacturing countries, employing over 160,000 workers in 10,000 companies. Exports of machinery accounted for the majority (79%) of CA\$ 42.9 B worth of sales in 2015. Of the 535 companies which operate in this niche sector, 91% are SMEs with less than 99 employees (Canadian Industry Statistics 2018). Agriculture equipment manufacturing is a highly specialized and valuable, niche part of this larger national industry. Many of the SMEs are

mainly located in communities with a population of less than 10,000 and are a significant source of employment in rural areas (Binkley, 2018). In 2017, agricultural machinery sales were made to 154 countries, generating an aggregate export value of \$ 1.98 B, excluding tractors (Canada 2018).

Agriculture equipment manufacturing is particularly important to the Saskatchewan economy, and in 2017, export shipments of farm machinery totaled \$16 B (Ibid). Of the 164 self-declared companies included in the Saskatchewan Manufacturers Guide (Saskatchewan 2019), most manufacturers are SMEs and account for nearly 40% (or 4, 400) of western Canada's farm and ranch implement manufacturing jobs (Saskatchewan 2017). Typical products include world-class seeders, precision GPS technology, and advanced spraying systems (Ibid).

Maru (2018) describes three areas relevant to Agriculture 4.0 innovations, the widespread acceptance of the field robot DOT™ and potential challenges faced by an SME being first to market with a potentially transformative innovation. First, there are 'scaling out' challenges enabling innovation behaviours reaching a greater number of people. Second, 'scaling up' typically requires an adjustment or a change in institutions, and third, 'scaling deep' requires a cultural shift and change in values and beliefs of stakeholders. The author argues that all three scaling challenges must be overcome in order to sustain innovation. If this is true, a subsidiary argument is that, *public policy has a vital role to play in shaping and stabilizing the Agriculture 4.0 innovation frontier, and specifically, smart farming.*

## **1.2 Outline of dissertation**

The next chapter of this thesis reviews the literature on smart farming and Agriculture 4.0 based on what is reported in the academic scholarship, industry, and grey literature (government reports). The literature is summarized firstly in Sections 2.1 and 2.2 as three narratives.

1. The collective benefit narrative and sustainable agriculture.
2. The prospects narrative and the digital wild west.
3. The access narrative and smart farming challenges.

Section 2.3 explores the evidence on the use of digital technology in agriculture, tracing back to the 1990s, and specifically the widespread use of digital technologies bundled in agricultural equipment. Many of the popular technologies delivered value by reducing input costs, or they simply made life a bit easier and safer for equipment operators. The section concludes with consideration of robotics as the next technological step that may address a pervasive problem of farm labour shortages.

The Canadian prairie context of innovations in agriculture is presented in Chapter 3. The case study of DOT™ opens Chapter 4, the Research Strategy, which is organized into four main areas. The first subsection includes the case description and its boundaries which limit the study to (i) broadacre farming in western Canada, (ii) smart farming innovation in the form of agricultural equipment and impact on related inputs, (iii) creation of a smart farming innovation by an SME, (iv) the types of smart farming digital technologies in agricultural equipment, and (v) the time frame of the study. This is followed by description of the analytical framework, the IOS, and methods used to gather data. Limitations of the research strategy conclude the chapter.

The IOS is a new analytical framework and therefore, deviates from traditional ways of presenting results and combines multiple sources of data. Chapter 5 simultaneously presents the results and the analysis for each of the four elements of the IOS framework (i.e. Architecture, Actors, Activities, Aftershock). The main source of primary data for this case study is based on a series of in-person interviews with the senior management team of Dot Technology Corp. and its sister company, SeedMaster. The interview data is supplemented with researcher's observations at farm events and industry statistics. Secondary data is drawn from farm media publications and social media.

Chapter 6, the Discussion and Conclusion, addresses each of the research questions listed above by drawing on the literature review and presenting conclusions which compare and contrast the evidence with what is known about smart farming.

At the time of writing this thesis, and based on a series of attributes suggested by the IOS authors (Flowers et al. 2017), DOT™ fits the description of New Form Innovation in an Unstable IOS. Therefore, Chapter 7, Policy Implications, presents strategies for stabilizing the Unstable DOT™ IOS. It sets as a goal, policy approaches for mobilizing resources, capturing and holding the IOS as a competitive strategy to support creation, commercialization and utilization of Canadian smart farming innovation through a shift in farmer behaviour. Information on recent events that extend beyond the case boundary is included in Chapter 8.0, the Postscript. Appendix documents present details on the methodology and antecedent information and events that led to the selection of DOT™ as a case study.

## **2.LITERATURE REVIEW: SMART FARMING**

The anticipated impact of digital technologies on the transformation of the agriculture sector is evidenced in a proclamation made in 2015 at the international agriculture trade show Agritechnica, the “dawn of the ‘fourth agricultural revolution’ or Agriculture 4.0, is upon us” enabling new levels of precision in agriculture using high-tech materials and digital technologies (Carl-Albrecht Bartmer 2015 in Frankelius 2015, 19).

Nearly twenty years ago, Tilman et al. suggested that sustainable intensification of agriculture was essential to “meet current and future societal needs for food and fibre, for ecosystem services, and for healthy lives” (2002, 671). As we enter the second decade of the twenty-first century, the urgent need for an environmentally sustainable agriculture system has captured the attention of world organizations including various agencies of the United Nations including the Food and Agriculture Organization (FAO 2012, 2017) and the UN Committee on Food Security (CFS). Smart farming technologies are poised to become the means to support sustainable intensification of agriculture (Walter et al. 2017), conceptualized as, “the ability of farmers to continue harvesting crop and animal products without degrading the environment or the resource base while maintaining economic profitability and social stability” (Struik and Kuyper 2017:39). Smart farming is ‘process’ optimization. Schönfeld et al. (2018) add the anticipatory planning aspect makes this new way of farming different from what has been done before. Smart farming involves integration of human resource management and personnel deployment with decision-making about purchases (e.g. farm inputs), risk management, warehousing, logistics, maintenance, marketing, and yield calculations (Ibid). Through this process optimization, farmers will be able to improve production efficiency so better quality and quantity of agricultural products will be grown/raised. Crop yields will increase by narrowing the yield gap related to variability, improving the overall efficiency of agriculture while also reducing the carbon footprint of farming as new farming practices are brought together (Gan et al. 2014; Brown et al. 2016). Technologies with lower environmental impact, such as those offering sensor-based highly specific application of pesticides, will enhance soil health and make more efficient use of nutrients possible. In this aspect, the optimization of processes and smart farming practices will help to meet the demand for

food production increases using environmentally sustainable intensification (SI) of agricultural systems (Tilman et al. 2011).<sup>1</sup>

The smart farming technologies available to farmers are diverse. Balafoutis et al. (2017a) categorized 39 different types based on three purposes or end uses. The first category is data acquisition technologies including Global Navigation Satellite System (GNSS) and mapping technologies, data acquisition of environmental properties, and machines and their properties. Second, data analysis and evaluation technologies comprising descriptions of management zones, decision support systems and farm management information systems. Third, precision application technologies involving machine guidance systems and automated weeding, Variable-rate (VR) application technology (VRT) of crop inputs, and precision irrigation. Precision farming, as suggested by Raj Koshla, is based on five ‘Rs’: the *right-rate*, in the *right-place*, at the *right-rate* (amount), using the *right-source* done in the *right-manner* (Zimmerman 2008).

At a broader level, the technologies are transferrable around the world, creating a technology transfer frontier and market opportunities, incidentally, improving nutrition, and enhancing worldwide food security (UNCTAD 2017; World Investment Report 2017). The Organization for Economic Co-operation and Development (OECD) report on agriculture policy suggests collaboration with public and private actors needs to be encouraged, concluding that better leveraging new ICT offers “untapped potential to improve policy performance and performance on farms – productivity, sustainability, and resilience” (OECD 2018, 34). Others suggest that by using digital technologies, the agriculture industry will become more sustainable and socially responsible (Adenle et al. 2015; Searchinger et al. 2013). With access to data and information tracking through digital records from ‘farm to fork’ the sector can address social concerns for animal welfare, traceability, and the environmental aspects of crop and livestock production (Busse et al. 2015; Herrero and Thornton 2013). Walter et al. (2017) assert smart farming will ‘boost’ consumer acceptance of agriculture. As information technologies advance, there will be new ways to bring transparency to the value chain beginning with food production processes, pricing of inputs and outputs, tracking financial transactions through block chain and providing information on the provenance or unobservable quality of food products to the end-use

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<sup>1</sup> The United Nations and the United States Agency for International Development describe sustainable intensification of agriculture following the concept suggested in the 1990s by Pretty as a ‘necessary approach’ to twenty-first century food production using the most suitable land use practices that will increase food supplies and protect biodiversity and ecosystem processes (Petersen and Snapp 2015).

consumer (Caro et al. 2018; Casado-Vara et al. 2018; Bermeo-Almeida et al. 2018; Ge et al. 2017). The myriad of opportunities envisioned with digital technologies applied to the agriculture sector have not gone unnoticed. In the last five years investment in ‘digitizing’ agriculture’ has exploded (AgFunder 2019). Yet, it is important to recognize while the benefits mentioned above broadly frame Agriculture 4.0 innovations in a positive light, the benefits are, at best, highly speculative. Moreover, shifting behaviours to support adoption of smart farming may be an enormous implementation challenge.

The effectiveness of policy measures encouraging the use of crop production digital technologies (i.e. incentivizing through subsidies) that confer environmental benefits such as reduced nitrogen runoff and carbon footprint is debatable (Schieffer and Dillon, 2014). Strict regulations enforcing sustainability or traceability in the livestock industry would need to be implemented with rigorous enforcement measures, which would be very costly and likely be countered with ‘considerable political pushback’ (TrustBIXS, N.D). Neither farmers nor ranchers are incentivized to participate and adopt environmentally sustainable practices or traceability systems desired by the consumer and, furthermore, implementing such systems will increase their farm management workload without returning tangible economic benefits (Ibid). O’Grady and O’Hare aptly described the challenge in 2017, “reconciling sustainability with productivity, economic factors and environmental impact is a formidable challenge” (180). Despite the potential for environmental and climate mitigation using smart farming technologies, Tamme van der Wal (2018) and Balafoutis et al. (2017b) observe the broader environmental benefits of smart farming and precision agriculture such as reduction of greenhouse gas emissions are seldom mentioned, whereas economic gain and reduced application of inputs feature prominently in discussions. Presently, there is a lack of evidence or predictive modeling regarding the positive social and environmental impact of new technologies, public and farmer acceptance of the technologies. Until this challenge is overcome, the widespread use of digitization of agriculture by farmers and recognition of the potential value support by society in general, is debatable.

The Agriculture 4.0 Revolution is in its early stages so a smart farming future is presently more of a vision than a reality for farmers and consumers. Shepherd et al. (2018) observe that different values are shaping the dialogue on what this smart farming future could look like. A scan of the literature confirms this observation. The vast majority of academic publications focus on the technologies driving the digital revolution in agriculture and are written mainly from computer



science and engineering perspectives, whereas, only 10% of publications are from agriculture and biological researchers while 4% are from environmental sciences and sustainability disciplines, according to the Web of Science Core Collection analysis of publications categorized as research areas in a topic search of ‘smart farming’, 1990 to 2019. The main publication source, accounting for 27% of smart farming literature, is conference proceedings, notably the IEEE (Institute of Electrical and Electronics Engineers). The IEEE is a professional network that includes computer scientists, software developers, information technology professionals, physicists, and medical doctors, in addition to IEEE's electrical and electronics engineering core group (IEEE, n.d.). In comparison to the 145 conferences within the IEEE group, only nine agriculture and two agriculture engineering conferences feature smart farming in their proceedings. Several individual (one-off) events feature smart farming, including researchers presenting on the bioeconomy, meteorology, ICT, Big Data, machinery and sustainable agriculture, and smart farming and autonomous systems.

Smart farming is also a ‘new thing’ in academic circles. In the early 1990s ‘smart farming’ appeared as a topic at conferences related to precision farming (e.g. Nelson et al. 1996) and in 1998, Ervin posited precision farming would support “smarter environmental policy for farming in the United States. In 2008, a special edition computer science journal was dedicated solely to technologies in farming and featured eight articles on smart farming applicable to crops and livestock operations. In general, as shown in (Figure 2.1), there were few smart farming publications until around 2015 when there was a marked increase in the academic literature on smart farming, especially from Europe when Sundmaecker et al. (2016) described the Internet of Food and Farm 2020 (IoF2020) framework.

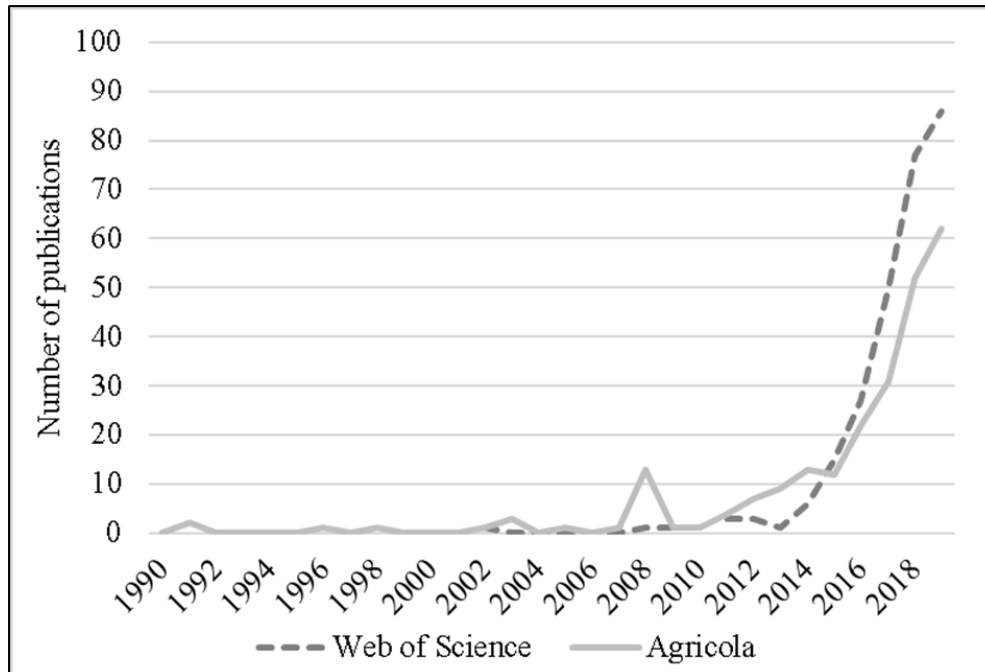


Figure 2.1: Number of ‘smart farming’ publications 1990 to 2019.

Source: Web of Science Core Collection and Agricola databases, downloaded from the University of Saskatchewan library.

By 2017, there was a shift in the source of academic disciplines studying smart farming. Social sciences entered the academic arena, representing about 7% of publications and ranking 4th as the main research area behind computer science, engineering, and agriculture, respectively, 1st, 2nd and 3rd. A distinct source classification of business and management research appears exclusively in the Scopus search engine, accounting for about 3% of publications. It is notable that social science and interdisciplinary researchers from environmental sustainability presently rank as the most cited sources after IEEE sources. Moreover, in 2019, a special edition journal (NJAS – Wageningen Journal of Life Sciences) featured 17 articles dedicated to the social, economic and institutional dynamics of precision farming, digital agriculture, smart farming or Agriculture 4.0. Carolan (2018), one of the highly cited rural sociologist researchers, posits the smart farming discourse and development of new technologies are being shaped by political ontologies rooted in neoliberal (free market capitalism) and not-so-neoliberal worldviews of farming. When technical publications from computer science and engineering disciplines are excluded, a scan of the smart farming literature cannot refute Carolan’s competing ontologies claim, and in fact, there is evidence of both agricultural industry and government institutional mechanisms of varying scope

and scale poised to shape smart farming innovation. This research uses these political ontologies view to structure different stories or narratives about smart farming.

Drawing on academic scholarship combined with government policy and non-government organization information including industry sources, the following two key narratives are poised to shape smart farming discourse:

1. a collective-benefit view where smart farming is a means to the ends of sustainable agriculture systems and sustainable farming.
2. a prospects-view where the data aspects of smart farming are a new market area for creating and capturing value throughout the economy (i.e. farm-to-fork).

### **2.1 Narratives shaping a smart farming future**

The first narrative explores the different institutional responses to the collective-benefit (public) good need for sustainable intensification of agriculture, while maintaining competitiveness of economies in emerging areas of technology which happen to intersect with agriculture and farming. This narrative aligns with Carolan's (2018) collectivist political ontology and a food sovereignty worldview focuses on building 'capabilities' to translate 'a thing' and bring value throughout the value chain. Those with this ontological position view smart farming as an opportunity for "democratic control of foodscapes that do not violate natural ecosystem limits," wherein the concept of 'foodscapes' includes the democratic control of 'datascape' (759). This narrative is most pronounced in the governance system under the European Union (EU) policy framework of the Common Agriculture Policy (CAP). EU member nations, as a collective, can operate under the Internet of Farming and Food specific for Agriculture 4.0 to develop and evaluate smart farming technologies through the lens of food production, distribution, and consumer engagement on a sector basis. Open source systems are a different example in the collective-benefit narrative and while presently not prominent in the industry. International development agencies and farm networks are embracing an 'everyone benefits' view of smart farming technologies, especially involving data acquisition, processing, and sense-making of data. The second narrative captures normative and individualistic perspectives on what the future of smart farming should, or could look like, including the anticipated opportunities and unintended consequences of the prospect-view of smart farming. Carolan (2018) suggests this political ontology is rooted in the ideology of individualism and a neoliberal market outlook and property views or prospect of smart farming (e.g., to own the technology is to benefit from data generated by the technology). A classic example of the 'market opportunities narrative' is underfunded agriculture R&D attracting angel

investors (venture capital) who realize the sector is ‘wide open’ for investment and the developing technologies are transferable worldwide (Waltz 2017).

### *2.1.1 Collective benefit narrative – top down and bottom up paths for smart farming*

Institutional mechanisms are presently the main drivers of smart farming innovation and policy approaches preparing for a technology-driven transformation of farming. Various approaches are taken including top-down and bottom-up approaches similar to those described by Kingdon (2003), Sabatier (1986) and Ostrom et al. (2012). Top-down institutional mechanisms include government-financed and academia-led, interregional and national policy approaches (frameworks) coordinating multiple types of innovation development activities. At the other extreme are bottom-up approaches coordinated by international development agencies. Bottom-up mechanisms in smart farming also include loose networks led by farmers. Both groups have aims of leveraging including open software and data systems to support sustainable farming systems. In between the top-down and bottom-up approaches are entrepreneurial-led innovation centres of excellence which are supported, but not steered, by government. These centres of excellence, sometimes known as incubators, have an aim of fostering a culture of cooperation across disciplines that focus on the core principles of social license and sustainability.

The first and significant example of the top-down collective benefit narrative is the European Union's Horizon 2020 research and innovation program, the Internet of Food and Farm 2020 framework (IoF2020). In the European context of the IoFF, smart farming is formally defined as involving the very precise monitoring, control, and treatment of animals, and crops being grown in m<sup>2</sup> sizes of land, in order to manage spatial and temporal variability of soil, crop, and animal factors (Sundmaeker et al. 2016 132). The purpose of the IoF2020 is to build a lasting innovation ecosystem to make the European farming industry more competitive and to generate outcomes of higher production yields derived from a data-driven farming system that is sustainable, socially and environmentally responsible (www.iof2020.eu 2018). The IoF2020 is open to participation by any EU member nations.

The IoF2020 approach to smart farming aligns with a collectivist political ontology and a food sovereignty worldview proposed by Carolan (2018). Carolan argues this stance focuses on building ‘capabilities’ to translate ‘a thing’ and bring value throughout the value chain. It views smart farming as an opportunity for “democratic control of foodscapes that do not violate natural ecosystem limits,” and foodscapes also extend to democratic control of ‘datascape’ (Ibid, 759).

The IoF2020 is an inclusive, reflexive approach to the digitization of agriculture referred to as a responsible research and innovation (RRI) approach (Long and Block 2018). Participants across an entire value chain are included in the development and evaluation (proving up) of smart farming technologies through a ‘Use Case’ project approach within specific sub-sectors of the farm and food systems, starting with potato, dairy, fruit, beef, and pork, and the Arable Use Case includes wheat, soybeans and potatoes (IoF2020 2019). Within an entire cropping cycle, existing sensor networks are linked with earth observations systems, crop growth models and yield gap analysis tools, and then incorporated into a variety of databases (www.iof2020.eu 2019).

Explicit (i.e. top-down) leadership and governance systems structure the IoF2020. Activities span the value chain and involve over 120 partners and 22 EU countries from a diversity of geopolitical regions and climate zones. The partners represent a complete farm-to-fork complement of actors from the public and private sector, the farming community, and food consumers. The IoF2020 is coordinated by Wageningen University, backed by a public-funded financial commitment of EU€ 34 M and it aims to make precision farming a commercially viable and socially accepted form of innovation and sustainable farming throughout the entire EU. New technologies and information are developed, introduced, and tested by tech users (e.g. farmers). High priority is placed on communication and knowledge translation (outreach) using social media to connect innovation partners, investors, new end-users, farmers, industry and citizens across political boundaries. The first projects are in progress although currently, it is not certain as to the success of the IoFF.

The United States is putting to action a very different, top-down, nation-wide institutional approach. Under the authority of the US Farm Bill, the United States Department of Agriculture (USDA) will have the power to collect and anonymize individual farm-level data, and to aggregate the information on American farming practices. Big data analytics will be used by researchers to analyze and create benchmarking tools to assess sector innovation and support R&D and policy mechanisms specially targeting conservation tillage practices (Janzen 2018b). Currently, there is no further information about this regulated, institutional approach and leveraging individual farm-level smart farming data to shape the nation’s future of an environmentally sustainable agriculture system.

A second, and slightly different sub-theme of the collective-benefit narrative of smart farming is the creation of a global data platform. The platform will harness the power of big data,

defined by De Mauro, Greco and Grimaldi (2016) as ‘4 Vs’, where High Volume, Velocity and Variety characterize the information asset that requires specific technology and analytics to transform the data into Value. The platform’s open access publishing and data sharing aspects will leverage big data to advance research in many regions of the world and is a classic example of a collective benefit institutional mechanism that involves a group of 85 international partner. Funding support is from the Consultative Group for International Agricultural Research (CGIAR) Trust Fund and UKAID, and the enabling policy mechanisms include a series of bilateral agreements with academia, government, private sector, international organizations and foundations, and International Center for Tropical Agriculture (CIAT) research institute. The aim of the five-year platform (2017-2021) is to ‘feed the future, byte by byte’ by solving developing world agriculture problems faster, better, and on a large scale (CGIAR 2019). Farmers in regions receiving international development support can upload and access information stored on the big data platform using their personal smartphone apps. The intended result is a building of capacity about farming throughout the 15 CGIAR research centres done in the spirit of democratizing information using an open data platform, where every farmer and researcher benefits.

One of the greatest concerns about smart farming reported in the academic literature and central to the power concerns about Agriculture 4.0 is the governance of data. There is little regulatory oversight concerning the privacy, security, and third-party use of data. In particular, around the world, there are few formal rules and consequently, there is a general lack of clarity about rights and ownership of agricultural data, or equity including distribution of the benefits of sharing the data (Stroebele 2014; Ferris 2017; Fleming et al. 2018; Jakku et al. 2018; Bronson 2018). Trail (2018) argues that, at a minimum, farmers should have the ‘right to choose’ how their data is used. Wiseman and Sanderson (2017) identify another dimension to the data discussion, reporting that agricultural data can be readily linked with personally identifiable information. Farm-level data often includes information about individual farmers, including the location of their farms and their farm practices. There are concerns that agricultural data could be used to make inferences about a farmer’s income, the value of his/her land, and operations. Wiseman and Sanderson argue this may not be a positive development for convincing a farmer to gather and share machine (i.e. sensor) generated data, agronomic data, or farm records data revealing pedigrees of animals, combination of inputs to improve production, etc.

Recognizing the issue of ethics and concerns of open data sharing, CGIAR proactively created an institutional mechanism to address these concerns. The ‘responsible data guidelines’ follow the FAIR principles –data are Findable, Accessible, Interoperable and Reusable (FAIR). According to Jansen (2019c), FAIR is one step towards resolving the tension between confidentiality and open data platforms.

The opportunities and risks of digital transformation of the agriculture industry, including the use of platforms generating and exchanging agricultural data, were discussed at the Global Forum for Food and Agriculture held in Berlin in January 2019 (Richter 2019; Rural21 2019). This is the first evidence of an international scale effort involving farmers across different sub-sectors of agriculture operating farms of a wide range of sizes. Data security and sovereignty were at the forefront of concerns for the farm organizations, the 74 agriculture ministers, representatives from commercial agri-business and science-based non-profit organizations and civil society groups who attended the conference. The outcome of the three-day meeting was a call for an International Digital Council (IDC) under the UN-FAO (Ibid). The IDC would be created with input from thirteen international organizations including: the livestock sector (World Organization for Animal Health), trade groups (the World Trade Organization, the World Bank, the International Telecommunications Union), and international rural development agencies. At the first consultation meeting stakeholders discussed a governance model for the IDC (CFS 2019). One hundred delegates to the Committee of Food Security (CFS) are tasked with developing the IDC Concept Note (FAO 2019, 2020). In the meantime, there is a bottom-up movement to coordinate digital technology resources including data. A fluid network of farmers, with ‘know-how’ in software coding, is sharing farm-level data and leveraging advancements in ICT and open source systems to solve their own problems.

Open environments are well known throughout the Information Technology (IT) sectors but are seldom reported in the academic literature on smart farming. One noteworthy example is Farm Hack, a ground-up (bottom-up) informal institutional mechanism that may shape smart farming future. Farm Hack is a virtual community of farmers around the world that is established for the purpose of sharing information and experiences through peer to peer networking. The type of information shared is diverse, ranging from open-source software (apps) to manage farm records and planning, to script that can be used to make custom seed rollers (<https://farmhack.org/tools>). Different countries sometimes have their own sub-groups such as Farm Hack UK, who are also

members of the worldwide group, La Via Campesina, or the International Peasant's Movement (<https://landworkersalliance.org.uk/farmhack/>). Three scientific papers are written about this community (Carolan 2018, Bauwens and Pantazis 2018; the later describing the Farm Hack UK group as an “on-line and open source learning and innovation communities between small-scale farmers, employees, engineers, software developers and agricultural development organisations” (Anderson et al. 2018 538). Bauwens and Pantazis (2018) claim Farm Hack is an emerging ecosystem of innovation bringing together individuals with a wide range of skills and training who like making things or tinkering and share a common value of moving towards sustainable farming. Carolan (2018) adds that Farm Hack is an example of collective benefit ontology, with aims of improving the “livelihoods of all farmers, and future generations of farmers”, through ‘farmer-to-farmer’ sharing of information and experiences. One of the tools developed by Farm Hack that is gaining traction is farmOS, an open-source web-based application for farm management, planning and record keeping (<https://farmos.org/>). The aim of farmOS is to provide a “standard platform for agricultural data collection and management. The aim of this group was explained by one of the farmOS designers active in North America - build a ‘community around the software’ (Bronson 2019).

The Netherlands is a different and illustrative example of the collective benefit narrative where there is neither a government top-down approach to smart farming, nor are farmers or industry creating ‘bottom-up’ institutional mechanisms supporting smart farming innovation. The country is considered an anomaly and their keys to success caught the attention of the investment community. The Netherlands has positioned itself as the world's second-largest food exporter, second only to the United States, which is 270 times larger (KPMG and AgFunder 2018). AgFunder and KPMG, wanted to understand the mechanism supporting the national motto of producing “twice the food using half the resources” (Ibid, 4) and how this small country grew to be a global leader of digital technology innovation in the agriculture sector. AgFunder and KPMG found that in The Netherlands, the government is ‘getting behind’ yet ‘not driving’ innovation by establishing technical and production clusters and centres of excellence that focus on the core principles of social license and sustainability. In their review of the innovation situation, KPMG and AgFunder noted strong leadership, broad stakeholder commitment and coordination of actors and activities spanning multiple levels of academic disciplines and types of businesses, including entrepreneurial start-ups. They concluded the country’s success is attributed to a domestic culture



of collaboration between academics and entrepreneurs, open innovation, co-investment, and “a melding between science-based and market-based activities” (2018, 6).

Beyond these examples of institutional approaches, the collective-benefits of smart farming innovation, including the use of big data analytics, while holding promise to set the stage for achieving broader goals of increased food production under sustainable agriculture systems, are highly speculative at this time. Speculation, however, is fuel for venture capitalists and this theme is parsed in the next section.

### *2.1.2 Prospects narrative – the digital wild west*

A second narrative emergent from the academic literature is representative of a political ontology proposed by Carolan (2018). In this theme there are several examples of the ideology of individualism and a neoliberal ontology that brings into play property aspect or prospects-view of smart farming. Industry insiders are referring to these early times of Agriculture 4.0 as a ‘digital wild west’ (Tatge 2016) – unregulated and wide-open for investment. Currently, this accurate description, means private industry is prospecting new opportunities (Griffen et al. 2016). New products and services are being introduced into a market where there is little or no regulatory oversight or policy frameworks to guide commercialization of the innovations or protection of the agtech-consumer’s rights. The ‘opportunities’ for digital technologies applied to agriculture is widely reported in tech investment reports (e.g. AgFunder, Pitchbook, Finistere Ventures, TechCrunch, Deloitte) and propagated by farm media.

The prospect of market opportunities in agriculture should not be unexpected; agriculture is an essential economic driver around the world. According to the United Nations Conference on Trade and Development (UNCTAD), the value add contribution to world Gross Domestic Product (GDP) from agriculture, fisheries and forestry has increased from US\$ 947.2 billion (B) in 1970, to \$3.08 trillion (T) in 2017, trending upward at a rate of \$ 43.5 B per year based on constant US\$ 2010 prices (UNCTAD 2019). The scale and increasing pace of investment are substantial as industry, scientific groups and researchers all ‘race’ to develop and sell more products and services (Tzounis et al. 2017).

Venture capital (VC) investments in the agtech sector and AgFunder reports over 11,000 companies are engaged in financing the development of new technologies. Investment activity accelerated dramatically between 2012 and December 2018, reaching a six-year total of US\$ 55.5 B and a 43% year-over-year increase in agtech investment (AgFunder 2019). Developing and

marketing upstream technologies is becoming the largest area of VC, with India and China outranking all other countries in this investment category (US\$ 10.0 B in 2018, representing 59% of total funds tracked by AgFunder). In 2018 that China's agtech investment focuses on e-commerce and encourages agtech investment that provides a 'new food experience' for its many consumers. Of the US\$ 1.8 B invested by Chinese venture capital in 2017, \$ 1.7 B targeted downstream investments in eGrocery, in-store, and online marketplaces, while farm management software, sensing, and the IoT attracted a mere 0.9% of investments (Ibid).

The most rapid annual growth across the fourteen categories of AgriFood Tech start-ups (43% year-over-year since 2012) recorded by AgFunder is in the FarmTech category focusing on investments in entrepreneurial start-ups "operating closer to the farmer" (AgFunder 2019 16). Global investments tracked in AgFunder's Farm Management Software, Sensing, and IoT category increased 15% between 2014 and 2016, to US\$ 363 M supporting 117 deals with agriculture decision support services and satellite-based technology firms attracting the largest deals (AgFunder 2016). One year later, investments reached \$572 M, and by 2018, \$945 M (Ibid, 2017, 2018). In comparison, Robotics, Mechanization and agriculture equipment represented a much smaller VC investment, attracting only 19 deals in 2016 worth \$109 M, yet VC more than doubled to \$268 M in 2017 with 59 deals, and by 2018, the volume of deals increased by 56% with 83 start-ups attracting \$368 M (Ibid, 2016, 2017, 2018, 2019). A similar trend is reported by Finistere (2019), with a 44% compound annual growth rate in agtech investment in the last decade, notably increasing since 2015. Finistere's agtech category, crop protection and input management was the leading investment area in 2019 (34.1% of US\$ 2.7 B) with hardware and software systems targeting Sensors and Farm Equipment accounting for global investments of \$ 337 M (approximately 8.2 percent total agtech VC).

In agriculture regions characterized by extreme climatic conditions, for example, Israel, VC and 'agritech' start-ups companies are targeting 'on-farm solutions', raising US\$ 80 M funding in 2017, with the Smart Farming Innovators fund accounting for \$39.0 M (Weiss 2017; Start-Up Nation Central 2017). A similar trend is reported in Israel, where in 2017, companies raised US\$ 80 M in funding for 'on-farm solutions', of which the Smart Farming Innovators accounted for \$39.0 M (Start-up Nation Central 2017). Israel's smart farming sector is growing 'three times faster' (94% growth and US\$ about 116 M from 2014 to 2017) than other 'agritech' area, followed

by irrigation and water management as the next leading area of growth in number of companies (Ibid).

There are, however, emerging concerns of slow adoption constraining earnings on Farm Tech investment and return on VC investment is reportedly falling short of venture capital investor's expectations. Finistere anticipates a growing need for companies to demonstrate "clear and broad value to customers"(2019 9). This opens the door to possibilities for established agribusiness firms to capture the prospective value of the new products and services and control the innovation within their business portfolio through corporate take-over of entrepreneurial start-ups (Waltz 2017).

The year 2013, known as ground zero for the agtech investment scene, was the year Monsanto, a leader in global agribusiness, purchased Climate Corporation and its team of Google engineers and data scientists (Finistere Ventures 2017; Tsotsis 2013). Climate Corporation's FieldView™ became an industry leading software platform for Monsanto digital solutions, integrating their crop input products with decision support services (Climate.com, 2018). Acquisition and consolidation are now occurring at all levels in the industry (Rogers 2018b) and AgFunder projects the pace of consolidation will continue. Deere and Company acquired Blue River Technologies, incorporating their 'see-and-spray technology' into John Deere equipment to offer highly specific application of products on individual plants (Deere & Company Press Release 2017). DuPont, Syngenta, Nutrien, Bayer, Cargill, ADM and Merk are also active in mergers and the acquisition of new start-ups (AgFunder 2019).

Within the prospects-narrative of smart farming, there is evidence of a trend towards monetization of agriculture data. Agricultural data is a broad category of farm data, which includes weather, agronomic, and machine data, although data about individual animals is typically overlooked in the legal definitions by Dowell (2015 a,b,c); Ferrell (2016) and Ferris (2017). Each type of agricultural data has relevance for smart farming, however, beyond the few examples described below, there is limited evidence of markets paying farmers or ranchers for use of agriculture data. Two firms, one in the Minnesota and other in Alberta, developed business models where farmers may sell their farm data on a per-acre basis. In the livestock sector, BIXS, or Business Info Exchange System, established in Alberta, pays a rancher on a per head (cattle)-basis for their participation in their Gate to Plate® third-party food traceability and sustainability information (data) platform (BIXS n.d.).

Farmobile pays farmers US\$ 2.00 per acre (/ac) for agricultural data and farmers have full authority to ‘authorize, or to deny access’ to their data which is collected and stored on the Farmobile cloud servers (Grassi 2015, 2016). The hardware component, the data collector, is interoperable with all major OEM implements and is described as a Fitbit™ for a tractor (Kramer 2016). The Farmobile Data Store platform is the iTunes™ for agricultural data (Farmobile Machine Scorecard). In 2016, Data Store capacity was set at 250,000 acres and a revenue split of \$4.00/ac was divided equally between the farmer and Farmobile (PRWeb 2016). The next year Farmobile expanded its customer base beyond Minnesota, although the value proposition decreased to \$1.00/acre (Coble et al. 2018). By 2019, the Data Store capacity had grown to over one million acres, and Farmobile changed their business model such that farmers can earn recurring revenue by licensing single-use copies of their data to approved third-party buyers (Farmobile 2019).

Decisive Farming’s business model serves three core functions: providing farm management services ‘to improve performance,’ providing precision agronomy support ‘to increase yield,’ and to ‘grow farmer revenue’ using their crop marketing platform (Decisive Farming 2019). When farmers sign up for Decisive Farming’s variable-rate technology (VRT) services on their malt barley acres, Decisive Farming pays CA\$4.00/ac. In return, Decisive Farming integrates the production and marketing data in its database and uses it to inform field-scale malt barley research (Hart 2018; Booker 2018a). This is the first Canadian evidence of a private firm leverage farm-level data in support of public and private research in the crops sector.

In the livestock sector, Eastwood et al. (2017) and Busse et al. (2015) report that data on a herd or individual animal behaviour is being captured and used to monitor feed intake, animal health and production processes. In Canada, TrustBIXS, a corporation traded on the TSX as, is based on a business model that enables operation-level certification program and tracing of the supply chain from farms and ranches through to the packing plant TBIX (BIXS, press release 2019). TrustBIXS is unique in that it is the first industry-funded incentive program which leverages Canada’s mandatory electronic identification system currently used in the cattle industry to track individual animals for health and disease control purposes. Once registered in TrustBIXS, a farm operation is audited and may be verified as ‘sustainable,’ using the Certified Sustainable Beef Framework developed by the Canadian Roundtable for Sustainable Beef (CRSB). Ranchers are paid to supply sustainable beef (i.e., beef raised socially responsible, economically viable, and

environmentally sound) to supporting retailers and restaurants (BIXS, n.d.). Since the start-up of this program in 2017, ranchers registered with TrustBIXS received CA\$10.00, \$20.11, 18.52, and \$18.24 per head - per operation in the first, second, third and fourth quarter of the pilot, respectively. In Year 2 of the pilot, \$18.48 per head was paid to individual ranchers as well as commercial feedlot operations, providing traceability and quality assurance on approximately one million pounds of sustainable beef. In the future, TrustBIXS anticipates that other livestock under Canada's mandatory electronic identification systems may be eligible to participate in their business model.

In other sectors of the agriculture industry, data is being leveraged to offer customized insurance products based on farm level agronomic, productivity and environmental data. Farmers' Edge, a decision agriculture firm (i.e. service provider) established in Manitoba has strategic alliances with insurance companies throughout North and South America (Stine 2018a). This is the first example of using data as a risk-reduction strategy benefiting smart farming -customers of. Yet, there is speculation that the 'data link' in the agriculture and food supply chain will go beyond farm-level decision-making, increased yield, farmer profitability, or both. In particular, the concept of tracing the origin of food production through to consumption (i.e., farm-to-fork) may bring a new meaning in value from farm data in globalized agriculture systems.

Agricultural data combined with smart farming technologies provide the opportunity to deliver information on the provenance or unobservable quality of food products, as well as provide transparency in financial transactions, two concepts of farm-to-fork. However, as the technologies advance, Farnese (2007) suggested there may come a need to consider the added dimension of tracking liability across the supply chain from farmer to consumer. And, as noted by Walter et al, (2017), the digitization of agriculture and data-enabled traceability throughout the supply chain may bring forth a paradigm shift in responsibility of the new technologies, for example, who is accountable for errors – the farmer, the software provider, or managers of cloud security systems, or the sensor manufacturer? Digital tracking and accountability of financial transactions across the entire supply chain, also known as blockchain, is beginning to attract attention in agriculture and creating new market prospects for the industry (Caro et al. 2018; Casado-Vara et al. 2018). GrainChain, operating in the United States, which is the first example of blockchain applications in a broadacre type agriculture supply chain. The GrainChain digital ledger system, launched in the first quarter of 2019, directly links farmers with purchasers (elevators, their agents and other

grain buyers). By summer 2019, over 84,000 transactions were completed, with approximately 1,440 active participants and 2.4 M tonnes of commodities processed ([www.grainchain.io/](http://www.grainchain.io/)). Beyond this, there is little evidence of commercial activity in blockchain systems in agriculture, and academic scholarship in this area is recent. Most articles appear after 2016. China and Singapore are the primary sources of blockchain academic studies contributing approximately 59% of publications from 2016 to 2018 (Bermeo-Almeida et al. 2018). Research by scholars from The Netherlands, Taiwan, Malaysia, Australia, and the United States constitutes the remainder of the academic scholarship. In The Netherlands, researchers examined why there is limited uptake by industry. Based on a series of case studies, Ge et al. (2017) concluded that stakeholders were ‘not ready’ for the paradigm shift of a ‘blockchain ready food chain’. The current limitation to ‘real-life’ implementation of blockchain applications in agriculture was scalability. Thus, while the prospect (value) of blockchain in agriculture is readily acknowledged, Ge and colleagues concluded blockchain is neither a panacea to address societal demands for more information about the food, nor is it a strategic ‘trustless’ way to build transparency and consumer confidence into the agriculture supply chain.

Social sciences literature prominently features other researcher’s (critical) reaction to prospect aspect of smart farming and the rapid advance of Agriculture 4.0. The data aspect of the digitization of agriculture and the public-good element of food and food production systems (e.g., environmental impact, animal health and wellness) is raising particular concerns about emerging power asymmetries, the ethics of smart farming and in a broader sense Agriculture 4.0 digital technology-based innovations (Ferris 2017; Dowell 2015 a,b,c; Ferrell 2016; Janzen 2017, 2018a; Wiseman and Sanderson 2017; Fleming et al. 2018; Jakku et al. 2018). Some researchers are questioning the distribution of power and impact on human life and society (Carbonell 2016; Carolan 2017a, b; Long and Blok 2018; Bronson 2018). Coble et al. (2018) report that much of the ‘useful’ big data currently generated is controlled by the private sector. They argue this creates the possibility where a few market actors have access to enough information in aggregated datasets to in theory ‘move’ or ‘even manipulate’ markets. Similarly, Carbonell (2016) focuses on the power asymmetry, suggesting large agribusinesses like Monsanto secure privileged positions in smart farming innovation. She raises a red flag about the ethics and use of big data analytics to provide insights at a field-level, claiming Monsanto has control of information on more than one-third of farms in the United States, which positions the firm in a favourable market prospect

position to manipulate pricing on crop inputs. Rose and Chilvers (2018) raise universal questions about the ‘directionality’ of innovation pathways and the capture of sustainable agriculture by ‘big emergent technologies’, at the expense of sidelining relevant stakeholders. Bronson (2018) claims that while private industry’s purpose is to maximize profit, including extracting value from agricultural data, farmers must be recognized as ‘data right’s holders’ and they have a right to know what is being done with their data. Furthermore, she asserts government has a democratic mandate to its citizens and must ensure that smart farming technologies contribute to society-as-a-whole, rather than solely focusing on economic agendas and capture by ‘productivist values’. Eastwood et al. (2017) also raised questions about the ethics of smart farming, observing that smart farming in the dairy sector is being driven by aims of productivity and efficiency. However, in this instance, the authors suggest the power balance is in favour of the farmers. Dairy farmers in New Zealand are not willing to share their data and the databases containing data records of pedigrees, management practices and performance of the milk cows. Consequently, data informing animal health are often no longer accessible for public-good purposes such as herd health testing (Ibid). Other researchers such as van der Burg et al. (2019) were not able to reach a conclusion about the ethics of smart farming but emphasized an urgent need to understand the issues and engage citizens in the unfolding agriculture revolution.

A general theme from the core group of rural sociologists and interdisciplinary researchers mentioned above is the claim that a more responsible (i.e. responsible research and innovation, RRI) and a reflexive approach to innovation is urgently needed. It is the view of several scholars that market forces alone do not generate socially optimum outcomes (Long and Blok 2018; Bronson 2019; Eastwood et al. 2017; Regan et al. 2018; Regan 2019; Jakku et al. 2018). There is call for “sharing everything with the public at large” to better understand “what is desirable for a smart farming future, and what is not” (van der Burg et al. 2019, 9). This is not surprising when the Industrial, Green, and Biotechnology Revolutions are considered. Each of these times of major change in agriculture involved a re-organizing of economic institutions, and the changes affected social dynamics, income growth, and the distribution regulation of the labor force. The technological changes affected many aspects of organized society, and, as suggested by Ruttan (2002), sometimes these innovations have unanticipated consequences. Some of the consequences of innovations marking the Revolutions are summarized by Gibson (2012) and Yahya (2018), Borlaug (2000), Swaminathan (2006), Pingali (2012) and Evenson and Gollin (2003), Cohen et al.

(1973), Cohen,(1977), Berg and Mertz (2010), Phillips and Khachatourians (2001), McNaughton (2003), De Beer (2007), Knudsen (2011), Rótolo et al. (2015) and Tsatsakis et al. 2017.

The new way for Agriculture 4.0 Revolution is a vision of Responsible Innovation (RI). The RI group of researchers anticipate a deepening of the digital divide and increasing power asymmetries in smart farming. Transformation of the agri-food system is a meta-responsibility, which “means taking care of the future through collective stewardship of science and innovation in the present” (Schomberg (2011), cited in Stilgoe et al. 2013, 1570). Long and Blok (2018) further add that the innovation ‘process’ for agriculture needs to be more ‘inclusive and democratic’ and R&D should generate outcomes that are ethically acceptable, sustainable, and socially desirable, citing Von Schomberg’s concept of RRI (2013, 464). Others assert RRI conducted ‘for-and-with-society’ will ultimately increase productivity and support eco-efficiency in a socially sustainable agriculture system that protects the rights of ‘data holders’ (Rose and Chilvers 2018, Bronson 2018).

The literature review identifies a gap in the academic literature where the RI stream of scholarship, typically based on qualitative research (interview) with sample size limited by small sample size in comparison to the total number of farm operators, at this time, does not adequately represent a broad diversity of size of farm operator perspectives operations or types (e.g. productivist farming commercial *or* organic, large or small holdings). There are, however, a few noteworthy exceptions and one of these is Carolan (2018), who conducted 93 interviews with individuals from a diversity of individuals within the agriculture sector and this research is highly cited in the social sciences and beyond. From these interviews, Carolan offers a third emerging political ontology that begins to define an access aspect of smart farming technologies which begins to fill a gap in the scientific literature. He describes an access-claim to smart farming that is based on rights, “legal or otherwise” (i.e., natural rights and property rights) to “access the smart farm artefacts, regardless of whether they owned them” (Carolan 2018, 759). Carolan presents evidence from users who could have claims to artefacts (e.g. data). Beyond this seminal work, six peer-reviewed scientific publications inform the access-claim narrative from the farm-level perspective of broadacre agriculture commercial farming systems, although the concerns about smart farming are implicitly captured by those practicing and teaching in laws impacting the agriculture sector (e.g. Janzen, Dowell and Ferrell in the United States, and Stroebel in Canada).



A small group of rural sociologists, Wiseman and colleagues in Australia (2017, 2019), examined the legal aspects of data rights in Australia.

### *2.1.3 Access narrative – comparative perspectives from broadacre agriculture stakeholders*

The next section focuses on the access narrative by drawing on the academic literature based on analysis of qualitative data gathered from interviews with individuals from within the agriculture industry, where researchers are striving to understand use of digital technologies and farm-level concerns. Additional information about farmer perspectives are sourced from industry information, government and farm organization reports as well as farm news media, all of which introduce the notion of natural rights pertaining to agricultural data and the use of agricultural equipment. Much of the academic and venture capital discourse about smart farming described above is based on the idea that smart farming will advance an end goal of sustainable intensification of farming, returning a profit on developing, and commercializing smart farming technologies, while at the same time benefitting farmers by making them more efficient. However, the real world ‘benefits’ are for the most part, speculative, likely due to the newness of smart farming and its artefacts.

At this time, four relevant ex-post studies were found in the international peer-reviewed literature that provide insight into opportunities, concerns, and challenges for a smart farming future as perceived by stakeholders in different countries where broadacre agriculture characterizes the industry. Research participants are actively engaged in developing, or in the future, using smart farming technologies, particularly those used in broadacre farming. Beyond these studies, the summary presented below relies on industry sources of information.

#### *Views from Australia*

The first group of scholarship that fills the gap on the access narrative, focuses on Australia, where agriculture is an important part of the national economy, contributing 2.72% to GDP in 2017 (World Bank 2019) and providing 2.54% total employment (Trading Economics 2019). Arable land area is substantive with 921 M acres (Australian Bureau of Statistics 2019) with 916 M acres agricultural land (Trading Economics 2019) with farms and ranches operated by approximately 157,000 farmers in 2011 (Australian Bureau of Statistics 2012).

Fleming et al. (2018) and Jakku et al. (2018) interviewed 26 stakeholders who were farmers as technology end users, and grains industry stakeholders from public, private and non-government organizations. The study objective was to identify and explore participant perspectives and

expectations of, and experiences with, smart farming and specifically its big data aspect. Their discourse analysis, based on a coding hierarchy for key language, rules, norms, and values and assumptions, revealed two opposing groups of stakeholder views: “Big Data is for Big Farming” and “Big Data is for Everyone” (Fleming et al. 2018, 23). Key languages in the big-data-for-big farming group were maximizing profits and efficiency, rule structures based on contractual agreements between the end-user and a service provider, norms centered on individualism, and smart farming/big data conferring a competitive advantage to individual farmers. Core values were centered on economic rationale, e.g. ‘survival of the fittest’ and a perspective that ‘information is valuable’ (Ibid, 6). The contra discourse, where everyone benefits from smart farming (big-data-for-everyone), was characterized by stakeholder language of sharing and co-operation and participant views that everyone should be involved in developing rules for smart farming. Norms included integrity and trust, with a realization that the benefits of big data and smart farming will take time. The core value is “helping the struggling” reflecting the overall assumption that the collective is greater than the individual and that a recognition to accommodate the inherent heterogeneity of farming is crucial if smart farming is to be sustainable in Australia (Ibid, 7).

Despite these divergent views, there is convergence across both discourses regarding risk. If the nation is to remain competitive with international developments in smart farming, it will be imperative to adapt big data to the needs and unique contexts of Australian agriculture. All stakeholders are highly concerned about access to ICT due to infrastructure limitations. Participants expressed a need for a national broadband service and informed the researchers that mobile communications (i.e. cellular) infrastructure was considered substandard and far below what is necessary for smart farming. A need to build trust was common in both discourses, however there were differing perspectives about trust mechanisms. In the big data-for-big-farming group, trust is associated with data storage and regulations and government rules potentially restricting the use of big data. In comparison, the big-data-for-everyone group is focused on maintaining individual farmer rights and safeguarding benefits that flowed back to farmers. The authors concluded that ethical, moral, and practical questions are emerging and the impact of big data on the Australian agriculture industry will be influenced by ‘who engages with big data’ and in a broader sense, resolving (ICT access) infrastructure limitations to smart farming.

Jakku et al. (2018) further analyzed the Australian stakeholder interview data and explored the perceived ‘who benefits’ and ‘what risks’ of big data in smart farming. Benefits clustered in

two areas, on-farm benefits, versus value dispersed among the various industry actors across the supply chain. The on-farm value is improving efficiency, increasing productivity and profitability, enabling a more informed decision-making process, and the potential of having greater insights become available as more data sets are linked. At the broader supply chain level, benefits are optimization of processes across the supply chain, including, for example, improvements in predictive and analytical capabilities for storage, transportation and marketing logistics, and traceability systems. There are also new opportunities for niche markets and product differentiation (Ibid). Risk areas grouped into technical, social, and institutional themes. There is a recognition there may be a shift in “what it means to be a farmer”, participants suspecting there will be a need for farmers to develop management skills and expand their base of knowledge and displacing the need for hands-on expertise and labour (Jakku et al. 2018, 8). Data concerns include accuracy, reliability and transferability, and data fragmentation. There is a great deal of uncertainty regarding data principles, rights and compliance, privacy and security, international competition, and an unclear value proposition for farmers regarding the sharing of their data. However, what is noteworthy about Jakku and colleague’s analysis is the revealing of a loss of control of farm level data that is rooted in a lack of trust in current data governance mechanisms. Their research uniquely identified a differential access theme not previously described in the literature. Based on the participant’ interviews in Australia, there is a city/country divide and a deep cultural pattern of non-trust and inequality that reflects asymmetries of power (large corporations versus the individual farmer and urban actors versus rural farmers). The researchers concluded ‘cultural identity’ will influence how big data and smart farming innovations are perceived, potentially shaping stakeholder relationships in the sector, views of rights and access to the benefits of smart farming.

### *Views from Brazil*

Brazil is an ‘agricultural powerhouse’ and one of the world’s largest net exporters of agricultural products (AFC 2017b). While an accurate number of farmers is not reported in statistics, it is estimated there are 4.4 M family farms (Gross 2019). Agriculture contributes 4.63% to national GDP (World Bank 2019) and provides 9.28% of total employment. Arable land area is 200 M acres (Trading Economics 2019) with 700 M acres agricultural land (Ibid).

The agriculture potential of Brazil was the reason Pivoto and colleagues studied the role of smart farming, presently at a very early stage in the country, the authors finding “few enterprises

and professionals that were dedicated to this subject” (2018, 23). Their dataset gathered by Pivoto et al., consisted of interviews with four experts identified as pioneers in their area of expertise relevant to the future of agribusiness in Brazil. The experts emphasized that at this early stage of smart farming, the market is most interested in investing in tools for crop-based agriculture in comparison to livestock operation. The sugarcane industry is leading development of smart farming systems, followed by vineyards, fruit crops, and coffee. Unmanned aerial vehicles are used to capture what are happening in the fields and managers are beginning to leverage this information to aid decision-making and manage risks. More advanced technology such as artificial intelligence systems will not be incorporated into farming systems for a ‘long time’. Meanwhile, the focus is on developing technologies perceived as “the first step to creating a smart farm”, including machinery and equipment with automated guidance systems and telemetry technology and apps for accessing field information using a smartphone (Ibid, 26).

Connectivity (i.e. ICT access) is a major barrier to smart farming as telecommunications infrastructure in Brazil was considered by an expert as ‘precarious’ and data transmission using mobile devices is ‘unreliable’ and even basic access to IT systems remains limited to large farms. A second barrier is access to actionable information. The cost of processing data collected by sensors on new equipment limits the use of the information, with one expert indicating much of the vast amounts of data being generated remains unexplored by farmers, and the process is greatly hindered by limited connectivity in rural areas.

A third access-related barrier is that agribusinesses are lagging in offering ‘simple and coherent interoperability’ between systems, services, and stakeholders. With compatible systems, farmers could transfer data between machines or farm management information systems, and integrate weather data with soil information, particularly valuable for the high value grape, fruit and coffee industries. Knowledge and skills are the fourth barrier. One expert indicated that above all, the (low) level of farmer education, lack of knowledge, and low technological level of farms are the main barriers for farmers incorporating smart farming technologies. The majority (53%) of farmers have an elementary level education and 27% are considered illiterate. Similarly, the available labour force has low levels of rural schooling and in the northern regions there are limited use of machinery and equipment and few farmers fertilizers or manage fertility of their fields. Consequently, smart farming technology in Brazil is focused on creating new tools targeting farm operations that are already using a high level of technology. Until these major barriers are removed,

development of new tools is expected to be concentrated in machinery and equipment. Improved decision-making, and the information and data aspects of smart farming remaining a ‘work in progress’ despite the potential of smart farming to increase both productivity and production across such as large area of agricultural land.

### *Views from North America*

Agriculture is an important sector for the United States and Canada and employment in the sector is similar for both countries, 1.41% in the United States and 1.49% in Canada States (Trading Economics 2019). However, the scale of agriculture differs between the two countries. Agricultural land area, monetary impact to GDP, and the number of farmers, are much larger in the United States than its northern neighbour. Agricultural land area in Canada is 154.8 M acres versus 1,002.9 M acres in the United States (Trading Economics 2019). Agriculture contributes CA\$ 111.9 B (6.7 % of total) to Canadian GDP (AAFC 2017a), whereas agriculture contributes US\$ 1.053 trillion (T) and accounts for 5.4% of American GDP (USDA. 2019). Moreover, there are 271,935 Canadian farmers and 23.4 M American farmers (AAFC 2017a).

Farming innovations and agribusiness activities flow between the United States and Canada, due in part to similar dryland agriculture challenges, commodity cropping, and broadacre farming practices in the Great Plains of North America. A few social sciences researchers from Canada are studying smart farming issues including big data, data access and natural rights, and responsible innovation (Bronson and Knezevic, 2016; Bronson, 2018). Bronson (2019) focused her studies on the upstream end of smart farming technologies, interviewing 22 technology ‘designers’ from private industry and public sector organizations reflecting smart farming activities in the United States and Canada. Agribusiness firms such as Farmers Edge, a Canadian decision agriculture firm, and farmOS, the open data platform connected with the Farm Hack farmer network, comprised the dataset. Interviews were conducted between January 2016 and June 2018 and the designers included computer scientists, biologists, statisticians, geo-spatial specialists, and agriculture engineers. A business aspect of the access-narrative was captured in Bronson’s research, concluding that in North America, there is an emerging ‘digital divide’ where “not all farmers are equally advantaged via digital tools” (Bronson 2019, 3). There is evidence of a group of designers who view farming-as-a-business and develop products and services that target farmers who are rational economic agents and companies that are highly competitive. They offer products and/or services that will solve problems faced by commodity farmers. The ‘tight control’

of data collection and storage is an area of high importance for the designers, in addition to securing data privacy and system reliability (Ibid, 4). In contrast to the farming-as-a-business group of designers, Bronson identifies an ‘activist’ group who develop products amenable to supporting diverse farming operations targeting farmers with an alternative value set. These designers are not focused primarily on main-stream commodity production systems and instead ‘work with’ farmers, scientists, and engineers to develop smart farming technologies such as farmOS, mentioned above in the collectivist benefit narrative, are available in ‘open design’ systems.

Based on the four studies of broadacre agriculture and smart farming described above, the access narrative of smart farming signals an emerging bifurcation in smart farming. This ranges from preferential design of products and services for the larger farm (commodity) operations at the expense of smaller and more diverse farm operations, the use and value of data for big-data-for-big farms, versus big-data-for-everyone, or as basic as segmentation based on vastly different levels of education conferring an advantage or disadvantage impacting ‘access to’, and understanding of, smart farming opportunities, and unequal connectivity in rural and remote areas.

Big data and use in broadacre farming are however, not the only area where the digital divide may be on the horizon as concerns for smart farming. In Ireland, smart farming is perceived to ‘benefit some farmers’ while others will be marginalized (Régan, 2019). Régan’s interviews with 21 experts in the Irish agricultural sector indicate there is a belief that smart farming will likely threaten the livelihoods of older farmers and those with smaller size farms. This is viewed as a critical aspect for Irish agriculture as the marginalized (threatened) farmers currently comprise most of the farmer community who may lack “skills, capabilities, money, or motivation required to capitalize on digital technologies” (Ibid, 6). In 2016, 76% of the farm holders in Ireland were older than 55 years (Ireland, 2019). There are many (137,500) small size farms (average size 80 acres); total agricultural land area of 10.98 M ac is about one percent of that in Australia, Brazil, or the United States (Trading Economics 2019). The ‘over-emphasis’ on increased yield and productivity with smart farming, plus marginalization of the traditional Irish farmer, could lead to a re-shaping of the public image of Irish farming; this was not necessarily a good thing for the Irish agriculture industry despite expert’s recognition that smart farming will create new jobs in agtech (Regan 2019).

One approach to bridge the divide are open source systems, both hardware and software. Yet, interestingly, there is little reporting from the industry stakeholders and farmer views on the

later - open design system software platforms. As described above in the collective benefits narrative, open access platforms are being used for international development. There is, however, little evidence that open systems such as farmOS or global data platforms are attractive to the larger group of broadacre agriculture (commodity) farmers in North America. However, one example is found in the farm media news and it would be considered as a hybrid data platform, neither open access system nor agribusiness-controlled.

Farmers Business Network (FBN) is an entrepreneurial start-up built on the ideas of leveraging agriculture data and on-line purchasing of farm inputs. An individual farmer can pay a flat rate farmer-membership fee (CA\$ 800) and access data uploaded to the platform by all farmer-members participating in the for-profit business model. FBN, established in 2013 in California, claims to democratize information and provide unbiased data analytics (i.e. farm data is anonymized and aggregated) that leverages farmer's knowledge of product performance. FBN started operations in western Canada in 2019 and claims to have over 700 Canadian farm members and data on 4 M acres of cropland (FBN, 2019). The company's vision is making farmers more competitive by determining, for example, how seeds and inputs are working (and costing) in the real world, while also offering discounted input products to their members (Pilger, 2019). Pilger reports that FBN is an interesting, yet newly emerging business model of farmers engaging with digital technologies in response to a need for profitability and leveraging innovation to support 'farmers learning from fellow farmers' by accessing aggregated farm-level data uploaded by FBN members. There are however, challenges to this hybrid data-e-commerce platform and the Competition Bureau is investigating agribusiness suppliers for alleged anticompetitive practices blocking FBN from accessing branded crop inputs and expanding operations in western Canada (Johnson 2020).

The next section presents access challenges as viewed from farm industry sources and technology-oriented scholarship. It builds on the access narrative interpreted by the fourth social science research groups mentioned above in the introduction to the literature review and begins with one of the most salient issues for smart farming, the governance of agricultural data. This is an issue particularly relevant to the both the collective benefit and prospects narratives and particularly salient given the emergence of farmer networks such as FBN, and farmOS. Beyond data as the first access challenge, is found a pragmatic view of other access challenges for smart farming including the following: (i) (restricted) access to the basics of connectivity in rural areas;

(ii) (restricted) access to use of combinations of specialized agriculture equipment best suited to the conditions of a field or a management preference that integrates different brands; (iii) (restricted) access to copyright-protected operating systems as a necessity to make timely and cost-effective repairs; and (restricted) access to sharing of data across different machines or monitors due to lack of universal data platforms.

## **2.2 Five access challenges to a smart farming future**

Some of the most basic challenges to smart farming identified by the farm community are infrastructure and logistic-type constraints specific to farming in rural areas (e.g. internet access and speed) and use of sensor-driven equipment in extreme weather conditions. Other access challenges are emerging as the norms associated with the agriculture equipment industry evolve rapidly and two specific issues are reported. Interoperability, i.e. the ability of different brands of farm machinery to connect and operate as one unit - each brand is configured with their own application programming interfaces (APIs) and proprietary operating systems - and protection of intellectual property as copyright law used in the IT sector enters the realm of agriculture equipment manufacturing corporate strategies. The new approach to protecting innovation is impacting the traditional farm model of explicit ownership, and control and right to use and repair equipment. In response to a need to gain access to their equipment while risking violation of end user agreements, farmers have resorted to hacking equipment operating systems. This activity has exposed yet another access challenge, or more appropriately, a cybersecurity threat to connected smart equipment. Protection of operating systems by 'first to market' equipment manufacturers magnified the final smart farming access challenge, systems incompatibility and lack of communication between software systems and applications such as those containing prescriptive applications of inputs based on the mapping of discrete areas in a field in need of more-or-less product.

### ***2.2.1. Governance of agricultural data***

The greatest concern about smart farming reported in the academic literature is central to the collective benefit, prospects and access narratives and global concerns about Agriculture 4.0, is the governance of data. The lack of governance about agricultural data is an extremely important innovation challenge, mainly, because trust is an implicit cultural factor in the agriculture industry. Furthermore, the issue of data governance will likely grow in importance with the increasing digitization of agriculture, partially, because of the scale of the data and the potential number of



farms impacted and scope of food production potentially affected. Meola (2016) projects that by 2050, an average size farm will generate an average of 4.1 M data points per day.

Decision support services firms, and equipment manufacturers are gathering agronomic, or machine data, respectively, and using it without the owner's consent or knowledge (Janzen 2017, Wall, 2018). For example, in the instance of gathering and use of machine-generated data from each sensor on a machine is an area, there is little regulatory oversight for data collected off a piece of farm equipment purchased or leased by a farmer. Yet, these sensors capture information about the functionality of farm equipment such as fuel consumption, emissions, and diagnostic codes and transfer the information back to the manufacturer (Dowell 2015 a,b,c; Ferrel 2016; Ferris 2017; Janzen 2017). For the manufacturer, there is value in knowing how their machines are performing under different conditions and multiple locations, additionally, depending on the service agreement signed at the time of purchase, dealerships may also monitor equipment in real time and use the information for preventative maintenance services (Phillips et al. 2019). For the farmer, sensors and monitors communicate equipment diagnostics expeditiously so the operator can act quickly to do a less costly repair instead of replacing an entire machine, depending on the severity of the problem. There are concerns that the equipment operators may be liable if they do not act on the machine data warning that is passively communicated to the dealership or manufacturer. The dealership will contact the farmer before the farmer knows of an issue, and if the farmer chooses to not follow the recommendation, he/she runs the risk of losing warranty on the purchased equipment. It is, therefore not surprising that farmers are losing trust in what is being done with the data gathered on their farm, and equity and the distribution of the benefits of sharing the data are emerging concerns (Fleming et al. 2018; FCC 2018; Jakku et al. 2018).

There is a convergence of views that the legal assignment of agricultural data is vague (Strobel 2014; Trail 2018; Fleming et al. 2018). Arguably, there is little value associated with the individual data points, however, when data from the multiple sensors, equipment and fields, and animals is aggregated and analyzed, the machine-data also has intrinsic value about farming practices and food production systems.

In Ireland, industry stakeholders assert an anticipatory governance approach is needed in order to address industry stakeholder concerns on data sharing, contractual agreements, and fairness and equity in emerging smart farming business models; action on data ownership is 'urgently needed' (Regan et al. 2018). Among the 21 experts from the Irish agriculture sector,

there is a convergence of views that “farmers’ rights needed protection” (Regan 2019, 7). Governance in advance of smart farming is viewed as very important; decisions “made now will shape how smart farming is going to unfold for the years and decades to come” (Ibid, 16).

In the United States, farmers are especially concerned that information specific to their farming practices could be used for regulatory enforcement purposes (Ferris 2017), or that farm level data might be used in civil or regulatory litigation (Janzen 2017). The United States Congress, Senate Subcommittee on Consumer Protection, Product Safety, Insurance, and Data Security held hearings in November 2017 and questions are being asked about the role of government and regulations that could bring clarity to the murky issue of ownership, access, and third-party use of agricultural data (United States Senate 2017). Dowell (2015b) and Ferrell (2016) suggests farm data would fit trade secret-type protection including the management techniques (practices) used by the farmer to produce food. In the courts, trade secret as a form of IP protection of farm data, is a matter of (American) state law and authority lies outside the domain of constitutional law and legislation authority of the federal system, like trademark, patent, or copyright forms of IP rights (Dowell 2015b). In the current American legal system, Dowell concluded farm data as a trademark would be readily discarded by the courts, patent law would be inapplicable, and the ‘works of authorship’ would have to be proven if farm data is argued as copyright IP. This leaves farm data protection under trade secret IP as one remaining potential (legal) approach that could bring clarity to ownership rights of farm data. However, the farm data describing the practices such as planting rates, yield, machinery paths, inputs, conditioning, processing, etc., must first be shown to bring economic value to the owner of the trade secret and secondly, that reasonable effort has been done to protect its secrecy.

Privacy of personal information type data is regulated primarily on an industry basis in the United States. The financial and health sectors are highly regulated when it comes to customer/patient data in order to prevent disclosure of their personal information and allowances for consumers to choose what is done with their data (Ferris 2017). Ferris reports health legislation strictly enforces patient notice requirements about privacy policies, as well as disclosure to third parties (Ferris 2017). While it has been argued that agricultural data is not personally identifiable, that may not be entirely correct. Presently, regulation for agriculture data falls under state law, which differs throughout the United States of America (Dowell 2015 a,b), Ferrell (2016). This essentially means that in agriculture, unlike health or finance sectors where personal information

is protected, information about food production practices is not included in existing privacy legislation even though this practice is linked with a farmers' personal information. As suggested by Ferris (2017), it would be preferable to have an examination of personal information 'identification and re-identification' techniques (i.e. anonymization) and regulatory enforcement of data ownership rights implemented at federal and industry levels (Ferris 2017).

The Australian situation for agriculture data rules (ownership and management) was studied by Wiseman and Sanderson (2017) and three general topics were highlighted in their report:

1. Industry guidelines and data trust, transparency and certification.
2. Data privacy, confidentiality and contracts.
3. Potential barriers related to IP, including copyright and regulations of data ownership, control, use, availability, and access of agriculture data.

They found the current legal framework in Australia for agricultural data is both complex and fragmented and currently, contracts, rather than copyright law, govern ownership of farmers' data. The authors concluded that it is unlikely that agricultural data would constitute trade secret type information in Australia. In addition, there is a lack of awareness in terms of data licenses, suggesting the industry needs to make the terms of license use and other aspects of arrangements with agtech providers more transparent (Ibid). Like Ferris (2017) in the United States, Wiseman and Sanderson (2017) acknowledged that agricultural data in Australia is not generally considered personal information. Nevertheless, with georeferencing of location with farm data, the Australian authors assert an individual farmer could be identified, thus making the geographic information system (GIS) tag, which is linked to the farm level data, being interpreted as personally identifiable information.

The Office of the Australian Information Commissioner has developed the Australian Privacy Principles (APP) and federal policies related to facilitating big data activities provide a mechanism to protect personal information. In the February 2018 legislation, there is a legal requirement for mandatory notification when a data breach occurs (<https://bit.ly/2Nd2Bou>). Currently, however, agriculture data tend not to be considered personal information and is, therefore, not covered by the *Privacy Act* and its APPs (Wiseman and Sanderson 2017, 24). Agricultural data and linked personal information remain controlled by the contracts between farmers, third parties, and agribusinesses.

In Canada, personal data is very broadly defined as information about an ‘identifiable individual’. As reported by Kardash and Kosseim in a review of data protection laws, information is deemed to be about a person “where it is reasonably possible for an individual to be identified through the use of that information, alone, or in combination with other available information” (2018, 55). Each Canadian jurisdiction has an Information and Privacy Commissioner to oversee data protection laws in the respective jurisdiction. There are essentially four statutes: the federal *Personal Information Protection Electronics Document Act* (PIPEDA), the two provinces of Alberta and British Columbia have a Personal Information Protection Act and protection of personal information in the private sector in Quebec is governed according to the Quebec Privacy Act (Ibid).<sup>2</sup> While most provinces have health privacy legislation, there is no such equivalent for the agriculture sector. Strobel (2014) examined the issue of information ownership in precision farming and suggested PIPEDA may have relevance in agriculture as it is intended to prevent exposure of private data in commercial activities. For example, a corporation may be held liable for use of data beyond what it is designated to do or use data without informed consent.

The industry has embarked on self-regulation mechanisms to bring transparency to the process of collection and use of agricultural data. In the United States, the American Farm Bureau Federation (AFBF) working with commodity groups in the United States, as well as general farm organizations and agriculture technology providers, helped establish the Privacy and Security Principles for Farm Data. These principles are incorporated into a voluntary industry standard named the Ag Data Transparency (ADT) certification system. ADT was created in 2014 with farmer input through a coalition of the AFBF, commodity organizations and numerous industry stakeholders recognized as agriculture technology providers (AFBF 2014). The many principles address various aspects of agricultural data including: education, ownership, collection, access and control, transparency and consistency, choice, portability, terms and definitions, disclosure, use and sale limitations, data retention and availability, contract termination, and unlawful or anti-competitive activities, and liability and security safeguards (AFBF 2016). Agribusiness firms that agree to the principles and a third-party audit of their records receive an ADT certification (Janzen 2015, 2018; Ag Data Transparent 2018). Certifications are subject to expiry, and as with other

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<sup>2</sup> Under *PIPEDA*, the following ten principles are identified: accountability, identifying purposes, consent, limiting collection, limiting use, disclosure and retention, accuracy, safeguards and openness, individual’s access, and challenging compliance. A business or another organization is required to identify an individual within the institution to ensure compliance with the principles.

types of policies or principles, they are generally not legally binding contracts between a company and the producer, and Dowell and Ferrell (2015) posit a signed Non-Disclosure Agreement would be ‘much more desirable’ for a farmer rather than relying on a company and its representatives to comply with the ADT general principles.

In New Zealand, the dairy industry developed the Farm Data Code of Practice to provide guidance on the governance of farm data and the Code is now used in other sectors (New Zealand Farm Data Code of Practice n.d). In the EU, the Code of Conduct on Agricultural Data Sharing by Contractual Agreement (EU Ag Data Code) is part of the *General Data Protection Regulation*, GDPR (European Commission 2018), and as assessed by Janzen (2018a), the Code is similar to the ADT. A basic principle is that data produced by the farm operator (or commissioned by the same), is the property of the ‘data originator’, and as the person who has initial rights to the data, the originator decides how the data will be used or shared. The concept of ‘pseudonymization’ is embedded in the Code thus rendering data ‘less identifiable’ and reducing risk of linking with personal identifiable information. The Code also prescribes conditions for contracts concerning agricultural data, including on-line amendments (Ibid).

The Data Codes and ADT principles may not be enough to resolve the governance of data concerns. At the heart of concerns is a lack of trust on the part of data contributors (farmers) with those who collect, aggregate, analyze, and then share farm-level data. After a series of interviews with farmers in Canada and United States, Wall, presenting information based on Farm Credit Canada (FCC) surveys (FCC, 2018), and Janzen (2019a), reporting on similar surveys done by American farm organizations, cautioned that erosion of trust in issues related to new technologies can become be a severe impediment to acceptance of new digital technology innovations. Failure to consider the trust factor and agricultural data is also a critical factor for Australian farmers (Higgins et al. 2017; Wiseman et al. 2019). Based on interview data gathered from numerous industry stakeholders, Wiseman and colleagues found that only 6% of 895 farmers had ‘total trust’ that their service or technology provider would not share their data with other third parties, and 36% had ‘no trust at all’.

Security of data and trust are issues recognized as critical factors for the Canadian livestock sector. In the early stages of development of the TrustBIXS (Beef InfoXchange System), President and CEO, Hubert Lau, a tech developer, and Senior Vice President, Deborah Wilson, a rancher, put data security and trust ‘up-front and center’ of the TrustBIXS model (p.comm., Lau and

Wilson, 2017). The TrustBIXS policy for protecting personal information Are based on the principles prescribed in PIPEDA and Alberta's *Personal Information Protection Act*. Privacy agreements between the farmer/rancher and TrustBIXS clearly define data sharing, including third-party use by BIXS program participants (e.g. Cargill, McDonalds). Multiple layers of mechanisms (e.g., password, cloud server, backups) protect the data collected by TrustBIXS, including personal farm information, farm operation identification (i.e. ranch or feedlot as Premise ID number), Verified Beef Program status, and individual animal information (e.g., sex, breed, pedigree, vaccination and health, calving, carcass data).

In all the above examples of industry self-regulation addressing the challenges of governance of agricultural data, a company or organization's choice to participate in the industry standard remains voluntary, and the principles and codes are non-binding and, except for Trust-BIXS, industry participation is limited. According to current information on the web portal, only 37 companies have agreed to the 'Core Principles' for agricultural data and 20 companies are ADT certified. Most are American companies along with a Brazilian company (ProdutorAgro) and two Canadian organizations, FCC and AgInsights Go360|bioTrack, and more recently, Farms Business Network, a signatory to ADT, established operations in Canada (Ag Data Transparent 2019; FBN. n.d.). FCC is a federal crown corporation reporting to Parliament through the Minister of Agriculture and Agri-Food (Farm Credit Canada, n.d). AgInsights is an Ontario-based not-for-profit co-operative and their bioTrack program uploads animal identification information directly into the Canadian Cattle Identification Agency's database and the organization works closely with Trust-BIXS (Canadian Cattleman, 2016; BIXS, n.d.).

Regulating the data governance aspect of smart farming will be a major institutional challenge, and at its most basic level is implementation. The scale of sensors embedded in agricultural equipment is substantial and regulating, for example, a new combine harvester typical of broadacre farming would contain at least 240 sensors according to anonymous industry sources, and a new large tractor would have upwards of 60 sensors. (The number of sensors used in livestock operations is not common knowledge.) Each sensor is collecting data and transmitting it to a local server or the Cloud, thus conferring real-time information about the location of the machine (e.g. geographic information system or GIS coordinates, the inputs applied, the status of health of the crop or animal, time and data of harvest, and yield). Harris (2018) claims that even in Canada, the scale of the data being collected from farms 'is staggering' (Harris, 2018). Weersink

and colleagues suggest, “our ability to generate data exceeds our ability to manage, analyze, and use those data” (2018, 32). The authors conclude the landscape of agricultural data is “a somewhat chaotic and fractured data ecosystem” and identified governance of data as an ‘extremely challenging’ issue (2018, 27). They suggest that all data players (from major corporations to government) are grappling with the challenge of building coherent regulatory frameworks and standardized protocols, also identified by Stočes et al. (2018) as a constraint. As data is downloaded and uploaded, stored and transmitted, Weersink et al. (2018), also identified communications infrastructure, specifically a lack of broad band and rural connectivity as a major barrier to smart farming.

### *2.2.2 Rural connectivity and sensors*

The second, and fundamental dilemma for smart farming is limited access to broadband internet. In comparison to urban areas, access and availability of ICT is a barrier in rural areas around the world, although access varies between countries. The most influential factors determining ICT access and broadband infrastructure supply are the “economic level of the country, the level of competition in the telecommunications market, the demographic distribution of the population, and availability of telecommunications infrastructure” (Cava-Ferreruelaa and Alabau-Munõz 2006, 453). While the rural connectivity challenge is recognized by global organizations such as the OECD, there is “no general agreement about what government policy should be” (Ibid, 449). In addition, the authors noted an absence of metrics to determine the effectiveness of various strategies adopted, concluding there is no universal approach to address the common problem of connectivity. Moreover, depending on the region, the term broadband has a diversity of definitions. For example, in the OECD countries, broadband technology implies minimum transmission speeds of 256 kilobit per second (Kbps) for downstream connections and 64 kbit/s for upstream connections (Ibid) and the primary mode of delivery is a digital subscriber line (DSL).

The EU has extensive fibre-based broadband infrastructure that provides ultra-fast (high speed) of 30 megabits per second (Mbps) for all Europeans (Abrardi and Cambini 2019). Many of the EU member countries directly subsidize broadband infrastructure investment, including in rural areas, and Abrardi and Cambini report that half of the population would have access connections of more than 100 Mbps. Consequently, rural infrastructure would not likely not limit smart farming for most farmers in the EU in comparison to other countries within the OECD.

Broadband is an ‘internet dilemma’ in rural United States and in 2017, it was estimated that 29% of American farms do not have (any) access to the Internet (Husain et al. 2018). Since 2010, broadband speed internet is defined as a minimum connection speed of 4 Mbps download speed and 1 Mbps upload speed (Bennett et al. 2016). Unfortunately uploading capacity is limited in rural areas and this is a problem for farming. Precision and smart farming depends on broadband connections for data collection and analysis that is done either on-farm or through remote data centers. Limited or no internet also creates learning barriers for farmers by restricting access to IT-based courses offered by land grant universities and the latest information on precision farming technologies. However, the biggest issue is that in comparison to urban broadband consumers that rely on high download speed, data transfer between farm equipment or uploading data from the field equipment to the (cloud) online servers requires greater (upload) capacity than 1 Mbps upload speed (Coble et al. 2016). Unfortunately, despite the policy strategy of “encouraging competition between DSL and cable platform operators” (Rajabiun and Middleton 2013, 11), there is little commercial business interest in infrastructure upgrades considering the high investment costs for scaling up (greater speeds and expansion of cellular infrastructure), terrain challenges and fewer users in rural compared to urban areas. Alternatives such as ‘high-powered Wi-Fi radios’ show potential as a viable communication option for communication between piece of equipment (Bennett et al. 2016). Little progress is being made to address the problem and Coble et al. (2018) emphasize rural infrastructure capacity in the United States is rapidly becoming a major policy issue.

In Canada, providing access to telecommunications infrastructure has been a government priority since the 1990s and the policy approach is much like the United States strategy of market forces responding to a business demand (Rajabiun and Middleton 2013). The Canadian Radio-television and Telecommunications Commission (CRTC), Canada’s telecommunications regulator, defines target internet speeds as 5 Mbps download and 1 Mbps upload within a 25 square kilometres (km<sup>2</sup>) (Canada 2018a). Spectrum and network management are handled by incumbent ICT providers (Canada 2018e).<sup>3</sup> Rajabiun and Middleton report CRTC target internet speeds are “aspirational minimum service quality targets”, adding the network monitoring process is not clear

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<sup>3</sup> “Spectrum refers to spectrum band which is a specified band or range within the overall spectrum of electromagnetic radio waves used as a channel for sending or receiving communications” (Canada 2018d, 17).



and the program review process lacks transparency (2013, 9). Nonetheless, a range of technologies are available to Canadians including: coaxial cable, DSL (copper lines), fibre, fixed wireless (licensed and unlicensed spectrum), long-term evolution (LTE) mobile and 4G cellular technology between mobile phones and cellular towers, and satellites to receive a signal and transmit it to DSL or fibre services (Canada 2018 a,e).

New entrants to the Canadian ICT market may access fixed line infrastructure developed by existing ICT service providers, but unfortunately, similar to the United States, market forces are failing to provide broadband connectivity needs in rural areas. While there are concerns with a lack of comprehensive data (e.g. metrics on access speeds), the Federation of Canadian Municipalities (FCM) estimates about 20% of broadband consumers in rural areas (less than 400 people/km<sup>2</sup>) had access to 30 Mbps speed in 2012 compared to nearly 90% for urban centres with populations between 30,000 and 99,000 people (FCM 2014). What is noteworthy about the urban-rural divide connectivity problem in Canada is that provincial governments have authority to deliver social and business infrastructure. In Alberta, an innovative policy approach to ICT service in rural areas is direct government investment in building broadband capacity. The Alberta government did not use the local incumbent providers (i.e. the federal CRTC policy), and provided public funding to develop an open access network using high capacity fibre and wireless networks, referred to as the Alberta SuperNet (Rajabiun and Middleton 2013, 14). Other policy approaches may be on the horizon according to the report. In collaboration with Innovation, Science and Economic Development Canada, CRTC aims to support broadband in rural and remote area in order to provide a minimal essential service of 50 Mps download and 10 Mps upload. The outcome of the Canadian Senate recommendation to change federal government policy regarding spectrum regulation by incumbent providers, thereby encouraging small providers (including not-profit providers (Canada 2018d), however, remains contested (Saltzman 2016; Lyseng 2017c; DeKay 2017; Duckworth 2018; Duhatschek 2018; Gilmour 2018; Bickis 2019; Wichers 2019).

In African agriculture economies the access and the availability of IoT is a significant challenge to the full adoption and usefulness of digital technologies (Pant and Hambly-Odame 2017). Limited connectivity is also a problem in areas such as Brazil characterized by large agriculture production land areas, a relatively smaller customer base for telecommunication service providers, and poorly developed rural telecommunications infrastructure (Pivoto et al. 2018). Unfortunately, despite the widespread recognition that ICT systems, poorly developed rural

telecommunications infrastructure and limited broadband connectivity, there is little evidence in the academic literature making the claim that access to IoT nor ICT capacity are primary access constraints for smart farming.

The next basic connectivity challenge smart farming is the state of technology for sensors. Sensors used in agriculture are routinely exposed to harsh environments conditions (i.e. extreme temperatures, dust), which impacts functionality (Gershgorn, 2017). The concern/heightened levels of frustration with digital technology embedded in agriculture equipment is triggered when a sensor controlling machine functions is compromised by dust, climate, or other malfunctions. The machine will power down (i.e. work at a very slow speed) or shut down completely until a qualified service technician travels to the farm to find and clear the error code and replace the sensor. Meanwhile, the limited time available to complete farm operations is lost, and the cost for the technical repair (inclusive of the authorized technician's time and travel) would be substantial. While these logistics challenges seem basic, they are nonetheless frustrating when the system fails their user. This challenge, however, will presumably be minimized with advancements in development of sensors.

### *2.2.3 Equipment interoperability*

The third access challenge for smart farming is related to the lack of integration between brands, software, and signal interfaces as firms integrated digital technologies and proprietary systems into their equipment, also known as interoperability. Incompatibility between the proprietary hardware and software (data formats) systems is limiting the farm-level value of smart equipment, although there is progress being made in this area with developments in both hardware and software (Garvey 2018a). Both approaches show promise to address the farm level-interoperability challenge.

The development of standardized physical connections between electronic components is one of the first industry responses to the interoperability challenge. Controlled area network (CAN) and the Binary Unit System (BUS), together known as CAN-BUS (Fountas et al. 2015) were developed and are increasingly used by equipment manufacturers. Next, the International Standards Organization (ISO) standards improved data communication. ISO-BUS 11787:1995 provided an Agricultural Data Interchange Syntax (Stafford, 2000) and ISO 11783-1:2017 is the worldwide serial and data network communication protocol for the agriculture industry that enables data communication between tractors, other implements, and farm management software

(Freimann 2007; Cavallo et al., 2014, 2015; John Deere 2013; ISO, n.d.). The third strategy is development of open-source software solutions to accommodate the needs of farmers to transfer data between preferred Application Programming Interface (API) and different pieces of equipment, or integrating different field-map based crop production recommendations.

Agriculture is a diverse industry and in addition, approaches to farm management vary widely from region to region, within region and type of farming system, and other micro environment factors such as soil type, climate, availability of labour, and so forth. Consequently, farmers will adapt their farming practices to integrate existing new technologies in a cost-effective way and this often means using different brands of equipment with different data types of software programs for planning field paths, managing zones within fields for seeding and application of inputs, and then layering this information with yield information. Previously, these records were captured in paper records, or sometimes they were simply stored in the farmer's mind. With smart farming, data is captured in many ways including yield information from monitors on combines or from grain cart (weight) monitors. Yet, data collected is not used to its full potential due to incompatibility between the proprietary hardware and software (data formats) systems. However, when the early stages of computer systems are considered, this is not unexpected as information technology (IT) related issues in agriculture equipment are similar to the early innovation stage in personal computing devices.

In the late 1970s, through to the mid-1980s, tech users were frustrated with the lack of interoperability between personal computing and smartphone devices that used different operating systems (e.g., the Apple microcomputer and the MS-DOS and Windows 1.0, the iPhone and Android versions of smartphones). The personal computers and connected devices would not 'talk to each other' and documents created by word processing software programs developed for each operating system could not be interchanged for either read or write access. It took several years before differences between the operating systems was resolved. The smart farming analogy is the lack of ability to share information between one brand of tractor with its proprietary operating system and a different brand of seeder and on-board seeding or yield monitors as each has different APIs. The IT challenge of incompatibility between brands of equipment or absence of a universal operating platform in agriculture is, therefore, not an unexpected innovation challenge given the early stages of digitization of the industry.

The Ag Data Application Programming Toolkit (ADAPT) is a first step towards common data syntax that leveraged the ISO 11783-10 standard XML format. ADAPT is described as the Rosetta Stone for digital agriculture (Crakker et al. 2018), and it is a platform-based software solution and accommodates the needs of farmers to transfer data from their preferred API displays into different OEM software systems (<https://adaptframework.org/>). The development of ADAPT began in 2016, and the ‘interoperability solution’ is the result of collaborative effort of over 200 agribusiness companies including SMEs, and large OEMs including several European Union (EU) value chain participants (AgGateway 2018; IoFF2020 2018).

ADAPT is available to any user and consists of: a programming interface (platform), a set of open source code that is hosted on GitHub), proprietary data conversion ‘plug-ins’, and a ‘common object model’ describing field operations (AgGateway 2018). Companies can support ADAPT through a hardware and software approach by developing a plugin for their proprietary file formats (hardware), or they can directly integrate ADAPT into their operating systems (software). The Eclipse Public License for the Application Data Model in ADAPT allows each plug-in writer to select a licensing and distribution model that best suits their business model (Craker et al. 2018). In March 2018, several European Union (EU) value chain participants were using ADAPT, including the following: CaseIH, New Holland Agriculture, and Steyr (owned by CNH Industrial N.V); and Challenger, Fendt, Massey Ferguson, and Valtra (owned by AGCO) (IoFF2020, 2018). The list of participating companies continues to grow and many of the major industry actors are now listed on the ADAPT website as supporters, including: John Deere and AgLeader Technology SMS™ Software (MachineFinder 2018), AgLeader, Raven Industries, Topcon, Trimble Ag, and Climate (FieldView™).

Despite the initiatives led by the industry, interoperability remains an operational challenge to smart farming. ISOBUS prescribes a minimum scope of functionality for hardware and software across implements, and ISO 11783 is a voluntary multi-master (serial control and communications data) network standard based on CAN. Furthermore, there may be different visions of connected equipment emerging from the European Union and North America. The European value chain participants is represented by the European Agricultural Machinery Association, or CEMA. CEMA, also a member of AgGateway, has taken a position that connected farm implements are core to digital farming and machines must be able to ‘seamlessly talk to each other’ (CEMA. n.d). A similar common strategy has not been proclaimed by farm machinery equipment manufacturing

organizations in North America, notably the Association of Equipment Manufacturers (AEM) where their website highlights their role in shaping policy and harnessing data (AEM, n.d.) Smart agriculture equipment still lacks a universal operating platform to connect the entire operating ecosystem (Manning 2017); i.e. there is yet to be a universal operating system platform available for use by different manufacturers of agriculture equipment and software developers.

#### *2.3.4. Intellectual property and copyright law*

The fourth access challenge is related to new business models in the agriculture industry including the use of copyright law and digital ‘locks’ to control access to equipment operating systems; these are radically different than established norms in the farming community and the patent form of IP and return on investment in research and development (R&D) in agriculture equipment. Intellectual Property (IP) policies, particularly copyright law, for example on the source code for a machine (Lyseng 2018b), is impacting the right of an equipment owner (farmer) to modify and fix a piece of equipment they purchased without running the risk of jeopardizing warranties (Higgins et al. 2017; Carolan 2017a, b; Right to Repair 2018; Raine 2018; Lyseng 2018 a,c; Phillips et al. 2019).

Research, development, and commercialization of new technologies are expensive and Zambon et al. (2019) observes that smart farming innovations are limited to a few pioneering firms, notably larger enterprises. A few global agribusinesses and original equipment manufacturers (OEMs) dominate commercialization of Agriculture 4.0 innovations and many of the innovations are geared towards large commercial farms with service agreements arranged by local dealerships (Bronson 2019; Fleming et al. 2018). The OEMs first out of the gate with agtech innovations are following intellectual property (IP) strategies similar to the Information Technology (IT) sector and a series of issues are spilling over into agriculture sector. The foremost issues challenging innovation in the IT sector are privacy, protection, regulation of data, security implications of big data storage and analytics, and copyright protection of operating systems software (Gordon-Byrne 2014).

As a result of this shift in the agriculture equipment IP-business models, a farmer who purchases post 2015-era John Deere™ farm implement, for example, is in a situation where he/she does not own the technology that operates their equipment (Raine 2018). Digital locks on machinery manufacturers’ proprietary technologies restrict a farmer from making a quick, on-farm fix when equipment breaks down, or ‘tinkering’ with their machinery in order to adapt it to their

specific farm situation (Higgins et al. 2017). The OEMs position is if anyone except an authorized dealership repairs or modifies the equipment, the outcome could result in unsafe operation. Besides, the resale value may be adversely affected, the capabilities and performance of the machine may be compromised, and the equipment may no longer be compliant with environmental regulations (Right to Repair, 2018). From a legal perspective, ‘breaking’ the system for a farmer-fix is a violation of the copyright owned by the equipment manufacturer. The frustration is that even minor glitches in the software can cause the machine to shut down and be rendered inoperable or, in some cases, the machine powers down to a fraction of its capacity, and a machine can be rendered inoperable for several days due to the malfunction of a windshield washer fluid sensor, which is not a priority/safety-related issue related to functioning of an implement such as a combine (Lyseng 2018b).

Intellectual property and copyright control are especially contentious issues in the United States where the United States *Digital Millennium Copyright Act* (DMCA) is the legal avenue by which farmers are compelled to comply with the company’s licensing agreement. Violators may be met with fines or, in extreme cases, ‘jail time’ (Wiens 2015; Sydell 2015). As the OEMs try to protect their IP, the ‘Right to Repair’ movement is growing, and farm organizations in 20 states are filing government bills calling for ‘fair repair’ (Lyseng 2018a; repair.org/legislation, 2018). Until the court challenges are resolved, farm groups have petitioned the United States Copyright Office for exemptions on farm equipment in the anti-modification provisions of the DMCA. Exemptions were made in 2016, but the United States Copyright Office noted that End User License Agreements (EULA) superseded copyright law and recourse for remedies would be through state law (repair.org/legislation 2018). California passed legislation requiring equipment dealerships to provide access to service manuals, product guides, and onboard diagnostics to aid a farmer with identification of any machinery problem; the law does not, however, provide farmer’s access to parts and diagnostic software (Wiens and Chamberlain 2018). However, the scale of the challenge in balancing farming traditions such as repairing and tinkering, with protecting the new IP, is seldom reported beyond the Right to Repair movement group of industry actors. In addition, DMCA has no effect in Canada (Phillips et al. 2019).

### *2.3.5 Unintended consequences of the IoT in smart farming systems*

A final farm-level access challenge is the unintended loss of control of equipment as a consequence of farmers circumventing digital locks and software restrictions on repairing equipment. Controlling the operation of a farm vehicle is not a trivial matter, nor are the broader implications of doing so. In response to restricted access to equipment operating systems and being ‘locked out’ of their own equipment, an underground revolution is emerging in the agriculture sector. Hacking and open source ‘firmware’ are used to break the OEM brand software code, enabling farmers to make their own, affordable repairs on their equipment (Lyseng 2018a; Gehrer 2018). In addition to legal penalties for this action as indicated above, there are other concerns and security and intelligence agencies are taking the issue very seriously.

In October 2018 a report prepared by Boghossian and collaborators with assistance from the United States Department of National Security (DNS) and the United States Office of the Director of National Intelligence (DNI) identified a series of threats to precision agriculture. Based on interviews, the authors concluded that hundreds of farmers in the United States are using pirated software to ‘jailbreak’ their tractors in order to self-diagnose error codes when sensors or software malfunction, doing this simply to keep their equipment operational (Boghossian et al. 2018). While this solves a farmer’s immediate problem to diagnose a problem and make a repair, accessing the operating system by the pirated software leaves both the software and the equipment operating systems vulnerable to ‘backdoor’ coding and easy access by malicious actors (pirates). Thus, access is a serious threat to precision agriculture and smart agriculture equipment in the United States, and alarmingly, the authors of the report identified that the pirates, including those who wrote the source code, often reside in jurisdictions beyond the arm of American law. A pirate could readily shut down a farmer’s machine, and even more significant, if a pirate gains access to a general operating system, he/she could, in theory, control equipment linked in a dealership and/or the OEM network, thereby exercising control of entire fleets of equipment at the discretion of the ‘pirate’.

Repercussions of pirates opening the backdoor and accessing control of smart equipment are very real, and highly significant, with the opportunity, lying dormant until the pirate chooses to gain access through remote control of the system which would impact completion of time-critical farm operations. Farmers were generally unaware of this vulnerability (Boghossian et al.

2018) and the issue of access and the behaviour of jailbreaking and attack by pirates is seldom mentioned by policymakers in the context of agricultural equipment operation.

### **2.3 Implementing smart farming technologies**

There are many unsettled issues as how to measure, judge, and ultimately achieve gains in productivity and understand who benefits from agriculture R&D and how farmers benefit in the long run (Alston 2018). Margins on sales of the agricultural products is the most important factor critical in the development and acceptance of new technologies, according to El Bilali and Allahyari (2018). With Agriculture 4.0 and smart farming, there is little evidence of why different digital technology is adopted. This poses a unique challenge to advancing a smart farming future because the uptake of some digital technologies in farming are slow, while some aspects are quickly and widely adopted, and other technologies are not. Based on several in-depth studies and high-profile reports of precision farming, Lowenberg-DeBoer and Erikson (2019) suggest the acceptance of digital technologies lags for both economic and technical reasons. In a long-term economic study of a wide range of precision agriculture technologies available for use by farmers in the United States, Schimmelpfennig (2016) concluded the economic benefits are not consistent across all farms and all commodities. Data analyzed in a long-term study by the United States Department of Agriculture (USDA) showed that the major crops of soybean and corn in the Midwestern United States are examples of where precision agriculture has increased profitability (Ibid). Bramley (2009) similarly reports precision agriculture has improved management of certain commodities by targeting management of production inputs. Evidently, the universal benefit of digitization of agriculture has not yet been demonstrated and a few explanations for this innovation challenge are suggested.

Rabobank reports that new software technologies lack a clearly articulated value proposition and selling software as a service to farmers has been a problematic revenue generation strategy (Manning 2017). Lindblom et al. (2017) found that agriculture decision support services have implementation problems and the digital technology solutions for farming neither aligned with farmers' needs nor do the new software-systems-based technologies offer cost or time-saving solutions to production problems. Meanwhile, other researchers concluded that decision support tools are used by farmers (only) when they are required to document compliance with quality assurance schemes, regulations, or market requirements (Rose et al. 2016). Zhang et al. (2002) observed that government incentives matter, concluding that strict environmental legislation in



Germany, Denmark, United Kingdom (UK), Australia, and the United States incentivized adoption. Schieffer and Dillon (2014) found the type of technology matters, especially if public policies such as tax incentives, subsidies, or cost-share programs support the adoption of the technology. While this may be true, there is compelling evidence of farmer acceptance and widespread use of digital technologies in agriculture without the need for government intervention. Innovations embedded in agriculture equipment is a classic example. Agriculture equipment is a major capital cost, an essential asset for farm operations, and investment in new technology embedded in equipment is a long-term commitment to use of a smart innovation. Tozer asked the question already in 2009, and now has relevance in the context of more recent agriculture industry concerns – is the investment in digital technologies ‘worth the money?’ The evidence reported below suggests, yes.

Automated milking systems (AMS) and feeding systems offer regularly scheduled daily milking routines without the need for human labour. In a review of AMS, Jacobs and Siegford (2012) report the technology was first used in 1992 in The Netherlands and then the technology was brought to Canada and the United States. With AMS labour savings and optimization of animal nutrition and health using sensors that monitor udder health, feed intake and body weight changes and milk production for each cow, the technology demonstrated value through increased production (2 to 12%) and freeing up the farmer’s time to focus on other farm management activities (Ibid). AMS is now ubiquitous in the international dairy sector and by 2009, over 8,000 dairy farmers around the world were using AMS. In the leading dairy industry countries of The Netherlands and the New Zealand, farm-level data from each cow is aggregated, matched with pedigree records and analyzed to inform dairy breeding programs, monitor herd health and milk production (Eastwood et al. 2017). Fully robot milking systems (RMS) are now available that milk cows on demand (i.e. several times per day when the cow chooses to be milked), however, the economic benefit is not consistent and whereas RMS used by dairy farmers in The Netherlands allows them to “milk more cows and produce more milk with less labor”, in the United States, RMS presently remains cost prohibitive, however, if access to immigrant labour is restricted, the economic situation may change for midwestern USA dairy farmers (USDA 2019).

In the crops sector, digital technologies used for precision agriculture also referred to as precision farming, is traceable to the 1980s. Global Positioning Systems (GPS), initially developed by the National Aeronautics and Space Administration (NASA) in the 1990s, was incorporated

into John Deere™ agriculture equipment (Hall 2018; NASA Tech Briefs 2017). GPS is a foundational digital technology for precision farming and a standard feature in most brands of farm equipment. The technology delivered efficiency in the application of crop inputs by enabling farmers to account for spatial variability as fields in many areas around the world have highly variable soils, topography, and drainage (Stafford 2000). Auto-guidance is the second type of digital technology widely deployed at the farm level, effectively reducing product and fuel input costs, enhancing operator comfort and safety (Cavallo et al. 2014, 2015), improving operator's reaction times, and reducing mental errors (Bashiri and Mann, 2015). An added benefit is that auto-guidance systems can be installed on new or older machines (Booker 2018b). Differential GPS correction further enhanced auto-steering and navigation systems by reducing overlap and misses of crop inputs during the application process (Adams 2013; Mulla and Khosla, 2015). The third core digital technology widely adopted is automatic sectional control (ASC) technology. ASC technology provides a precise distribution of products across the width of an implement, and when combined with electronic control units (ECUs) that monitor and control machine function, and GPS-based auto-guidance; different 'sections' may be shut on and off as needed, reducing waste of seed and chemicals (Bennett et al. 2016).

The above mentioned three types of digital technologies are standard features in farm implements, they are not difficult to use, they solve a farm-level problem, and they offer substantial farm-level benefits, mainly by reducing farm input costs and making the difficult working conditions for the equipment operator safer and easier. The impact of the use of these core technologies is evident to observers. Rows planted with tractors and seeders equipped with auto-guidance and auto-navigation systems are straighter and plant stand is more uniform than ever before, creating the conditions for higher yield potential and better-quality crops. Fields managed with GPS-based auto guidance, and ASC technologies, lack the spraying 'misses' where the tractor operator misjudged lining up the sprayed with unsprayed areas. Similarly, fields harvested with equipment that have these same technologies have less waste. After harvest, there is little standing crop remaining where the combine harvester turned and the remaining stubble is even in height. Less obvious are the gains in operational efficiency realized due to less fuel usage, work operations completed in less time, a 'more even' application of input per unit of time, and the optimization of nutrient and seed inputs confer a positive and longer term environmental impact (Ashworth et al. 2018; Smith 2013; Mulla 2013; Schieffer and Dillon 2014; Schmaltz 2017).

### *2.3.1 Equipment-based smart autonomous farming*

Farming is an extreme human activity requiring repetitive work that is physically and mentally demanding, and often done in rural areas, under uncontrolled environmental conditions with seasonal terms of employment. Foreign workers are often used to fill employment gaps when the domestic labour market falls short of meeting demand, but this government intervention solution is not durable given the context of prairie farms - rural location of operations, seasonal work, and specialized skills needed to operate high tech farm equipment. Moreover, grain and oilseed commodities are not included in the National Commodities List, therefore, access to agriculture specific employment programs such as Seasonal Agricultural Worker Program (SAWP) and the Agricultural Stream of the Temporary Foreign Worker Program (TFWP), is restricted (CAHRC 2019, 36). It is therefore not surprising that economies of scale, including purchases of large manned equipment and larger farm sizes, are standard approaches to rural labour shortages on the prairies and narrow window of time to complete spring and fall crop-based operations.

The use of smaller scale and lighter weight unmanned machines will be a paradigm shift in the trend of bigger and faster agriculture equipment. Autonomous systems, and in particular, robots, are being used on large and small-scale agriculture operations as alternatives to human labour.

Commercial cattle feedlot operations use robots to address safety issues experienced by animal handlers (cowboys) (Stine 2018b). Commercial poultry operations integrate robots into their housing facilities to monitor and shift the activity of birds (Lyseng 2017a). This strategy keeps the birds active and causes less disturbance and stress for the animal than if humans herded the animals. On smaller-scale operations, multiple robots (swarms) are employed for weed control, field scouting, and harvesting (Shamshiri et al. 2018). In addition to the highly specialized single task functions performed autonomously, robots are used to complete an entire cycle of field operations in the UK, beginning with planting (drilling) through to harvest, without human labour. In 2017, the Hands-free Hectare (HFHa) project marked the world's first successful demonstration of robotics to complete an entire cycle of farming activity necessary for production of a barley crop ([handsfreehectare.com](http://handsfreehectare.com)). The second successful harvest was completed in 2018 (Spencer, 2018; Hart-Rule, 2018).

Field robots are defined as “a mobile, autonomous, decision making, mechatronic device that accomplishes crop production tasks” supported by human supervision, but without the need and cost of direct human labour (Lowenberg et al. 2019). In a review of robots and field production, Lowenberg et al. (2019) found that of the few economic studies, the focus was on small robots such as those used in greenhouse operations, orchards, or vineyards. Little is known about use of robots in broadacre farming, likely due to lack of necessary data.

Labour costs and availability, as well as safety regulations for robots differ between countries and accordingly, the economic benefit of field robots will vary across geographies. Lowenberg et al. (2019) suggest that data collected by field robots may possibly bring as much value as the savings in labour costs. There is, however, scant evidence to substantiate direct or indirect economic benefits of field robots due to reduced labour or value from the data they gathered, respectively, or environmental benefits, or constraints in license to operate field robots. A range of environmental benefits are hypothesized including reduced pesticides, ability to maneuver around landscape and maintain natural flora, fauna, and waterways (Ibid). However, at this time, none of these above mentioned economic and environmental benefits have been quantitatively documented in the literature.

Robots are significantly lighter in weight than manned equipment and this is an ‘unexpected advantage’ of agricultural robots (Berggreen 2018). Reduced soil compaction is a possible environmental benefit. Furthermore, from a climate change view, Berggreen argues that with increased occurrence of extreme events, field robots create the possibility of being able to access and operate in wet fields more easily than conventional equipment.

In one economic analysis of the feasibility of autonomy in agriculture equipment, Shockley and Dillon (2018) modelled multiple scenarios of replacing a manned with unmanned machine, finding there were numerous benefits supporting the use of robots in agriculture. In all cases autonomous machinery was the more profitable outcome. They also identified a shift in social dynamics. With the use of field robots, farm operators had more leisure time to spend with their families, the risk of injuries from farm machinery would be reduced, and the tech-savvy and younger generation may begin to view agriculture differently and potentially view smart farming as an area of ag-tech opportunity (Ibid). In their recent study of autonomous vehicles in grain crop production, Shockley et al. (2019) report potential economic benefits compared to conventional equipment including reduced input costs and yield increases related to reduced compaction. The

authors further suggest the establishment of intelligent controls must be cost effective and the highly variable breakeven investment price will depend on grain prices, level of risk aversion and farm size.

Considering the above challenges with robots and uncertainty about the benefits, it is, therefore, not a surprise that autonomous tractors, a key implement for farm operations around the world, have not reached commercialization despite the availability of the technology (Allen 2018; Myers 2018b; Case IH 2016; New Holland 2016). Ghaffarzadeh (2017) estimates the value of the autonomous tractor market to be around US\$ 27 B, although the IDTechEx report suggests it will still be about five years (2024) before the market for autonomous technology changes. Regulations, high sensor costs, and lack of farmers' trust are constraints to large-scale market introduction (Ibid).

After 20 years of working to develop an autonomous tractor, Deere & Company realized their approach was 'insufficient'. In a 2017 interview, senior executives of Deere & Company acknowledged that it is still not able to fully replicate everything a human can 'see and feel' while sitting in the tractor cab (Gershgorn, 2017). Management has learned that an autonomous navigation system for use on the farm needs to "sense everything the human would" (Ibid). Others add that autonomous technology is much more than substituting a driver with remote control. There are broader issues, including insurance and practical aspects, as well as inability to 'mathematically react' to a failed clutch mechanism, for example. A farmer from Alberta, who has a 'hobby' of hardware development and programming, advised an audience of prairie farmers, just because we can make autonomous farm equipment through access to open software systems, the real question is, should we? (Brian Tischler, in Rance 2019). Tischler adds that while there is tolerance in society for human errors, this is not the case when it comes to equipment errors and posits that liability, not the technology, is the reason why OEMs are reluctant to bring autonomous farm equipment to market.

Nonetheless, at the individual farm level, tractors have been made autonomous by leveraging farmers' abilities to make and fix things and accessing on-line resources. Information is found through 'farm hacker' forums and AgOpenGPS mapping software developed for tractors equipped with CANBUS technology (Booker 2018b). Farmers who have formal post-secondary training in computer science, learn code and write their own software. Some farmers, such as Matt Reimer from Manitoba, made his tractor autonomous out of necessity at harvest time when labour

was not available (Hackaday.io). The tractor, used to pull the grain cart while running alongside the combine harvester for unloading grain on-the-go, was made autonomous by Reimer accessing support from an online community centered on robotic tools, Robot Operating System Agriculture (ROS-A). Another example is Kyler Laird, a tech-savvy farmer from Indiana, USA, who made a John Deere™ 6330 tractor (the Tractobot03) autonomous and used it to plant 535 acres (217 ha) of corn in 2017 (Laird 2018; Bennett 2018). Laird has a vision of planting 10,000 acres of soybeans in 2019, using Tractobot03, beginning in fields from the United States and seeding along the way through to Canada (Bennett 2018), advocating for new technology and demonstrating the self-made robotic system.

The advantages of robots are being demonstrated. Bloomberg recently reported the change to autonomous agriculture is coming faster than expected, adding that Canadian and Australian SMEs have been the drivers of driver-less farming systems (Robinson et al. 2019). As noted in a western Canada farm paper, “move over Tesla, agriculture is where the real autonomy is at” as the early adopters of autonomous farming equipment lay the groundwork for agriculture innovation (Myers 2019).

In general, however, widespread used of agricultural robots is presently limited by high investment and maintenance costs compared to available and inexpensive labour; although, Pedersen et al. (2017) argues this may change in the future as labour costs increase and the cost of robotics declines. When this time comes, it is possible that there will be yet another shift in IP models used by agriculture equipment manufacturers. Lowenberg et al. (2019) speculate that strict conditions on the license to (only) operate, and not repair or modify equipment, may influence robotic systems entrepreneurs to develop a service model like Uber.

### **3. PRAIRIE FARMING CONTEXT: A CULTURE OF INNOVATION**

Agriculture is important to the Canadian economy and invention and innovation is essential in order to continually improve the efficiency and economic profitability of the many processes characterizing the industry, minimize waste and ensure the nutritional quality and safety of the food produced. In 2017, the agriculture and agri-food production system accounted for CA\$ 35.16 B in 2017 and when supporting services for agriculture, forestry, and fishing are included, the contribution to GDP increases to \$37.78 B, about two percent (or \$1.889 T) of total national GDP (Statistics Canada Table 36-10-0402-01). Agriculture and Agri-Food Canada (AAFC 2017a) report that in 2016 the agri-food sector directly contributed CA\$ 112 B to the economy, accounting for 6.7% of Canada's GDP and employed 2.3 million people or 12.5% of Canada's total workforce.

#### **3.1 Prairie farms and farmers**

Approximately 46% of Canada's total farms are in the three prairie provinces of Manitoba, Alberta, and Saskatchewan (Statistics Canada, 2016, Table 32-10-0440-01), where the bulk of Canada's grains, oilseeds, pulse, forage crops, and Canada's livestock exports originate (AAFC 2017a). In 2016, farm area in the three Prairie Provinces is about 64.2 M ha (Statistics Canada, Table 32-10-0153-01). Based on operators reporting their income class and farm type in the 2016 national census, cattle ranching/farming and oilseed/ grain farming represented about 21% of farm operator income, followed by 'other crop' farming (12.6%), poultry and egg production (4.5%), hog and pig farming (3.5%), greenhouse, nursery and floriculture (3.1%) and dairy cattle and milk production (2.2%) (Ibid, Table 32-10-0027-01).

Sole Proprietorship is the most common type of farm operating arrangements, although in 2016, there was a 20% decrease from 2011 (56,256 in 2011 to 34,505 in 2016). In comparison, the number of Family Corporations increased in both absolute and relative amounts with 5,514 more (7.23% gain), for a total of 21,129 operations considered a family business. There was minimal change in Non-family Corporations, with a gain of 38 farms in 2016 to total 5,135 farms (a percent change of +0.16%). All other operating arrangements (Other, Partnerships with and without written agreements) decreased (Ibid, Table 32-10-0433-01). Succession planning is an issue of concern as the census data suggest a small proportion of the Sole Proprietorships have

arrangements in place for the transfer of the estimated CA\$245 B in Canadian farm assets over the next ten years when the aging farmer should be retiring (Diamond 2019).

There are 123,095 farmers in the Prairie Provinces and across all age groups of farm operators in the three provinces, 32% (or 39,125) have a secondary (e.g. high school) diploma or equivalent, 18.9% (or 23,090) have a college certificate or diploma, and 16.3% (or 19,885) have a university certificate at, or above a bachelor level (Ibid, Table 32-10-0011). Approximately 44% of farm operators aged 55 years or older have completed apprenticeships or trades certification, college or non-university certificate or diploma, or college degrees. As the senior farmers reduce their work load and retire, future industry growth will be in the 35 to 54-year old group, and under 35-years, where 54% (or 23,265), and 58% (or 6,680) respectively, of these group have education levels preparing them for use of advanced technologies (apprenticeship or trades, college or non-university certificate or diploma, and college degrees). Improved level of education is identified by the Centre for Study of Living Standards as an influential factor for multifactor productivity on a value-add basis (MFP-VA) in primary agriculture, in addition to increased levels of mechanization and intensity in the use of inputs (CSLS 2011).

### **3.2 A culture of innovation**

The prairie region is known for extreme or highly variable climatic conditions and soil types, and as a semi-arid climate, water issues are often the biggest challenges for the prairie farmers (Padbury et al. 2002; Campbell et al. 2014). Deficits of water limit crop production (Bueckert and Clarke 2013), and most water loss on the prairies is by evaporation (Martin et al. 2000). The timing of precipitation in the form of 'green water' (snow or rainfall) is unpredictable and annual precipitation varies on a yearly basis ranging from less than 300 mm in the southern semi- arid grassland regions of Alberta and south west Saskatchewan, to about 700 mm in central Manitoba (Sauchyn and Kulshreshtha 2007). Extensive and persistent drought is the reality (Bonsal et al. 2013; McGinn 2010; Kulshreshtha 2011).

Prairie farmers have a history of adopting new technologies in response to the extreme climatic conditions, and this culture contributes to productivity increases. Total Factor Productivity (TFP) growth from 1940 to 2009 in the crop and livestock sectors has been achieved in all three prairie provinces primarily through technological change, rather than scale effect, i.e., expansion of farm operation size (Darku et al. 2016). One of the most dramatic technological and arguably



cultural changes, is the widespread use of conservation agriculture technologies. This transition took several decades and began with priority setting by federal and provincial governments.

As a farm management practice, conservation agriculture includes both no-till (NT) and zero tillage systems (ZT). At its most basic level, it means the land is cropped continuously with minimal soil disturbance. The new way of farming, which began circa the late 1980s, challenged the decades-old tradition of letting the land lie uncropped during the growing season (summerfallow). Summerfallow was a farming practice recommended by the government as settlers came to the prairies, broke the sod and began homesteading (Marchildon 2011). The concept was promoted as a means of storing scare water for the coming cropping year and controlling weedy species.

By the 1930's summerfallow was having negative impacts on prairie agriculture productivity, soil health and the environment. The thirties were a tipping point - a time of extremely dry conditions. The combination of widespread drought, strong prairie winds, summerfallow, and wheat-fallow crop rotation norms, left the soils in a vulnerable state. Soil organic matter rapidly declined, erosion and salinization increased, and the water holding capacity of the soil was compromised. This severe problem was identified, and the urgency to change the trajectory of tillage operations was highlighted in the Standing Committee on Agriculture, Fisheries and Forestry report, *Soil at Risk: Eroding Canada's Future*, authored by Senator Sparrow 1984 (Senate of Canada 1985). In order to understand the severity of the problem, extensive programs were implemented document the health of soils across Canada (AAFC 1995). The problem was indeed severe, and the environmental and economic sustainability of the traditional ways of farming was at risk. The other problem suggested by Awada et al. was that the alternative was "incompatible with their accepted socio-cultural values and beliefs", for example, that summerfallow was the best practice for managing the land and available (soil) water resources and weedy species (2014, 54).

Many technologies, institutions and actors played a role in the transformation of prairie landscapes, coordinating farm demonstrations encouraging farmers to try new ways of farming. The types of technologies developed and demonstrated were diverse and included innovations in equipment, new herbicides and formulations of fertilizers, new crop kinds, and decision support services (e.g. new recommendations for best agronomic practices for seed placement, rates and fertilization, and stubble management). Government resources were allocated to coordinate

technology evaluation and knowledge transfer activities by government agencies and farm groups and to engage farmers with conservation agriculture technologies (Marchildon et al. 2008).

Policy was implemented by the Prairie Farm Rehabilitation Agency (PFRA), which worked closely with local soil conservation groups. The soil conservation accords and agreements were coordinated under the National Soil Conservation Program (NSCP), with PFRA allocating funding programs to farmer groups in Manitoba, Saskatchewan, Alberta and eastern Canada (Lindwall and Sonntag 2010). From 1985 to 1988 there was a steady increase in the number of farm groups receiving support to educate farmers and demonstrate Beneficial Management Practices (BMPs). These groups were instrumental in coordinating information exchange (extension) using demonstration projects, workshops and field days, but ultimately, the combined effort is a classic example of shifting the behaviour of farmers and establishing a new culture of farming practices.

The changes in farm management, soil, water and air quality (greenhouse gas emissions), and biodiversity were documented in a series of Agri-Environmental Indicator Reports (AAFC 1995; 2000 a,b; 2005; 2010; 2016). From 2004 to 2008, farmers could receive cost-share funding to implement BMPs under the National Farm Steward program, established under the Agriculture Policy Framework. Funding could be used for purchases of no-tillage equipment or enhancements to equipment used for conservation tillage. PFRA was a significant part of the implementation process and conducted several studies to understand the broad range of issues associated with conservation tillage adoption including coordinating a series of meetings with farmers to identify constraints and potential opportunities for further conservation tillage adoption across Canada (Lindwall and Sonntag, 2010). By 2016, nearly 87% of the total acres on the prairies were managed as NT or zero-till (ZT) (Statistics Canada, Table 32-10-4008-01). However, it took many years of research by universities and government research institutions before the economic and environmental impacts of the new norm of conservation agriculture (NT and ZT farming) was better understood (Brandt 1992; Zentner et al. 1996; Gray et al. 1996; Lafond et al. 1996; Clapperton et al. 1997; Janzen et al. 1998; Janzen et al. 2001; Halvorson et al. 2002; Doerksen et al. 2002; Blackshaw 2005; Lafond et al. 2009; Malhi et al. 2009; Tiessen et al.; 2010; Zentner et al. 2011; Lafond et al. 2011; Légère et al. 2013; Gan 2014; Cessna et al. 2015; Halde et al. 2015; Larney et al. 2017).

Many of the technological innovations in conservation agriculture involved the creation of new equipment specialized for use on the prairies. The NT or ZT precision air seeders, fertilizer applicators, straw spreaders and tillage implements were often invented and manufactured by SMEs directly situated in the agriculture region of the North American Great Plains (Wetherell and Corbet 1993; Grosse 1999; McInnis 2004 a,b; Bitner 2012). This is because the large original equipment manufacturing firms have historically not been interested in R&D for equipment, including the relatively small market (limited potential) of ZT systems on the prairies (Lindwall and Sonntag 2010). In a summary prepared by Saskatchewan's Western Development Museum, it is estimated that about one quarter of the 3,200 patents issued by Saskatchewan inventors are for agricultural equipment.<sup>4</sup> In the 1970s, there was 'good awareness' of the benefits of ZT on improving soil health and conserving water, however, non-residual herbicides were costly and NT equipment from other countries were both expensive and not suitable for dryland agriculture due to poor seed placement or ineffective packing (Ibid). Consequently, this set the stage for a vibrant industry for equipment manufacturing, typically shortline manufacturers, those that produce only specialized equipment rather than a full line manufacturer who would make an entire fleet of complementary but different pieces of farm equipment. Presently, Saskatchewan manufacturers are particularly strong in the manufacture of air seeders used for conservation tillage (NT or ZT systems), precision GPS technology, and advanced spraying systems (Saskatchewan 2016).

Innovation in agricultural equipment is one of the key factors which led to the widespread adoption of the new technologies of conservation agriculture on the prairies, however, the shift in farmer behaviour is a remarkable achievement that captured the attention of researchers (e.g. Knowler and Bradshaw 2007; Tarnoczi 2009; Tarnoczi and Berkes 2010; Awada 2012; Awada et al. 2014). Several of these researchers noted the key role in communicative learning, or farmer-to-farmer sharing of information, observation of field trials and demonstrations, experiential learning and social norms). Researchers have recently studied the behavioural aspect of innovation. Micheels and Nolan (2016) surveyed about 500 prairie farmers with livestock and/or crop-based operations to understand drivers of adoption of new technology, concluding that the decision to adopt an innovation was dependent on: recognizing an opportunity, understanding how the

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<sup>4</sup> A history of the short-liners was prepared for the Western Development Museum display in Saskatchewan and is one of the few recorded historical accounts of the industry (DyRyk 1991; McInnis 2004 a, b).

innovation may be applied on their farm, transforming this knowledge into usefulness, and exploiting the innovation to increase farm efficiency. Social capital and absorptive capacity influenced farmers' behaviours. Social capital is defined as "the goodwill available to individuals or groups developed through social interactions" (Ibid, 128). Absorptive capacity is "the ability to acclimate and transform externally generated knowledge into their operations" (129). Like Darku et al.'s longitudinal economic analysis, Micheels and Nolan's empirical model - using economic analysis (multi-variate regression model) - demonstrated that scale-factor variables for technological innovation are less important than social capital and absorptive capacity. Their final conjecture was that farms with greater social capital have better absorptive capacity. The peer to peer networks and farm manager access to organizational resources enabled them to more readily acquire information on new products and processes than farmers who were 'less connected'.

### **3.3 Digital technology use and farm level concerns**

The above studies documenting the culture of conservation agriculture technology use by Canadian farmers are augmented by the 2016 Agriculture Census data on the types of technology used on prairie farm operations. However, it should be noted that information is based on the type of digital technology used on *a* farm operation in the year prior to the Census (2015), therefore, not a direct relationship to adoption of technology by an individual farmer as multiple farmers can be associated with one farm operation.

Statistics Canada (Table 004-0243) data are illustrated in Figure 3.1. Computers and laptops, followed by smartphones and tablets, are used on approximately half of the farms on the prairies and a similar use of the IT technology is reported on a national basis. Equipment-related digital technologies including Global Positioning Systems (GPS) and auto-steering are the next most used group of technologies, more commonly used on prairie farms and in particular Saskatchewan with 50.5% of farms reporting use of GPS, and 41.5% auto-steering. Approximately ten percent of farms use Geographic Information Systems (GIS). Beyond these core types of technology listed as alternatives in the Census, less than five percent of farms use automated controls for animal housing or animal feeding. When the prairie farms are considered in aggregate, proportionally more farms use computers/laptops (+3% prairies relative to Canada), smartphones/tablets (+6%), GPS (+11%), auto-steering (+13%). Relatively fewer farms on the prairies use greenhouse automation (-1%), or automated feeding controls (-3%) and/or

environmental controls for animal housing (-3%), whereas there is little divergence between the prairie region and Canada, for proportion of farms using GIS, or robotic milking.

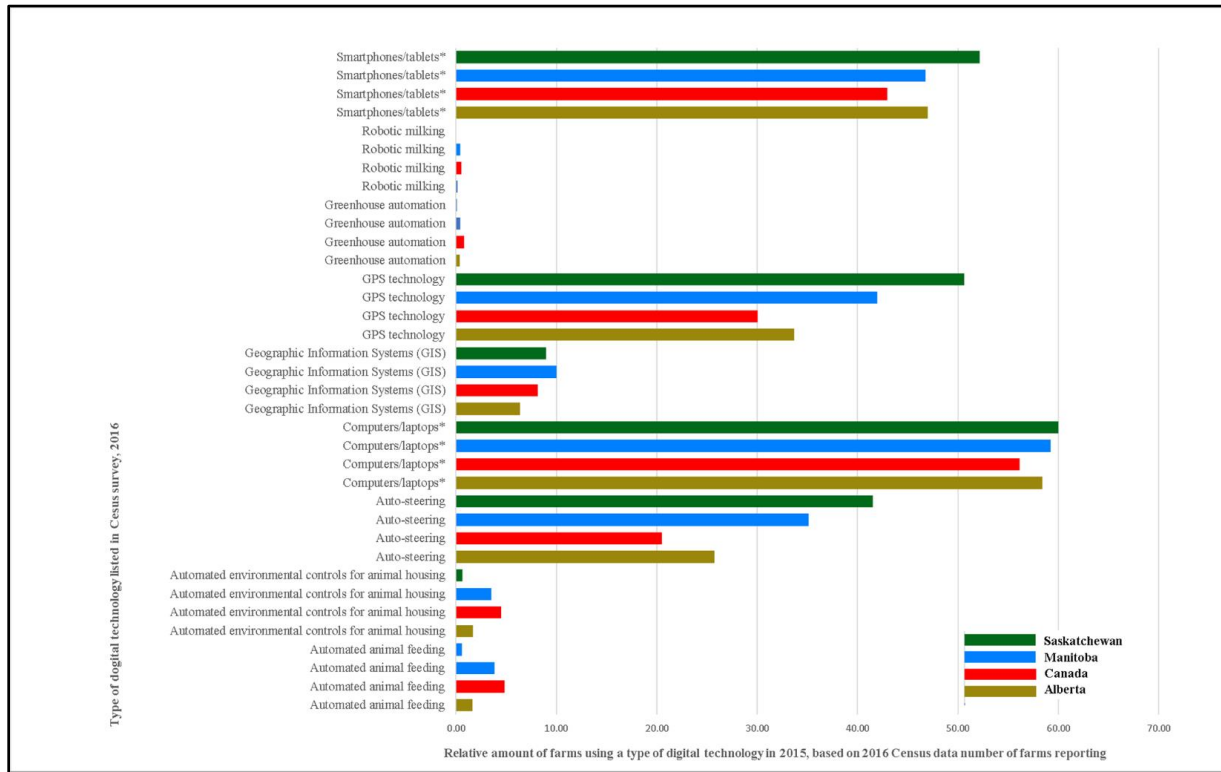


Figure 3.1: Use of digital technologies on prairie region and Canadian farms, 2015. Source: Statistics Canada. Table 004-0243 based on national agriculture census and farms reporting technologies used on respondent’s farm in the year prior to the census, noting potential underreporting of computer and smartphone use.

Statistics Canada data, the most representative sampling of the Canadian farm agtech scene, indicates that digital technologies are generally being used on farm operations throughout Canada. Furthermore, when reported on a relative basis, the use of different types of technologies suggests varies for the prairie provinces where most of the broadacre grain and oilseed farm operations are located. In addition to the Census data, four surveys (2017 and 2018) by industry and non-government organizations further inform digital technology use on prairie farms and highlight hurdles and catalysts that have been identified by farmers.

Following the national census, a voluntary e-survey was commissioned by Agriculture and Agri-Food Canada (AAFC) and took an in-depth look at digital technology adoption by individual western Canadian farmers. These data, reported by Steele (2017), is supplemented by a survey of 514 Saskatchewan farmers done by Turland and Slade (2018). The 261 farmer participants surveyed by Steele (2017) operated an aggregate of nearly 405,000 ha of cropland in western

Canada. However, Steele clarifies the findings should not be considered as a representative sample of farmers' behaviour. He cautions that one should assume results are biased toward early adopters as younger than average-aged farmers participated in the survey, and they operated larger farms and generated higher than average gross farm revenue, i.e. these farmers were more likely to allocate resources to invest in new digital technologies. Steele's results revealed five key aspects of digital technology use by western Canadian farmers. Several of his findings are similar to those of Turland and Slade (2018).

First, farmers aged 35 to 54 years have higher rates of technology adoption compared to younger or older farmers, less than 25 years or over 65 years, respectively. Second, equipment-based digital technologies are widely accepted with GPS auto-guidance systems used by 98% of the respondents, 80% used autosteer and 70% used ASC and temperature and moisture sensing technology for monitoring stored grain (Steele 2017). Turland and Slade (2018) report similar use (94%) of GPS auto-guidance systems. Third, the use of yield monitors and variable rate technology (VRT), two yardsticks commonly used to measure adoption of precision agriculture-type technologies (Griffin and Lowenberg-DeBoer 2005), is much lower when compared to GPS and auto-guidance. Steele found about 50% of western Canadian farmers had combine-harvesters equipped with yield monitoring capability, notably, participants in the AAFC survey report they do not always use the technology, whereas, Turland and Slade report a high level of use (75%) by Saskatchewan farmers. The use of VRT such as prescriptions for fertilizer recommendations were used by less than 50% of respondents in Steele's survey, and Turland and Slade documented that only 30% of 514 farmers used VRT.

Private industry commonly conducts surveys to understand their customer's behaviours. For example, Stratus Ag Research, a private consulting firm, conducts an annual survey of approximately 750 farmers in Canada to understand changes in the adoption trends of new technologies. Their database is a random sampling, however, for the 2017 survey, participants were screened to represent farmers operating more than 400 acres in Ontario and Quebec, and a minimum of 2,000 acres (809 ha) farm size in western Canada. The vast majority (71%) of participants from western Canada (including British Columbia) were operating, on average, a medium sized farm size of 4,483 acres (1,814 ha). Of the 34% who reported they were using field data management software, most were younger farmers and those who work with independent crop advisors (i.e., decision support service providers). Fertilizer application and spraying and harvest

records were collected by approximately 90% of respondents; however, MacLean emphasized that 40% of farmers who have the equipment to capture GIS data, did nothing with their data. Fifty-eight percent of respondents used the harvest data collected by yield monitors; 46% used data to inform seeding practices, 46% for pesticide application, 43% for fertilizer application, and 7% for managing irrigation type production. Stored data stayed on equipment and was transferred to an external storage device, but no further analysis was conducted. Compared to the private firm's 2016 survey, there was a statistically significant increase in the use of equipment that captured agronomic data in 2017. Equipment-based technologies such as field boundary mapping (e.g., GPS) and technologies for input application and management (e.g. auto sectional control or ASC) were used by 57% of respondents. Software-based technologies for yield mapping was used by 53% of respondents, while 29% used field imagery (e.g. data captured by drones or satellites).

Stratus Ag Research found most respondents identified that catalysts for the use of digital technologies were a 'need for profitability' and 'better information for my farm' (MacLean 2018) and when forced ranking was imposed on respondents, the three most important aspects of DT adoption were: (i) ease of use; (ii) having all the data easily accessible in one place, and (iii) the ability to maintain ownership of the data. Similarly, the AAFC survey document that price is the greatest impediment to the adoption of new digital technologies. Participants also reported barriers of weak communications infrastructure, lack of knowledgeable people to address farmers' concerns, constant evolution of the technology, incompatibility with legacy systems, and a technology-mismatch with farmers' needs (Steele 2017).<sup>5</sup>

Another industry survey is conducted on an annual basis by the Farm Credit Corporation (FCC). The fall 2018 survey documented digital technology readiness based on a sample size of 2,000 Canadian farmers (FCC 2018a) and Wall presented the results of the survey at an industry meeting. Respondents indicated the benefits of precision agriculture 'remain uncertain', although 69% reported increased efficiency in operations via the lowering of input costs or achieving better yields, and 65% indicated the new digital technologies improved management control and decision-making. However, three problems were mentioned. The number one concern is the

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<sup>5</sup> In Canada, rural internet access is a contested policy area. The major telecommunications providers of Bell, Rogers and Telus are often in dispute with the federal regulator, Canadian Radio-television and Telecommunications Commission (CRTC) over rates they may charge for leasing network access to smaller companies (Bikis 2019). The situation is widely recognized as a hinderance to farm business (Duhatschek 2018), and rural internet service is referred to as a 'blackout zone' (Saltzman 2016), and rural cellular customers are held hostage by the telecommunications providers withholding access and infrastructure expansion (Bikis 2019).

complexity of the technologies, followed by inconsistent return on investment (ROI), and trust (FCC 2018a). Similar responses were reported in the surveys by AAFC (Steele 2017) and Stratus Ag Research (MacLean 2018) both noting additional concerns of data access, storage and privacy, and cybersecurity.

What is noteworthy about the surveys described above is evidence of the growing concern, regarding trust in data management (FCC 2018a) and the need for compensation for use of farm data (Turland 2018). Of the 2001 FCC survey participants, 58% of farmers indicated their comfort level regarding sharing their data with organizations had not changed since the 2016 survey; however, 25% had ‘become less confident sharing their data’ and are very concerned about data security, privacy, and transparency. Reporting the FCC survey results at an industry conference in November 2018, Wall boldly asserted the industry had not progressed in earning farmer’s trust since the FCC survey two years prior, emphasizing that trust is a critical factor for technology acceptance by the farming community in Canada (FCC 2018a).

Following the November 2018 Precision Agriculture conference organized by Farms.com, where Wall raised a red flag of concerns for the future of precision agriculture and smart farming in Canada, Booker (2018c) contacted various government agencies, concluding ‘farmers are on their own’ regarding ownership and use of farm data. He reported that agricultural data did not fall under the regulatory authority of the Privacy Commissioner of Canada. Authority of the Competitions Bureau is limited to the *Competitions Act* and regulating deceptive marketing strategies. As such, this policy is relevant in addressing complaints filed by farmers. Bronson (2018) reports similar lack of clarity in ownership and rights regarding agricultural data in Canada.

There is, however, one interesting observation on farmers’ attitudes to data, which suggests there may be subtle distinctions among industry actors that have not been previously reported in the literature. The AAFC survey found only 15% were comfortable sharing their farm data with the government (Steele 2017). Turland (2018) further examined results from Turland and Slade (2018), exploring willingness of farmers to participate in a big data program, with or without financial incentive choices. Her study found that the Saskatchewan farmer respondents were ‘most willing’ to share their data with university researchers, in comparison to agriculture input suppliers, producer organizations, financial institutions, or equipment manufacturers. In addition, farmers were more willing to share data under conditions of positive or non-financial incentive.



Smart farming is a new frontier of technological innovation in Canadian agriculture, and the survey data suggest similar trends in other countries. The Canadian data on types of technologies used are not unlike the use patterns reported in the longest-running (10 years), based on the most complete, continuous non-government organization survey of farmers and retailers in 29 American states (Erickson et al. 2017). Authors of the Purdue University study found only 38% of the 209 respondents used VRT for application of nutrients, although VRT for pesticide application was trending upward, and the most widely-used DT reported by retailers is GPS auto-guidance systems and autosteer (78%) and ASC (73%) (Ibid). Hurdles and catalysts of digital technologies for Canadian farmers align with views from abroad (Wiseman and Sanderson 2017; Wiseman et al. 2019; Jakku et al. 2018; Regan et al. 2018; Regan 2019; Kuehne et al. 2017). The Canadian evidence of erosion of trust as a hurdle for technology adoption is similar to two previous studies in the United States (Janzen 2019b). However, in Australia, the failure to consider the trust factor, including what is being done with agricultural data is a critical factor for Australian farmers (Higgins et al. 2017). Wiseman et al. (2019) found that in the Australian situation, at the ‘heart of concerns’ is a lack of trust on the part of data contributors (farmers) with those who collect, aggregate, analyze, and then share farm-level data (i.e. third parties). A mere 6% of the 895 Australian farmers surveyed had ‘total trust’ that their service or technology provider would not share their data with other third parties, and 36% had ‘no trust at all’.

Where the Canadian surveys diverge from the evidence in the United States and elsewhere concerns copyright and the right to repair equipment. These two access challenges described previously (see Section 2.2) seldom appear in the prairie or Canadian farmer discourse. Moreover, when the FCC (2018) survey asked respondents to score the emerging digital technologies with the greatest potential to transform the agriculture industry in Canada, big data was not on their radar. Yet, that does not necessarily imply that smart farming is not the radar for Canadian farmers.

When the 2,001 FCC (2018) survey respondents were asked to score the emerging digital technologies with the greatest potential to transform the agriculture industry in Canada, 36% of survey respondents selected new precision agriculture tools. The least promising, chosen by only 9% of respondents is artificial intelligence, and incrementally more promising technologies are genomics (10%) and farm management software (13%). One of the most revealing results, not previously reported in farm surveys, is that 28% of the respondents chose robotics as new technology with the greatest potential to transform the agriculture industry in Canada. This

evidence builds on the farmer responses documented following the July 2017 Langham, Saskatchewan demonstration of DOT™, what is believed to be the world's first field robot scalable for broadacre, dryland agriculture, commercial (commodity) farming on the prairies. Three-quarters of the 400 Glacier Media survey respondents indicated they would be ready to use an autonomous agriculture vehicle in three to five years (Lyseng 2017b; Glacier Media 2017). DOT™ is locally made; much is known about the success of equipment innovation on the prairies and the inventor is of the entrepreneurial culture and manufacturing zero-tillage equipment. There is however, a gap in our knowledge of smart agricultural equipment and this thesis begins to fill this gap and focuses on SME-origin of a smart farming innovation in the form of field robots which could disrupt the tradition of broadacre agriculture equipment pulled by tractors and eliminating the need for the labour cost of a dedicated tractor operator.

## **4. RESEARCH STRATEGY**

This case builds on the work done in two related prior research projects, Creating Digital Opportunities (CDO) Partnership Grant supported by the Social Science and Humanities Research Council Creating Digital Opportunities Partnership Grant (project number 416303) see Phillips et al. 2019), and a policy study funded by the government of Canada (AAFC, Strategic Policy Branch) Contract 01B68. The research work for the two projects was instrumental in establishing relationships with industry innovators, specifically the SME, SeedMaster which facilitated identification of an industry first smart farming innovation and access to the inventor of DOT™ and management team of the Dot Technology Corp. as case study participants and sources of data for the thesis research. Antecedents to the thesis research based on the CDO project and AAFC grants are summarized in Appendix A. The University of Saskatchewan Behavioural Research Ethics board approved the research done for the CDO project, receiving the Certificate Approval, BEH# 14-317, on September, 10, 2014 (Appendix B).

### **4.1 Case selection and description**

The five boundaries of the case summarized above in the Introduction are expanded below.

#### ***4.1.1 Broadacre farming on the western Canadian Prairies***

Prairie farms are large, hence the term broadacre, with 26% cultivating more than 1,425 ha (Statistics Canada, 2016, Table 32-10-0156-01). Many of these farms larger than 5,000 ha are not distinctly classified in the 2016 national agriculture census. Large farm size, however, does not reflect large income earnings as reported in the census. On a relative basis, the number of prairie farms in the census income categories reporting operator income above CA\$250,000 account for only 1.9% (or 2,310) of prairie farms. Figure 4.1a shows that most prairie farms (57% or 70,245) report an annual farm operator income under \$49,000 (Ibid, Table 32-10-0027-01).

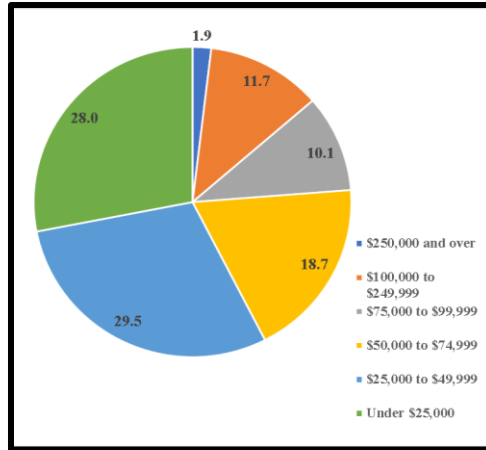


Figure 4.1a: Percentage of farmers across six income categories relative to total 122,090 farm operators in the three Prairie Provinces, all income classes, 2016.  
Source: Statistics Canada Table 32-10-0027-01.

Farm land is the largest asset for prairie farms, accounting for 56% of total farm capital, with 89,952 farms reporting for an aggregate value of CA\$ 280.9 B in 2016 (Ibid, Table 32-10-0437-01). Figure 4.1b illustrates the relative importance of the farm capital components, notably land (\$156.2 B) plus buildings (\$70.5 B) represent 81% of total farm capital. Livestock and poultry represent the approximately 7% (or \$19.2 B) of farm capital with 52,463 farms in the three Prairie Provinces reporting this type of farm capital value.

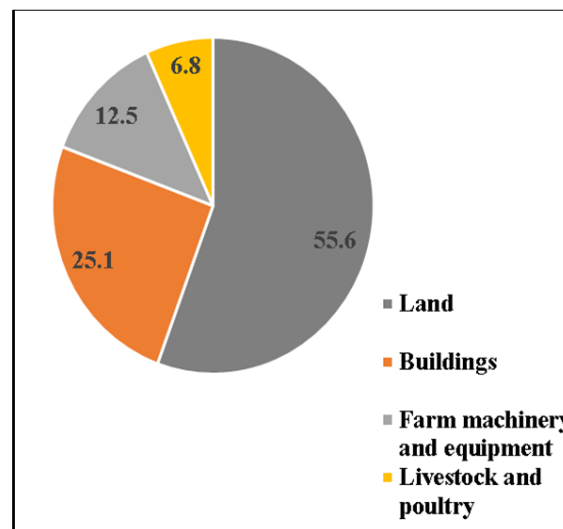


Figure 4.1.b: Relative contribution (%) total to farm capital on farms in the Prairie Provinces, 2016.  
Source: Statistics Canada Table 32-10-0437-01.

### 4.1.2 Agricultural equipment and associated farm inputs

Agricultural equipment accounts for approximately 12% (or CA\$35.17 B) of total farm capital (Figure 4.1.b). Tractors are the main form of equipment capital at \$10.6 B with 63% of prairie tractor capital being the largest-size tractors and census category over 149 horsepower (hp). Approximately 2.2% (or \$0.78 B) of total farm capital is accrued to swathers and grain harvesters (combines), with tillage, cultivation, seeding and planting equipment representing 1.3% (or \$0.45 B).

Operating expenses (total gross) for farms in the Prairie Provinces were CA\$24.04 B in 2016. In terms of operating expenses before rebates illustrated in Figure 4.1.c, the main expense is farm inputs. Approximately 31% (or \$7.4 B) is spent annually on synthetic crop inputs (9.5% pesticides, 5.9% commercial seed and 15.6% fertilizer and lime). The next greatest operating expenses, approximately 13% (or \$3.1 B) are from machinery and repairs, and machinery fuel, 7.4% and 5.5%, respectively; fuel costs represent 6% (or \$ 1.75 B) of total farm input expenses. Labour cost in 2016 accounted for about 7% (or \$ 1.78), of which 51% is non-family wage (Ibid, Table 32-10-0049-01).

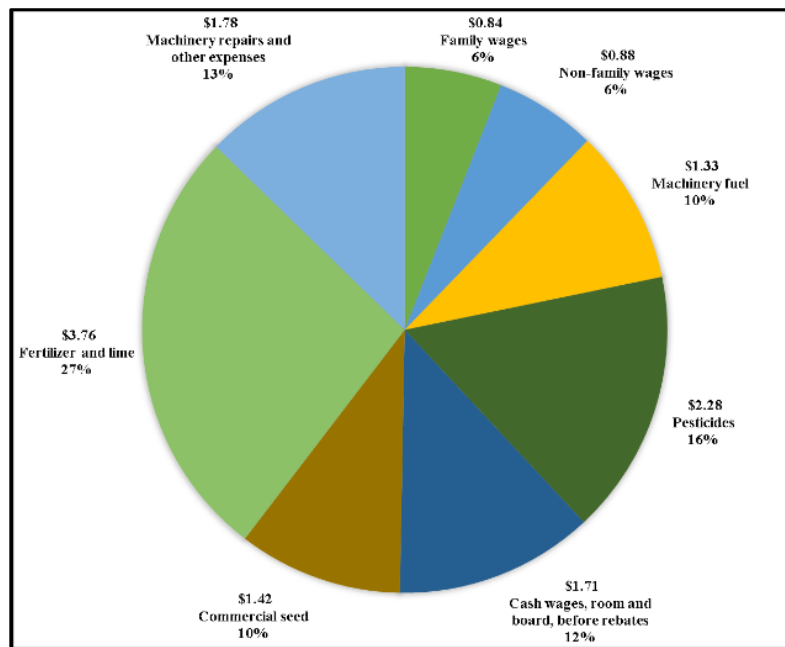


Figure 4.1.c: Operating expenses farms in the Prairie Provinces, value in billion dollars and relative contribution to gross operating expenses, 2016.

Source: Statistics Canada Table 32-10-0049-01.

### *4.1.3 Advanced equipment manufacturing capacity*

DOT™ has its origin in the culture of shortline equipment manufacturing in Saskatchewan. Canada is a leader in agricultural implement (equipment) manufacturing and most firms are SMEs located in communities with a population of fewer than 10,000 and are a major source of employment in rural areas (Binkley, 2018).<sup>6</sup>

Nearly 40% (or 4, 400) of western Canada’s farm and ranch implement manufacturing jobs are with Saskatchewan SMEs. An estimate of the number of manufacturers in Saskatchewan is available in The Saskatchewan Manufacturers Guide, a voluntary list, which includes agricultural equipment manufacturers. There are 164 self-declared companies listed in the database (Saskatchewan 2019). Typical products manufactured in Saskatchewan include world-class seeders, precision global positioning system (GPS) technology, and advanced spraying systems (Saskatchewan, 2017). These products are used throughout the Prairie Provinces, the United States, Australia, Mexico, Western and Eastern Europe, South America, Kazakhstan, the Middle East, and Africa. The SMEs are also original equipment manufacturer (OEM) suppliers to multi-national corporations, including Deere & Company, Case New Holland (CNH), Vaderstad, and AGCO Corporation. Traditionally, the patent form of IP is a dominant innovation pathway for inventors of agriculture equipment, particularly for entrepreneurs in western Canada. Between 1905 to 1976, about 3,200 inventions were patented in Saskatchewan, and thousands went unrecorded (Western Development Museum Patent Index n.d).

One of the Saskatchewan agriculture equipment manufacturers is SeedMaster, described in the Introduction. Norbert Beaujot is president and founder of SeedMaster, an SME established in the 1990s which specializes in manufacturing zero-tillage air seeders used in conservation agriculture farming around the world. Beaujot is also the inventor of DOT™, is well familiar with the ‘patent pathway’ to innovation with over 30 patents granted by the United States Patent and Trademark Office (Justia Patents 2019). Dot Technology Corp. formed as a sister company to SeedMaster (SeedMaster 2018a b). The Edenwold manufacturing facility originally targeted production of 30-foot (9.14 metres) DOT™ units sized for North American, Eastern European and

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<sup>6</sup> Canadian Industry Statistics NAICS Code 33311 includes establishments “primarily engaged in manufacturing machinery for use in performing farm operations, such as the preparation and maintenance of soil; planting, harvesting or threshing; field spraying; and preparing crops for market; or for use in horticultural and residential lawn care.” In 2019, the government of Canada reports 529 establishments in tagricultural implement manufacturing with approximately 88% having 0 to 99 employees with salary data in 2017 of \$756.9 M (Canada 2018b).

Australian markets (Raine 2017). The first field testing (prototype evaluation) occurred in spring 2018 at the SeedMaster Research Farm in southeast Saskatchewan near Langbank, at the family farm homesteaded by Beaujot's grandparents (SeedMaster management p.comm).

#### *4.1.4 Smart farming technologies bundled in DOT™*

DOT™ may be conceptualized as both a physical and virtual system. Physically, it is designed as a propulsion system for agricultural equipment. Visually, the innovation is a 12-foot high (3.66 m) platform or U-shaped frame (the DOT Power Platform™), black in colour with stainless steel accents and weighing approximately 5,570 kg. The power source is a 163 horsepower (hp), 4.5 litre Cummins diesel engine with 320-litre fuel capacity diesel engine that incorporates the latest (Tier 4) standards in fuel emission technology (DOT-TechSheet 2018; Cummins, n.d., seedotrun.com, n.d.; Garvey 2019). The U-shape of the Power Platform™ was specifically designed to accommodate timely (less than five minutes) and efficient (hands-free) loading for a potential 104 different pieces of equipment (DOT-TechSheet, 2018; AGDealer TV.com 2017).

DOT™ is a virtual operating system platform hosting a suite of sensors and communication systems used in autonomous vehicles and are being deployed to support automation of farm equipment as described by Bacco et al. (2018); Adams (2013); Carballido del Rey et al. (2014); and Balafoutis et al. (2017a). Presently, DOT™ does not travel on public roadways, instead, the Power Platform™ with its paired implement, is loaded onto a trailer using remote control and transported to the field for crop operations.

In the field, DOT™ operates in full autonomous mode, deploying all three types of sensors used in autonomous vehicles described by Luciano (2017) and Rudolph and Voelzke (2017), i.e., cameras, radar and LiDAR. Using satellite imagery plus other images and records of the field elevations (topography maps), a line of travel (a path plan) unique to the field is generated by Dot Technology Corp. proprietary software. Field boundaries and obstacles to travel (e.g. power and communication lines, buildings, water bodies, shelterbelts, stone piles) are mapped with sub-inch accuracy. Once the path plan is developed, it must be approved by the user. Human to machine (HMI) communication is done using a Windows Surface Pro Tablet. The tablet talks to DOT™ through a local wide area network (wireless broadband LTE- WAN) with Real-Time Kinetic (RTK) base stations. DOT™'s guidance and navigation system intelligence sense distinct boundaries and obstacles, day or night, and DOT™ powers down when these boundaries are

violated or obstacles are detected. If the preselected limits are triggered, DOT™ will stop. Sensors continually analyze slippage and mud sinking and control the four independent hydraulic cylinders on each wheel.

#### *4.1.5 The timeframe of data collection*

Studying innovation during the digital revolution in agriculture is a challenge. These are the early stages of deployment of DOT™ and the industry is changing rapidly. As suggested by Wolfert et al. (2017), by the time research is completed, the dynamics of the industry and the innovation have changed. The timeline for this case study is inclusive of the ideation of DOT™ according to its inventor, this was around the winter of 2014 (p.comm. Norbert Beaujot summer 2017). Primary and secondary data began in October 2017, a few months after the reveal of DOT™ at the Ag in Motion annual outdoor farm show in Langham, Saskatchewan, July, 2017. Data gathering for the analysis concluded in July 2019 at the Ag in Motion event where other shortline manufacturers revealed their own version of smart agricultural equipment (field robots) based on the DOT™ Power Platform licensed by Dot Technology Corp. Events unfolding past this timeframe, which are relevant to the Discussion and Conclusions, are summarized in Postscript notes (Section 8).

#### **4.2 Analytical framework: The Innovation Opportunity Space**

Smart farming is a relatively new concept. In the absence of new approaches to study digital transformations in agriculture, or analytical and/or conceptual frameworks suited to a study involving novel business models for agricultural equipment, traditional frameworks used to research agriculture innovation were considered for this study. However, the innovation featured in this case study is not a good fit with any of the traditional frameworks for the following four reasons.

First, DOT™ is manufactured by a private corporation, and business information is confidential. This condition eliminated use of the Tidd and Bessant model for how firms manage innovation (Ferreira et al. 2015) and New and Emerging Science and Technologies framework (Robinson et al. 2013), both of which rely on access to business data.

Second, DOT™ is neither a product of co-innovation nor an open system, and in addition, the innovation system for field robots such as DOT™ is just beginning to take shape. Few, if any farmers, researchers, or government decision-makers have prior experience with the innovation or the new space being created. Thus, a logical choice of using the Agriculture Innovation Systems



(AIS) framework was eliminated. The AIS is an approach used by several researchers to understand the complexities of the system across multiple levels of actors (Klerkx et al. 2012). Typically, the AIS is used to study established innovation systems over a relatively long time period (e.g. five to ten years), and is appropriate for co-innovation projects, or open systems such as those reported by Pant and Hambly-Odame (2009), Borremans et al. (2018), Klerkx and Nettle (2013), Schut et al. (2018) and Turner et al. (2016).

Third, none of the traditional social science frameworks mentioned above and used to study smart farming or its artefacts (e.g. data) are well suited to an anticipatory and Responsible Innovation (RI) type study of a field robot that incorporates a broad diversity of specialized smart farming technologies and multiple artefacts. The innovation is already commercialized. Furthermore, the technology focus used in engineering and computer science scholarship falls short of critically evaluating the technology. At the present time, there is a gap in interdisciplinary approaches, models, or frameworks used to study the economic, social and cultural aspects of smart farming.

The fourth, and final challenge in finding a suitable framework and applying approaches taken by other smart farming researchers, is that this case was never intended to be a normative study. Conversely, the Responsible Innovation or Responsible Research and Innovation framework approaches consider four basic principles: anticipation, reflexivity, inclusion, and responsiveness (Stilgoe et al. 2013) Researchers including Long and Blok (2018), Regan et al. (2018), Jakku et al. (2018), and Bronson (2018) use RI and RRI to study smart farming where RI is based on the prospective notion of responsibility and promoting a diversity of views to ‘proactively anticipate’ outcomes of research and innovation (Eastwood et al. 2017a). This study does not have, as a goal, to prescribe what an innovation system ‘should be’ Instead, it is intended to support theory-building (Eisenhardt and Graebner 2007) and based on evidence, provide information for use by both policy-makers, government and non-government.

A new analytical framework, the Innovation Opportunity Space (IOS) framework is developed by Flowers, Meyer, and Kuusisto (2017) to create the opportunity to apply a new way (research strategy) to study a new frontier of digital technologies in agriculture, and, for the first time is being applied to smart farming innovation. A group of researchers including Flowers, Meyer, Kuusisto, and other colleagues found that the old ideas, traditional frameworks, labels and metrics are not always a good fit for studying digital transformations that are unfolding in the

twenty-first century. They observed that entrepreneurs are bringing fresh ways of accessing resources and are introducing novel business models that defies traditional classifications, measurement, and evaluation of output and outcomes. Flowers and colleagues observed that the new patterns of innovation involve many actors and interactions, and furthermore, there are often few rules or regulations. Consequently, the authors conceived the idea of an ‘opportunity space’, developed a new framework and used it to study a series of cases, including Kickstarter, Airbnb, and Uber, open data projects, and a community forestry strategy used in Finland. Based on their case studies, the IOS provides “strategic managers, entrepreneurs, policymakers and academics with an improved way of viewing innovation-related issues” (Flowers et al. 2017, 9). However, use of the IOS framework is a new idea and its use has not yet been reported by other researchers, except for Sætra (2018) who cited the IOS authors’ use of predictive rationality in the framework and noted potential applications to a study of big data analytics.

The key attribute of the IOS is its starting point that is “not the idea of a market for a commercial product” (Flowers et al. 2017, 62). Rather, it goes beyond the market itself and offers a neutral initial frame of reference: “*the space* [own emphasis] into which an innovation will be introduced and how value is created from innovation activities” (Ibid, 9). Four main features of the IOS framework make it well suited for this research. The first feature is the application of the IOS as a structuring mechanism for analysis of more than one group of actors. The framework is inclusive of the technology, the entrepreneurs, public and private sector actors, and the ‘open’ user community. The IOS allows a researcher to reconcile distinct types of activities by each group to map the entirety of an innovation space from ideation to commercialization. The second factor of the IOS is its flexibility. It accommodates consideration of three different types of ‘innovation space’ within one framework which are differentiated based on the scale and scope of four attributes for each type as described by the originators of the IOS framework. Table 4.1 below describes the three IOS spaces - emerging, unstable and stable -based on their attributes.

Table 4.1: Types of Innovation Opportunity Spaces

Attribute	Type of Innovation Opportunity Space (IOS)		
	Stable IOS	Unstable IOS	Emerging IOS
Products and services	mature products, services	the guiding assumptions for use of mature products, services are questioned	new products and/or services, or novel applications of existing products and services are created
Suppliers	a small number of dominant suppliers	new entrants challenge dominant suppliers	new entrants, new groups, new communities
Norms and practices regarding use	clear and enforced norms (regulations, standards)	existing norms, standards, regulations, and practices are questioned, challenged, or set aside	existing norms and practices are replaced as new technologies are created
Pathways to innovation	pathways are apparent, clearly communicated, and widely accepted	pathways to innovation are not clear and different versions of the future compete for dominance	many pathways, voices and visions seeking to influence how things develop without having these visions, leading to unpredictable outcomes

Source: Adapted from Flowers, Meyer, and Kuusisto. 2017. Capturing the Innovation Opportunity Space: Creating Business Models with New Forms of Innovation (62, 210).

The third aspect of the IOS framework is that it is intended for “examination of how resources can be mobilized and value created, co-created and appropriated” (Flowers 2017, 63). This aspect is particularly relevant for a study of agriculture equipment. The role of agriculture equipment is under-represented in the academic literature on smart farming, yet it is a very important aspect of technological change in agriculture. According to Maurel and Huyghe (2017), agriculture equipment and digital technologies warrant more attention for they represent “a set of resources to be mobilized” to achieve societal objectives of a sustainable agriculture future (1). The authors specifically identified autonomous agriculture equipment as an example of a ‘set’ of resources. Their perspective therefore aligns particularly well with the intent of the IOS framework.

Lastly, the IOS framework considers the breadth of multiple types of resources and incorporates the notion that different forms of value can be captured, destroyed, translated, or transferred by a wide range of actors. This notion enables the researcher to systematically examine

how financial and human capital resources are mobilized and appropriated to influence economic, social, environmental, or geopolitical aspects of smart farming innovation.

The IOS framework illustrated in Figure 4.2 below, follows the four elements described by its creators. Architecture and Aftershock are distinct elements, whereas, the Actors identified in the IOS analysis are mapped to their Activities, thus linking these two elements.

Architecture	Actors <i>and</i> Activities	Aftershock	
Norms, practices, behaviours, rules, and standards that govern the IOS.	Individuals identified as being involved in the IOS, including producers and/or consumers, firms, other bodies such as regulators, and online communities.	The activities of each actor are mapped to an activity to capture relationships such as who has done what to whom, or with whom, and for what reason.	Impact and outcomes of actions taken by actors within the IOS to identify barriers or opportunities, which may inhibit or promote innovation.

Figure 4.2: The Innovation Opportunity Space (IOS) framework (Flowers et al. 2017, 64).

### 4.3 Data collection and analysis

Research methods for this study were approved by the University of Saskatchewan Research Ethics Board under the CDO project. Data gathering and reporting for the CDO project started in June 2015 and continued until to April 2019. Three stages of data collection informed this thesis and are summarized in the Appendix (Appendix A.1). Stages 1 and 2 qualitative data used for the CDO project were collected from interview participants working in the area of digital technology innovation in agriculture in western Canada. Data collected in Stage 3 involved in-depth interviews with management of SeedMaster, an SME which incorporates advanced digital technologies into their zero tillage air seeders. One of the managers of SeedMaster had been included in the main dataset of the 25 interviews for the CDO project (Appendix A.2). The inventor of DOT™ was the owner of SeedMaster and the social ties between the prior researcher-participant (management of SeedMaster) enabled the unique opportunity of access to the inventor and the management teams of SeedMaster and its sister company, Dot Technology Corp. Interview data for this thesis was collected specific to DOT™ and the data gathering process began in July, 2017.

In the afternoon following the morning field demonstration (revealing) of DOT™ in July, 2017, an informal meeting was held between the researcher and the Beaujot family at the SeedMaster exhibitor display set up on the grounds of the Ag in Motion event. The goals of an in-

depth case study were explained and arrangements were made for interviews to be done later that year. The main interview, and included

Building on the researcher's knowledge gained from prior observations related to the CDO project, supplemented with information extracted from the academic literature, and farm news media, a specific series of interview questions were prepared. The Interview Guide is described in Appendix List A.4: One three-hour in-person interview took place at the Edenwold, SK location of the SeedMaster facility, October, 2017. The interview included five individuals, the inventor-owner of SeedMaster and Dot Technology Corp. plus four individuals from the senior management team of Dot Technology Corp. and SeedMaster. The interview was recorded and professionally transcribed using services at the Social Sciences Research Lab, University of Saskatchewan. Follow-up interviews to clarify interview responses were done over the phone from November to January, 2018. Interview scripts were imported into NVivo™ v10 software and coded for themes (main and child nodes) indicated in Appendix Table A.6. On completion of the coding, 96 articles sourced using the various search engines were further imported into NVivo and coded to relevant nodes.

A literature review of material specifically related to smart farming, and autonomous technologies was conducted after the October, 2017 interviews. This information was supplemented with articles and videos sourced primarily from farm media newspapers, magazines and websites (see Appendix Table A.5 below).

Observational data were collected when the inventor and the management team of Dot Technology Corp. were featured as keynote speakers at an industry conference on precision farming (Saskatoon, November, 2017, and December 2018) and when DOT™ was demonstrated at farm show events.

Analysis of the interview results, combined with information from the literature review, market and government statistics, is structured as illustrated in Figure 4.3 below, The Innovation Opportunity Space (IOS) elements for the DOT™ Innovation Opportunity Space.

#### **4.4 Limitations of the Research Strategy**

This research is not without limitations and three aspects have been identified - the source of the data, the novelty of the innovation, and the single-researcher coding of interview transcripts.

First, as with any case study approach to research, there are inherent limitations (risks) to the validity of the conclusions drawn from the data used to inform the case (Creswell, 2015). In

this case study, however, the risk was mitigated by having research participants who are experts in agriculture equipment innovations. The inventor of DOT™ and the management teams from SeedMaster and Dot Technology Corp. bring “context-dependent knowledge and experience”, and the inclusion of experts in the data set, according to Flyvbjerg (2009), help address threats to the internal validity of the case study (222). However, it must be noted that these experts represent an entrepreneurial and business enterprise viewpoint in the broader perspective of digital technology innovation and Agriculture 4.0 Revolution.

The second aspect of limitations pertains to the innovation itself. The authors of the IOS acknowledge a novel category error occurs when one is “trying to collect data on a matter, product or service that does not currently exist, is unfamiliar, or is poorly understood” (Flowers et al. 2017, 209). The novel category error is relevant to this research as DOT™ is the first instance of a commercially available field robot suited for broadacre farming. Such an innovation did not previously exist and field robots in general, are too new to be well understood. Conclusions derived from analysis of the research questions will be subject to a test of falsifiability (Popper 1963) when more field robots are studied.

A third aspect of limitations relates to the IOS framework, which encourages the researcher to use multiple sources of data. The research presented in this thesis follows this principle and multiple data sources are used when available, however, primary (interview) data is limited to one SME in agricultural equipment manufacturing and the technological aspects of one field robot. Interview data from other SMEs, policy-makers, farm media journalists or farmers was not available for analysis and consequently, secondary data is used to represent other actors and their activities. Furthermore, there is no market data available for autonomous, tractor-less agriculture equipment, therefore, the market that could be disrupted, namely tractors, is used. Future studies would benefit from having data from other SMEs and OEMs, federal and provincial government employees, public news media other than farm journalist sources and farmers who chose to use robots and those who do not. An additional improvement for future studies of a farming innovation would be the inclusion of a second (or third) researcher for coding of the data in the transcribed interviews.

<p><b>Architecture</b></p> <p><b>Cultural context</b></p> <ul style="list-style-type: none"> <li>• labour shortages</li> <li>• scale and size farms, equipment</li> <li>• dealerships</li> </ul> <p><b>Technological context</b></p> <ul style="list-style-type: none"> <li>• smart farming technologies</li> <li>• advanced equipment manufacturing technologies</li> <li>• information translation</li> </ul> <p><b>Policy context</b></p> <ul style="list-style-type: none"> <li>• standards</li> <li>• regulations</li> </ul> <p><b>Market context</b></p> <ul style="list-style-type: none"> <li>• traditional firm structures</li> <li>• issues/areas of concern</li> </ul>	<p><b>Actors</b></p> <p><b>Activities</b></p>	<p><b>Aftershock</b></p>	
	<b>Agriculture equipment manufacturers</b>		<p><b>The Innovation</b></p> <ul style="list-style-type: none"> <li>• a new thing created - DOT™</li> <li>• a new (licensing) model of value creation via a differentiated supply chain approach to equipment manufacturing</li> <li>• potential for application to other geographies</li> </ul> <p><b>Social outcomes</b></p> <ul style="list-style-type: none"> <li>• new industry skill sets created synthesizing experiential knowledge of equipment manufacturing with coding and software development</li> <li>• reduce farmer fatigue, improve health and wellbeing</li> </ul> <p><b>Environmental outcomes</b></p> <ul style="list-style-type: none"> <li>• reduced fuel emissions</li> <li>• reduced soil compaction</li> </ul> <p><b>Economic outcomes</b></p> <ul style="list-style-type: none"> <li>• reduced fuel costs</li> <li>• reduced labour cost</li> </ul> <p><b>Policy outcomes</b></p> <ul style="list-style-type: none"> <li>• innovation programmes</li> </ul>
	Innovation pioneer	• ideation	
	Computer programmers	• co-generation knowledge for invention	
	SeedMaster	• co-generation knowledge for invention, financing, manufacturing, R&D, testing of prototype	
	Dot Technology Corp.™	• co-generation knowledge for invention • marketing, promotion, information broker	
	Industry association	• advocacy	
	• SMEs	• licensing and manufacture DOT-Ready™ machines	
	• OEMs	• competition	
	<b>Government</b>		
• federal	• Industrial Research Assistance Program (IRAP) Youth Employment Program		
• provincial	• Saskatchewan Commercial Innovation Incentive (SCII) Patent Box Program		
<b>Farm event &amp; trade show organizers, farm news media</b>			
Western Canada Farm	• indoor farm events 2017, 2018		
Progress Show group	• showcase and award innovations 2017		
Glacier Media	• farm weekly publications inform producers • outdoor farm events 2017, 2018 • showcase and award innovations 2017 • farmer survey 2017		
Fams.com	• Precision Agriculture Conference, 2017, 2018		
<b>Farmers</b>			
Master Seeders	• workshop participants, 2017		
Observers, evaluators	• trade show, farm event participants, 2017, 2018		
Survey participants	• veivs of autonomous technology		
evaluators	• field tested innovation on their farms, 2018		
early adopters	• placed orders in advance of production and sales, 2018		

Figure 4.3: The Innovation Opportunity Space (IOS) elements for the DOT™ Innovation Opportunity Space

## 5.ANALYSIS

The analysis is presented based on each of the following the four elements of the IOS framework.

1. The architecture of the innovation space DOT™ is creating.
2. The actors involved in this space,
3. and their activities.
4. The aftershock, or the anticipatory impact of DOT™ as an example of a new thing in smart farming innovation.

The concept of ‘space’ is key to the intended neutrality of the analysis and examining the actions of different actors and their role in “enabling, developing, exploiting, or co-creating value” within, in this case study, the DOT™ IOS and the unexploited potential of autonomous, broadacre farming (Flowers, 2017, 59).

Operationalizing the IOS framework posed a significant challenge. There was little guidance in methodological tools as noted by Buheji and Ahmed (2018) in their review of the IOS book, and the metrics suggested by the authors were not available (they did not exist in public databases or data is not yet being captured). In this research, the analysis of the IOS for DOT™ is reported following the schema and template suggested by Flowers et.al. (2017, 67) and mapped above in Figure 4.3.

The IOS is a new analytical framework and therefore, deviates from traditional ways of presenting results. Section 5.0 simultaneously presents the interview results in addition to “many other forms of data and information drawn from traditional and non-traditional sources” as suggested by the authors (Ibid, 65). Types of data used in the analysis therefore include sector data pertaining to smart technologies, equipment manufacturing capacity for production and sales, customer demographics and purchasing behaviours, farm input costs, markets that may be disrupted such as tractors. Data and information on the rules (norms, practices, standards and regulatory structures) that will facilitate or prevent innovation activity are reported. Social systems are important features of a farming community and so information on mechanisms of knowledge exchange are included.



## 5.1 Architecture

DOT™ is a commercial innovation with origins in the Saskatchewan farming community. Analysis of the Architectural element of the IOS created by DOT™ and Dot-Ready™ technologies considers four aspects.

The first element, cultural context, is conceptualized as the Canadian agriculture situation and conditions which led the innovation pioneer to structure the problem-solution that the DOT™ innovation addresses, an innovation particularly relevant in the Great Plains region of western Canada and the northern United States. The technological context considers the smart farming technologies bundled in the innovation, the advanced manufacturing processes and capacity of SMEs and the ICT or communications connectivity. The market context includes analysis on market size and structure, number of firms, trends in commercial trade of equipment, and in this case, the tractor market for which the innovation may disrupt. Market context also includes the norms and emerging areas of change and concern in this market. As there is yet to be a market developed for autonomous agriculture vehicles and therefore, a proxy is used for the analysis. Industry trade statistics for the tractor market are described as this would be the one most likely disrupted by the innovation. Market factors for tractors greater than 174 horsepower, the largest size category for export and import trade value are tracked by UNCOMTRADE and ITC 2017 and that which is commonly used in the farming industry on the Great Plains region of Canada. The policy context examines government regulatory structures and programs setting the technological standards, and presence/absence of regulations. In this IOS, policy is explored in terms of regulations specific to the commercialization of the DOT™ innovation, specifically government regulatory structures and technological standards pertaining to the commercialization of autonomous vehicles and agricultural equipment. Emerging issues in this market have been identified in the academic and grey literature, and these are then summarized in the context of how DOT™ and Dot-Ready™ technologies align with the salient issues identified in the smart farming challenges (Section 2.3).

### *5.1.1 Cultural context*

Three aspects of the agriculture industry in western Canada influenced the identification of farm and industry-level problems and the integration of smart farming technologies into agricultural equipment as a solution. Two of these aspects, labour and farm size, represent a cultural context endemic to prairie agriculture and are therefore influential in shaping the

boundaries of the Architecture element of a smart farming IOS. In this research, cultural context is broadly interpreted as the social, economic, and environmental conditions well known by those familiar with the industry. The third aspect, escalating input costs and environmental impact on soil health, may be viewed as a consequence of the first two aspects.

First, labour shortage is a persistent problem for farming in Canada and the dilemma is creating a cascade of secondary social (health) problems, notably adverse effects on farmer health and wellbeing and working conditions. The second aspect is related to the export-market orientated farming. The larger farm sizes shifted the demand in favoured the use of progressively larger pieces of equipment including large tractors (e.g. 200 to 400 hp) to pull the large implements (e.g. 90 to 100-foot wide seeders, fertilizer applicators and sprayers), and large combine harvesters with greater on-board grain holding capacity. The larger equipment made operating a farm more efficient by making it faster to complete the work required and to accomplish this with less labour. However, as size of implements increased, so did purchase prices. Trade-ins of smaller sized equipment accumulated, causing a gradual buildup of equipment inventories, which in turn created problems for equipment dealerships and their networks of distributors. More fuel is required as most of the implements are ‘pulled’ by a tractor, and furthermore, depending on the interaction of soil type-climate-land management practices, in some field situations, the heavier machinery adversely affected soil health through increased soil compaction. The inventor identified these problem aspects and the next section presents evidence from the interviews and other sources to describe the cultural context of Architecture element as the industry problem and a field robot as the smart farming solution.

### *Labour*

Labour shortages are a persistent problem in the agriculture industry (Canada 2002; CAHRC 2016a, 2019; AIC 2017). The farm labour problem is severe. According to the Canadian Agricultural Human Resource Council (CAHRC), between 2000 and 2016, labour shortages doubled and the trend is anticipated to double in the next decade (CAHRC 2016b). The Agriculture Institute of Canada (AIC 2017) estimates the 26,400 unfilled jobs cost the agriculture sector CA\$ 1.5 B in lost revenue in 2014. Similarly, in 2017, CAHRC concluded untitled jobs cost the agriculture sector the equivalent of 47% in lost sales of product, the equivalent of \$ 2.9 B revenue. The remote rural location, negative perceptions of agriculture (long working hours and manual, physically demanding labour), lack of workers with required skills and experience in the sector

and the seasonality of employment, are among the factors driving the growing labour gap (CAHRC 2014; Conference Board of Canada 2016, 2019). The Dot Technology Corp. management team identified availability of labour had become an issue for the industry and signaled they felt very strongly about the labour problem and their belief that DOT™ is part of the solution:

*We want to make labor obsolete because there is no labour for us [participant emphasis].  
Many people just don't understand this (Interview participant).*

Labour shortages are causing delays in production and farm expansion plans are put on hold (CAHRC 2019). Further widening of the labour gap is anticipated as the labour requirement will likely grow with increased demand for food products from grains, oilseeds, beef, hogs and greenhouse operations. Adding to the dilemma is the anticipated loss of 37% of the present domestic agricultural workforce by 2029, effectively doubling the labour gap relative to the previous ten-year period of labour market studies. CAHRC projects that approximately 112,000 workers will be transitioning to retirement, creating a Canadian agricultural worker labour gap of 123,000 people with the equivalent of one in every three jobs going unfilled (Ibid).

The situation will be most severe for grain and oilseed operations and beef producers; thus, the labour problem is critical for Saskatchewan and Alberta and Manitoba, the major production regions for these commodity groups. Filling the gap with foreign workers is unlikely for grains and oilseeds farm operations as neither industries are included on the National Commodities List by Employment and Social Development Canada. As the two types of operations are not on the commodity list, neither qualifies for the Seasonal Agricultural Worker Program (SAWP) or the Agricultural Stream option available for farm operators to access temporary foreign workers (CAHRC 2019). Table 5.1 details labour issues by provincial CAHRC (2019).

In addition to the impact of the labour gap on limiting farm production (Briere 2018a), the social problem of labour shortages is being brought to light within, and outside of, the agriculture community, Stephenson (2018) reporting that in the United States, farming, forestry and fishing” industry had the highest rate of suicide of any occupation. In Canada, the AGRI-LIM survey by CHARC found that 90% of grain and oilseed producers report that excessive stress and long work hours for the owner/operator and other staff, are due to unfilled vacancies (Stevenson 2019). The revealing of the impact of labour shortages on farmer health and well being builds on prior work done by Jones-Bitton who concluded that farm stress is becoming a “major barrier to growth and

innovation” and reported her findings to the Standing Committee on Agriculture of the Canadian Senate (Canada 2018c)

Table 5.1 Farm and labour situation in the Prairie Provinces, 2018 and 2029 projections

Farm and labour situation	Alberta	Saskatchewan	Manitoba
Top two industries	beef grains & oilseeds	grains & oilseeds beef	grains & oilseeds beef
Lost sales in 2017 from labour shortages	\$821 M	\$574 M	\$367 M
Farmers unable to find workers in 2018	48%	40%	52%
Number workers needed 2029	62,000	41,400	27,000
Workforce losses from retirement	42%	41%	33%
Labour gap 2029 (jobs at risk of being unfilled)	19,600	12,300	5,300

Source: Data from Labour Market Information study by Canadian Agricultural Human Resources Council (CAHRC) conducted between 2014 and 2016, survey of 1,316 employers, 278 workers, 110 industry stakeholders. Value in \$CA (CAHRC, 2019).

Jones-Bitton found that 45% of farmers had high levels of perceived stress; 58% and 35% met criteria for anxiety and depression, respectively (Farm Credit Canada 2018b; Johnson 2018a;). The farming community acknowledges the problem and The Do More Agriculture Foundation, a charitable organization established by Saskatchewan farmers, focuses on the mental health of the farmer and reports that there are 20-30% more suicides in the farming community compared to other sectors (Do More Agriculture Foundation n.d.).

The autonomous technology of DOT™ deals with the labour shortage in two other ways. The first is related to the narrow time frame available for seeding operations. On the prairies, the growing season is limited to 95 to 120 frost-free days (Bueckert and Clarke 2013). The window for completing seeding operations is very brief (normally the end of April to the beginning of June). With labour often in short supply, and the timing of seeding being critical for the success of their income, farmers will work day after day, as many hours as humanly possible to complete field operations. Autonomous Dot-Ready™ seeders and grain (fertilizer) carts have a 24-hour, 7 days a week functionality and would create the conditions for safely completing seeding operations within the narrow time frame.

The second way DOT™ and associated Dot-Ready™ implements will address a cultural factor is by enabling aging farmers to remain active by minimizing physical requirements, fatigue and accidents associated with farming. The demographics of Canadian farm operators are changing and the proportion of farms where the oldest operator was 55 years or older has been trending upward since 1991, representing 48% of Canadian farmers in 2011 (Beaulieu 2014). By 2016, 54% of Canadian farmers were in this age category (Statistics Canada, 2016 Table: 32-10-0442-01). Safety is also part of the complex labour problem, particularly for senior farmers. The Canadian Agricultural Safety Association reported that farmers over 60 had an above-average fatality rate with farmers over age 80 having the highest fatality rate of any other group (Canadian Occupational Safety 2018). DOT™ is marketed to help aging farmers remain active by minimizing physical requirements, fatigue, and accidents associated with operating a tractor. An agriculture journalist prepared a special report featuring DOT™. Melchior (2018c). Beaujot is quoted as follows,

*[A]t one end of the scale you get the young, 35 to 40-year-old producers who really want to get going with anything new and high tech. ... but at the other end, we have producers who are 80 years old saying they're too old to get up and down from the tractor, but they still have a passion for agriculture. This would give them a way of still utilizing their brains and less of their brawn (Norbert Beaujot, Alberta Farmer Express, February 26, 2018).*

### *Changes in farm size and equipment*

Farm size is another cultural aspect of Canadian agriculture. Since 1976, there has been a reassortment of farm sizes in Canada. The relative size changes over the last 40 years are illustrated in Figure 5.1, below, with a convergent graph.

The largest relative change has been an increase in farm sizes 10 to 69 acres with a 4.6% increase, and those under 10 acres increased by 2.7%. It is unclear if these small-sized farms are farm-based enterprises (based on income derived from the farm), or if they represent on large 'acreage type' establishments with dwellings and non-agricultural income. There are 3.7% fewer farms 240 to 399 acres and 2.4% less 760 to 1,119 acres.

The second largest change in distribution of farm size, was a 3.8% increase in farms larger than 3,520 acres. The trend has been gradual. With each five-year cycle of census reporting, there was an average rate of increase of 1.1%. In 1976, about 16,500 or 5% of Canadian farm operations were greater than 10 quarter-sections or 1,600 acres (647.5 hectares) in size. By 2016, the number of large farms had increased and over 25,700 farms (or 13.3% of farm operations) were 1,600 acres

or more. The most change was in the largest census category of 3,520 acres (1,424.5 ha), which increased to 9,089 farms in 2016 from less than 3,060 in 1976; the majority of these largest farms are on the prairies – 2,859 in 1976 and 8,576 in 2016 (Statistics Canada Table 004-0201).

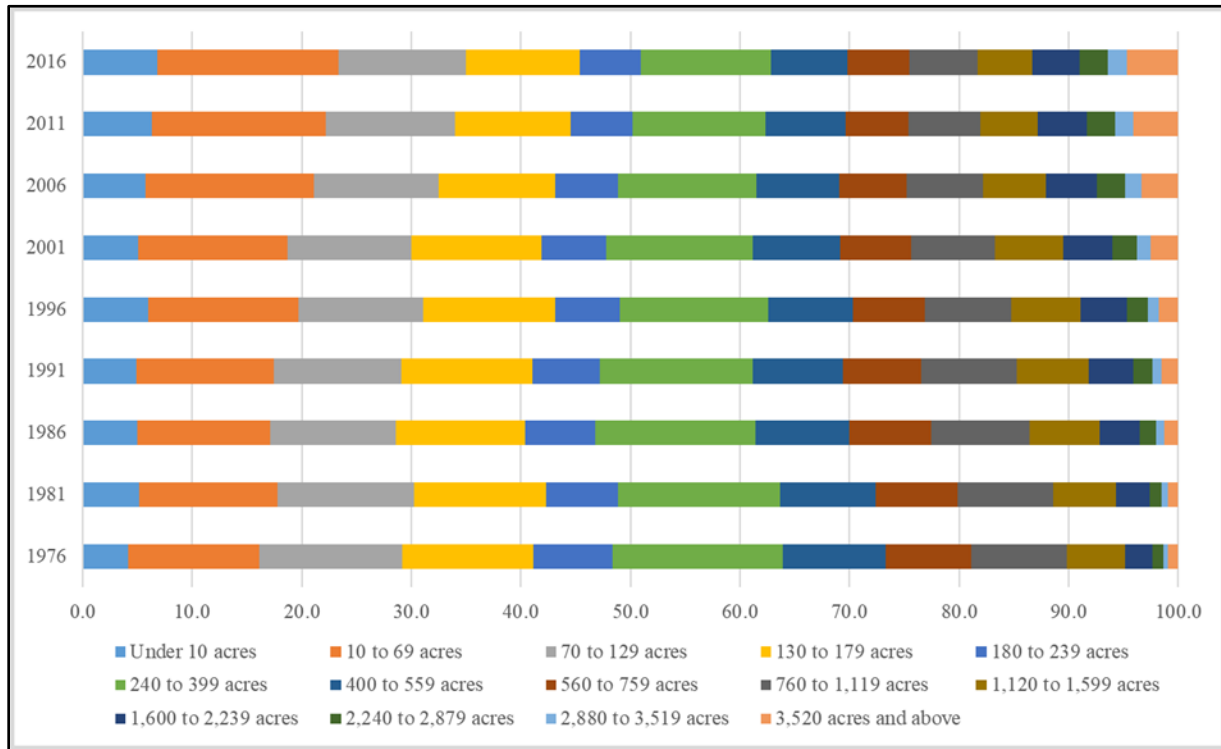


Figure 5.1: Relative change of farm sizes in Canada, 1976 to 2016  
Source: Data from Statistics Canada.

As farms grew progressively larger and labour became scarce, larger equipment was a solution to completing farm operations given these conditions. As farms grew progressively larger and labour became scarce, larger equipment was a solution to completing farm operations given these conditions. Larger tractors were needed to pull the larger equipment and over time, tractors got bigger in both size and horsepower (hp) and 400 hp tractors are not uncommon. Tillage, seeding, and spraying equipment increased in size and 16-foot to 20-foot units were replaced by 60-foot (18.3-m) units and equipment continued to get progressively larger. Ninety-foot (27.4-m) size seeders, sprayers, tillage units are not uncommon on prairie farms, and seeders, or tillage units 120-foot (36.5-m) in size are manufactured by SMEs and OEMs, all equipped with numerous DT (e.g. auto-lift headland turns, zone-specific seeding and/or fertilizer rates, overlap controls, auto meter rate calibration, load cell data, auto packing).

With the shift in demand for newer, larger machines, total equipment inventories in Canada increased by 25% from 2014 to 2016 (FCC 2016), causing difficulties for many dealerships and creating inefficiencies across the supply chain recognized by the creators of DOT™:

*Big farms want new equipment lines, leases. The auction marts are carrying big inventories but with a high price tag on these machines, they are still not affordable for the average to smaller farm and younger operators (Beaujot, 2017a).*

The OEMs in the United States similarly built up unsustainable inventories of equipment as leases expired and selling across national borders is limited by regulations for emission's controls (Context Network 2017). Systems-level diseconomies were perceived by Beaujot as,

*[T]he existing system has become obsolete. The farm auctions are at historic highs for moving used equipment but with the high price tag on these machines, they are still not affordable for the average to smaller farm and younger operators who also have to pay very high rental rates on land. Dealerships are having problems moving trades of big equipment. ... dealers are going broke because of the inventory of trades... even the big players, they're losing money*

The increasing scale of build-up of inventories led to inefficiencies across the supply chain.

*There is [also] a problem with equipment valuation. Big farms want new equipment lines, leases. The auction marts are carrying big inventories but with a high price tag on these machines, they are still not affordable for the average to smaller farm and younger operators who also have to pay very high rental rates on land. (Beaujot, 2017b).*

The inventor of DOT™ re-imagines retailing of equipment. With the DOT™ system there is neither a need for a large size, heavy weight and expensive tractor which often sits idle except for seeding and tillage operations, nor is there a requirement for a large seeder and sprayer.

Farmers need not go through a dealership to purchase DOT™ and Dot Ready™ implements as the units are made on-demand and the staff of manufacturer will provide servicing, and the inventor, Norbert Beaujot imagines farmer-owners would trade DOT™ units through market mechanisms such as on-line auctions or transaction platforms such as Kijiji.

### **Externalities of larger equipment**

Larger equipment requires tractors with increased horsepower in order to pull the implement and, on both counts, this added more weight onto the fleet of equipment traversing the field. The extra weight associated with a large tractor is known as ballast. The ballast is added to the front or back of a tractor design to counterbalance the load requirement in the large equipment and/or improve traction. Ballast weight is a substantial contribution to the total weight of a tractor. A fully ballasted 400 hp tractor weighs upwards of 40,000 pounds (about 18,100 kilograms), a minimum

size needed in order to pull the standard planting and tillage equipment currently used on most broadacre prairie farms.

With DOT™, there is less weight traveling in the field which is primarily related to the removal of ballast weight. In addition, weights from the tractor wheels, drawbar, hitches, and folding apparatus are also removed with a DOT™ unit. Weighing approximately 12,500 pounds (5,570 kilograms) in comparison to a tractor-driven system with equivalent fuel emission standards and typical ballasts to balance the pulled implement, a DOT™ unit weighs 12,500 lbs (5,570 kg), translating to nearly 70% reduction in weight traversing the field. As Beaujot explained to a journalist,

*[I]t's just physics... long story short, tractors need about 150 pounds [weight] per horsepower. When the tractor is towing something at low speeds, it needs that ratio not to spin out, so a 200-horsepower tractor has to be as much as 30,000 pounds... With DOT, the weight is put to it by the product itself (Norbert Beaujot quoted by Melchior 2018c).*

The difference may also be conceptualized as the difference between ‘pulling something’ in comparison to having it mounted onto some type of ‘prime mover’. Furthermore, the ‘pulling’ simply burns more fuel. The agricultural engineer explained in more detail in the interview,

*[T]hey put weights on a tractor to give it traction. The drag of DOT is reduced by simply removing a ballast tractor because there's no weight being put on it from the implement, or [at least] very little. That ballasted tractor takes between 20 and 30% more horsepower to move ... it's got nothing to do with the implement. So, when you convert that into the fuel burn, that horsepower equals fuel equals emissions, so that's where we should see [necessary] horsepower per foot, or per acre and therefore, fuel burn per acre, go down (Interview participant).*

Beaujot estimates DOT™ will bring an estimated 20% reduction in fuel costs and usage alone. Thus, yielding savings in operating costs and environmental benefits from fewer emissions due to total emissions reduced from DOT™’s relatively more efficient new Cummings diesel engine compared to older tractor engine technology (Beaujot 2017b).

### **5.1.2 Technological context**

Canada ranks among the world’s top machinery-manufacturing countries, employing over 160,000 workers in 10,000 companies and manufacturing of agribusiness machinery and equipment is an area of strength (Global Affairs Canada 2017). The industry was represented by 535 companies in 2016; over 91% of these companies are small to medium-size enterprises (SMEs) with less than 99 employees (Canada 2018a).



The Agricultural Manufacturers of Canada (AMC) indicates these companies are ‘shortlines’ meaning they manufacture specific types of equipment (e.g. seeders, rockpickers, sprayers) but the product line-up would not constitute an entire fleet of equipment (e.g. a tractor, seeder, grain cart, sprayer, baler, harvester). Canadian agriculture equipment manufacturers are recognized as innovators who are very specialized and very competitive worldwide using advanced manufacturing and are adding artificial intelligence to their products (AMC 2018). Their processes and products address the green technology agenda and challenges associated with making more efficient use of fertilizers and reducing greenhouse-gas emissions (Binkley 2018).

### Advanced manufacturing digital technologies

Several advanced digital technologies referenced by Berman (2012) are used in the manufacturing of DOT™ including 3D printing for rapid prototyping, Computer-aided Design (CAD) and additive manufacturing technologies (Levy 2010). The manufacturing process is described by the interview participants.

*It's all digital now in terms of the drawings and everything. We would probably within two years be looking at robotic welders. As far as the assembly, it would be a longer-term thing. Probably one of the important elements would be to make it easily assembled to a partial stage so it's easy to ship and then the final assembly at another location. 3D printing is a nice thing to talk about but in terms of reality, I've never seen an example of that used other than prototypes. It's handy for prototyping and for testing and stuff. We do all our own laser cutting. With many of the components being structural members that I can't imagine that you'd ever 3D print them and our meters are too technical to 3D print, or the sensor pieces. So more important I think is facilitating fast distribution, analysis of problem and distribution of parts and that's where, for example, the aerial drone may come into play (Interview participant).*

### Robotics

Robotics are being integrated into agriculture equipment and according to Carballido del Rey et al. (2014), this has been made possible by advances in Global Navigation Satellite System (GNSS). Of the dominant three types of sensors that drive autonomous vehicles, the ‘top choice’ for OEMs is cameras that visualize the vehicle's surroundings (Luciano, 2017). Radio detection and ranging (RADAR) using radio waves determine object distance, speed and relative angle to the vehicle, and LiDAR (Light detection and ranging) sensors are the costliest type of sensor and are less efficient in bad weather. Multiple layers of remote-sensing technologies, described on the ‘seedotrun’ website, are incorporated in DOT™ including cameras, radio detection and ranging, and LiDAR technology. When asked about the sensors driving DOT™, the management team said,

*[o]ur system will have all three on them. You need to have redundancy, multiple levels of redundancy for safety purposes. You can't run with just one; it's too risky, if it fails, then the machine fails. Then safety is compromised so you need to have multiple levels of redundancy to check that LiDAR is accurate. They all have different levels of reliability, so you need to have all of them (Interview participant).*

As with other machinery guidance systems supported by Satellite GPS; Cellular Wi-Fi/Bluetooth, and sensor detecting motion (LiDAR, cameras and radio), if an autonomous agriculture machine deviates from its path plan delimited by GPS imposed safety boundaries, it stops immediately (Adams 2013). The field boundaries are highly accurate with positional information built using an RTK GPS receiver. 3-D Light Detection and Ranging (LIDAR) sensors are typically used to make a 3-D map of the topography of the field in order to account for ditches, steep slopes, etc. (Ibid).

With DOT™, the guidance and navigation system intelligence senses distinct boundaries. The unit powers down when these boundaries are violated and alerts are sent to the farmers' tablet or smartphone as well as the central command centre (e.g. the farm base office) (DOT™ Tech Sheet, 2018). Remote human to machine (HMI) technology includes the following: HMI sensing and display of engine performance; HMI implement remote control and recording; and HMI long-range Wi-Fi and radio connectivity. These HMI technologies record and geo-reference various activities, including precise application of input prescriptions based on variable-rate field maps, as well as documenting real-time fuel usage and horsepower draw (DOT-Tech Sheet 2018). The HMI is a tablet (Windows Surface Pro) which talks to DOT™ through a local area network (LTE WAN) and Real Time Kinematic (RTK) base stations. All technology developed in-house is proprietary. Although not explicitly articulated in the interviews, at a minimum one would expect the software will have copyright protection.

The use of autonomous agricultural equipment requires a re-thinking of operations planning (Bochtis 2013; Bochtis et al. 2014). As indicated in the interviews, all DOT™ owners and users must attend the training sessions provided by Dot Technology Corp.in order to have hands-on experience before they operate DOT™ in a field (seedotrunk.com, n.d.). Farmers who purchase DOT™ units are encouraged to allocate time to plan routes and schedule tasks such as refueling.

If a farmer purchases more than one DOT™ unit, the machines will have the ability to communicate with each other but they do not yet have the capacity to learn individually (machine-to-machine communication - M2M). Machine-to-machine communication help prevents accidents

and collisions in the field. In the case of DOT™ units working long hours during seeding operations, M2M would also bring gain of efficiencies during re-filling operations, for example, a DOT™ seeder communicating with a DOT™ grain cart. The management team shared current R&D on the HMI and M2M technologies,

*We're also just finishing up the development on its ability to also talk to a human-driven unit as well. So, you could have a [DOT] using a seeder or a sprayer as an example, they could be operating in the [same] field; one driven by a human, the other driven autonomously, and they wouldn't hit each other. They would be what we call painting on the same map (Interview participant).*

### Artificial intelligence

One of most common drawbacks to applications of deep learning in agriculture systems is data and the machine learning 'training' necessary to create large databases (Kamilaris and Prenafeta-Boldú 2018). The DOT™ management team was asked about artificial intelligence (AI) in agricultural equipment as described by Zhu et al. (2018). Incorporating AI technologies that will allow DOT™ to learn-as-she-goes, is not in the present plans, although Beaujot explained, *I expect that would be a natural progression, especially in the obstacle avoidance.* With AI technologies available in DOT™, data based on records of field-specific information and machine learning for optimization of travel paths based on topography, compaction, obstacles, etc. would be required. Presently, for example, as a DOT™ unit travels once over the field path (e.g. seeding) and next pass (e.g. spraying), it would not 'remember' that the old schoolyard and stone pit was located at a certain coordinate, nor would it differentiate high yielding areas or water drainage patterns, each path needs to be created based on the user input parameters. The team added further comments, indicating they believe it will be a while before farmers are ready for having individual purpose machines with full automation of different pieces of equipment, but in theory, this is quite possible with DOT™. They also commented on swarms (i.e. multiple, small robots with M2M to complete a crop production task) or farms, [on having a central facility where a producer can see where individual DOT™s are working in their fields], according to the management team at Dot Technology Corp., *that's just a given. Every company can do that already. That just has to be there. It's more the swarm piece [but] at 15,000 acres, you'd need thousands of them.*

*I kind of see the DOT platform of being a step towards swarm type operations. Whether it goes all the way down to one opener seeding individually throughout a field seems a bit out there right now to me. But I think that this DOT piece could offer the same kind of swarmish mentality in a large setting because there could be multiples within a field. I*

*think there're a few things that are limiting the swarm piece. You would have to have guidance on every single one of them, which is still cost prohibitive (Interview participant).*

*The other piece is simply creating the network for them to run on. So, I'll put this out there. If people adopted swarms, they would need long range Wi-Fi. And long-range Wi-Fi is still a fairly expensive thing, and you'd run out of bandwidth. There's only so much virtual pipe there to run information through. ... I think where we're at today is within the range of the capabilities of the current networks, and we're not able to change the entire structure and framework of communications in order to do it. Whereas in order to get there, it's great for small-scale and, it looks really cool, but it's not that efficient today (Interview participant).*

### **5.1.3 Market Context**

An autonomous propulsion system could reduce reliance on pull-type systems (tractors) to complete farm operations and potentially shift manufacturing and export markets. As there is currently no market established for autonomous agricultural equipment, analysis is limited to the tractor market which DOT™ could potentially disrupt, the capacity of SMEs to fill the space created by this disruption, and farmer interest in autonomous equipment.

#### **International trade in tractors**

World trades in tractors are summarized by the International Trade Center (ITC). The largest size category, reported as the new HS code 870195, indicates exports for tractors with engine power more than 130 kilowatts (kW) or about 174 hp. This category would be most representative of tractor sizes used on prairie farms, even though 174 hp this would be a (very) small size power requirement for field operations on most broadacre farms.

Global exports of HS 870195 in 2017 were US\$ 5.8 B and Germany and the United States dominate the market, together accounting for 54% of global trade exports (ITC, 2018). Canada imported 3,872 units of HS 870195 tractors with an import value of \$ 472 M, more than double its exports of nearly \$ 211 M (ITC, 2018). United States is Canada's major trade partner and in 2017, import quantities from United States were 2,529 units (about US\$ 360 M).

The TractorData™ database provides a listing of manufacturers and models (TractorData n.d.). Of the larger size tractors (more than 200 hp), there are there are approximately 5,100 tractor models listed in the 2018 database. About 24 companies manufacture these large tractors, yet four major companies dominate world markets for 200 hp plus sized tractors. Each of the following four companies manufactures more than 200 models, including those made by: Deere & Company (John Deere™); AGCO (Massey Ferguson™, Fendt™, Challenger™); CNH (Case IH™, New

Holland™, Steyr™) and SAME (Lamborghini™, Deutz-Fahr™, Hurliman™). Deere & Company holds the dominant position in the tractor market for North America. Retail sales of all wheeled tractors in 2017, their 100<sup>th</sup> year of tractor manufacturing, were approximately 245,000 units with 20,884 over 100 hp, two-wheeled type, and 3,380 four-wheel drive units were sold in USA and Canada (John Deere 2018, 2019). The only Canadian tractor manufacturer listed is Versatile, a division of Buhler Industries, based in Winnipeg, Manitoba.

When tractor size is not taken into consideration (HS code 870190), the United States is the major tractor supplier (51% or US\$ 586 M followed by Germany (14%) and Japan (12%). Other major world exporters of tractors in the last 17 years include Italy, Japan, France, and the United Kingdom. Canada, on average, contributes about 1.3% of export trade value. It ranks second in world imports, and accounted for 6.3% of world market with import value of \$ 1.15 B in 2017 (ITC, 2018).

With capacity for innovation through SMEs, and recognition of regulatory uncertainties, the big question is - how large is the potential for such an innovation for manufacturers? Beaujot suggests that any farming community that has the expertise to do precision farming and has a labour problem, is a potential market for DOT™ autonomous technology (Beaujot, 2017b). Future industry norms have been projected by IDTechEx. Tractors equipped with intelligent technologies should peak at about 700,000 in 2027/202 (Ghaffarzadeh, 2017). Once the barriers of regulation, high sensor costs and lack of farmer trust have been overcome, the value of autonomy is proven, and prices fall, then the market could be worth US\$ 27 B from 2024 onwards (Ibid). From a manufacturing lens, any equipment manufacturer can adapt their products to the platform and manufacture their own line of 'DOT Ready™' autonomous, tractor-less, farm implements once they participate in the licensing model offered by Dot Technology Corp. (DOT-TechSheet 2018).

#### *Manufacturing autonomous agriculture equipment*

The market for Dot Ready™ products made by SMEs in Canada is substantive. In 2017, agriculture implement manufacturing exports to 154 countries totaled CA\$ 1.98 B, \$2.26 B in 2018 and 2.36B in 2019 (Canada 2018 b,c). Advanced manufacturing is important to the Saskatchewan economy with shipments of \$16 B in 2017. Equipment manufactured by Saskatchewan equipment manufacturing companies, many known as shortlines, could be adapted and used as autonomous equipment.

*[t]here's no market that wouldn't benefit from it [DOT]. Anywhere that has abundant labor, does not have the expertise in place today to operate in the modern precision farming framework. Everywhere that does have the expertise to [do precision farming] generally has a labor problem. So, trade barriers aside, there's not a market that is in the "farming business," from a cropping perspective, that is not a potential market for DOT (Interview participant).*

Four Saskatchewan SME-made, Dot Ready™ autonomous implements are available in spring 2019, including a conservation tillage seeder, a sprayer, a dry (fertilizer) spreader, and a grain cart (seedotrun.com, n.d.).

### *The DOT™ business model*

DOT™ was developed by an entrepreneur with tacit knowledge of the main issues affecting the agriculture industry – connectivity and ICT/Cloud systems security, interoperability, IP and the controlling of operation and repair of farm equipment, and ownership of data.

With a high bandwidth between the tablet and DOT™, large amounts of data are transferred without delay and data storage is supported by Cloud-based systems. Existing infrastructure, satellite signals, and connectivity are constraints which were identified during the development and field testing of DOT™.

*The real challenge comes from the cell network and its ability to process high amounts of data. ... because it's not reliable, we've got to set up a secondary long-range WiFi network that is a cost that's borne by the farm. ... future generation 5G network would make a big difference, but again that will first surround urban areas, so that's where the challenges lie. ... It's the coverage and capacity, pure bandwidth, the amount of data that truly needs to be transferred for successful autonomous and long-range telematics. It either needs to have its own network constructed within a closed environment, or we need to have a better more reliable system.... that's Precision Ag, it's driverless cars, it's a much greater issue than just what we're doing (Interview participant).*

Dot Technology Corp. worked towards solving that challenge. It is now possible for DOT™ to operate in rural areas that do not have reliable internet. DOT™ now communicates up to 2.4 kilometers using inexpensive (a few hundred dollars) components. The field research manager for Dot Technology Corp. explained this to a farm media journalist as follows,

*A high-power, high-range Wi-Fi network comes as part of the DOT package with SeedMaster essentially acting as the Internet service provider... the user app will be hosted on a web server through which the farmer will access DOT. ... We've proven we can communicate with DOT up to 15 kilometers through our local area network, but the price is higher for that capability (Owen Kinch, field research manager Dot technology Corp. reported by Melchior, 2018b).*

Other challenges to autonomous vehicles would include security of ICT systems and ‘availability’ type threats manifested from cyber-related issues identified by Boghossian et al. (2018). These threats include ‘malicious jamming and spoofing technologies’ that interfere with location technologies. Jamming of signals from RTK receivers and base stations, would block and/or alter signals or communications necessary for operation of equipment (Boghossian et al. 2018).

*If a malicious actor could identify a vulnerability in a piece of equipment and disrupt thousands of machines at once, or a poorly designed patch was released at the wrong moment which locked up significant amounts of equipment, it could have an impact on food security and severe reputational loss to the equipment manufacturer. This is the highest impact threat to the availability standard. Disruptions to positioning, navigation and timing systems are another threat. ... most guidance systems also rely on GLONASS and other foreign systems. Access to these systems could be denied during a crisis or conflict, limiting the ability necessary to fully exploit precision agriculture equipment... producers rely on a hodgepodge of cellular, Bluetooth, and Wi-Fi networks, and still heavily rely on USB drives that manually transfer data. Signal loss and data bandwidth limits common in rural communications networks are a major weak point for precision agriculture. It is the most likely threat impacting the availability standard. (DNS, 2018, 6).*

Interoperability is a concern with the shift in agricultural equipment manufacturing. The implement controls for DOT™ follow the ISOBUS 11783 protocol, providing the international standard of interoperability between equipment, APIs, etc. (Deere and Company 2013). That being said, the DOT™ management foresees the industry, including DOT™, generally moving to brand agnostic or software agnostic approach. The primary driver is efficiency and users of portable computer alternatives are familiar with the Tablet interface. For a much lower price, about one-third less, a farmer can purchase a surface tablet that has much more power than an onboard, branded monitors.

Next are concerns with IP protection. The primary IP strategy includes the traditional patent approach, similar to the strategy used with other SeedMaster inventions (Justia Patents 2019). In addition, a new form of IP is a licensing approach where DOT™ technology is introduced with DOT™ and is made available to other manufacturers, transferring technical information to the licensee and registering the technology user for updates to system software. This IP strategy allows “all manufacturers to adapt their technology to become Dot-Ready” and enter new markets without high R&D costs for the manufacturer (DOT-Tech Sheet, 2018). When asked about repairing DOT™, the first (limited release) units will be serviced by the Dot Technology Corp.’s mobile and remote support service team. Senior management acknowledged farmer concern about

the ability to repair their own equipment; it was their position that they would be more accommodating than the other OEMs. As indicated in the following interview quote, they have no desire to go out to the field, plug in a computer, and read the code.

*[i]n the electronic portions of it, we have to be cautious that they aren't meddling with something that could affect safety or machine health. ... [w]e don't want them fixing a radar sensor or something like that. ... most of those things are just - unplug - plug a new thing in - and go. You're not going to open a radar sensor and try to fix it. I wouldn't anyway! But we definitely will be more friendly than other OEMs with that aspect of it, as long as we can record who did what and when (Interview participant).*

*I think the problem with some of the OEMs, from my understanding, is they want their expert to go out there and plug in the computer and read the code. We would have no desire for that at all. We would much rather that code-error show up through the cloud or whatever and be readable by us without sending a tech out there. Where other manufacturers have gone is more towards an open-source type system where they actually have come out and said, "we will allow people to even play from a software standpoint, functionality standpoint with our products... It's also Android versus Apple type system. And the growers just simply not going to accept being locked down (Interview participant). As long as we can record who did what and when. It's also something that's built into a lot of auto agreements already as well. People are quite accustomed to- if you don't get your oil changed out on time that can change the warranty. It's just kind of a part of the bigger picture piece. We would still highly recommend the fix, whatever that is. And if the fix is a plug and play, then the farmer or a local technician would be fine (Interview participant).*

The issue of data privacy, ownership, and use of data was discussed in the interviews. Management is not explicitly interested in having ownership of data gathered by the DOT™. Although, when it comes to the autonomous nature of the equipment, the insurance liability issues also come into play. Accordingly, access to machine-type data takes on a new meaning that thus far has not been mentioned in the literature,

*We would definitely have it [data aspects] as part of the agreement with the producers, that we're allowed to view certain parts of the data that deal with machine health, in particular (Interview participant).*

*What's happening right now is that there's arguments – or there's concerns around data. Who owns my data? There are concerns around control of the machine. What do you own? Do you own the machine? Or do you buy a license to use the machine? I know that there have been situations where there are certain functionalities within technology on a machine that you have to pay for an unlock code, they're not transferrable. You didn't buy it; you basically licensed it from them for you. And that's not a transferable license. So when I, become the second owner and buy that as a used machine, I have to go back and buy that key... I've heard this at producer meetings where they've had data experts sitting there saying, "you owe me your data. It's got a value, and if somebody else wants it, they'd better pay you for it.". With DOT that's something that we've never gotten into (Interview participant).*



*In a way what we are seeing it's like using cookies on a website...People don't like it but it used for data mining processes. What we're trying to do is better interact with our customers and not provide them a bunch of noise, but provide them with salient information that will help them operate their farm one way or another. Our sales pitch isn't buy my iron, it's buy my customer experience, buy my finished results. ... Don't buy the drill, buy the crop. And if you don't buy mine, just at least do it the right way (Interview participant).*

### **The end user community**

Farmers are signaling interest in the innovation, at least partly because the investment is an affordable option. According to Beaujot, with an investment of CA\$ 500,000, a farmer would be able to purchase the DOT™ platform, a 30-foot (SeedMaster no-till) seeder, four product tanks (e.g. for seed, fertilizer, pesticide, fungicide), a 60-foot sprayer with a 1, 000-gallon tank and a grain cart for carrying seed, fertilizer, etc. (i.e. not a grain cart for use at harvest). In a press release reported by the SME, farmers had, by spring 2018, reserved and paid deposits on most of the projected production for 2019 and 2020 (Dot Technology Corp.™ 2018). A farmer from Alberta, weighed in on DOT™, she intends to purchase a unit “when the bugs are worked out”,

*[a] brand-new tractor is \$700,000 and a brand new, great big seed drill can be in the \$700,000 range - that's \$1.4 million to seed your crop. ... If you can buy a less-expensive robot that can run longer and save you some time, to me, it's a no-brainer (Brienne Brault, farmer from High Prairie, AB quoted in Melchior 2018a).*

### **5.1.4 Policy context**

The agricultural equipment market is governed through a combination of codes, standards, and guidelines set for manufacturers of goods or services for use in domestic and international markets. Canadian companies use manufacturing standards recognized by the International Organization for Standardization (ISO), emissions controls set by the American Society of Agricultural and Biological Engineers, and the Canadian Standards Association (CSA) for safety, health, environment, and quality of life (Agricultural Manufacturers Canada 2018).

There are, however, a few exceptions to this rule. One is related to sale of equipment and the other to operation. Market regulations are more commonly associated with specific country tariff requirements, and legislation served to protect consumers (e.g. emissions controls) and the relationship between manufacturers and dealers. Country-specific policies for exports and imports are available through the International Trade Centre (intracen.org), and market analysis tools linked to specific harmonized standard code (HSC). They vary widely between countries.

### *Jurisdictional authority*

At the provincial jurisdictional level, the provinces of Saskatchewan, Alberta, Manitoba, and Ontario have legislation prescribing the relationship between agriculture equipment manufacturers and dealers (Agriculture Equipment Statutes, 2019). Primary statutes provide the legal framework requiring equipment dealers, manufacturers, and distributors to supply repair parts for a period up to ten years following the date of sale on a new machine sold in the province. In addition, repairs must be made available within a specified time period, for example, an emergency repair during critical use periods such as seeding or harvest must be done within 72 hours in Saskatchewan (Garvey 2015). If these conditions are not met, a farmer may file a compensation claim to an oversight body appointed by the government executive council, cash settlements may be imposed on a dealer or distributor and a penalty fee awarded to the farmer as compensation. As of May 2019, it has not been confirmed whether autonomous agricultural equipment or operating systems covered by copyright protection, would be, or would not be, subject to these provincial regulations.

### *Insurance and liability*

The other main policy area relevant to autonomous agricultural equipment is liability insurance schemes for autonomous vehicles (Yeomans 2014; Janzen 2019c). In Canada, motor vehicle transportation is a complex policy area. Federal, provincial, and territorial governments have shared jurisdiction, and multiple government departments are involved.

Transport Canada is responsible for research and public education, setting safety standards for manufactured and imported vehicles, and enforcing compliance. Innovation, Science and Economic Development Canada governs technical standards, addresses data and intellectual property issues, and supports R&D investment. The Canadian Council of Motor Transport Administrator (CCMTA), a multi-stakeholder group includes government agencies and sets voluntary guidelines for the safe testing and deployment of highly automated driving systems (CCMTA, 2018). The provinces/territories are responsible for adapting infrastructure to support autonomous vehicle deployment, licensing, registration, safety inspections, insurance and liability (Ibid, 20). Authority for enacting and enforcing bylaws on local roadways resides at the municipal level.

According to the CCMTA, Canadian guidelines for autonomous driving systems are ‘in-scope’ for vehicle registration, driver training/licensing, and enforcement of traffic laws. However,

the CCMTA reports that several areas remain ‘out-of-scope’ including safety programs and criteria, data privacy and security, enabling infrastructure, and cybersecurity (Ibid, 15). There is neither classification for ‘farm vehicles’ and associated regulations for motor vehicle safety, nor are there are Canadian guidelines for autonomous agriculture vehicles (Garvey 2018b). It has been generally assumed that such vehicles would not travel on public roadways. This may not always be the situation in the future if autonomous farm vehicles move between farm fields and yard sites connected by rural access roads, in which case an e-tether system with a lead automobile could be an effective transport mechanism and one that is being developed by Dot Technology Corp.

## **5.2 Actors and Activities**

The next two elements of the IOS, Actors and their Activities, are discussed as one section of the analysis. Four groups of actors have been identified in the IOS created by DOT™ and are illustrated in Figure 5.2 in relation to how they shaped the creation, design, manufacture, development, revealed and acceptance of the innovation. The following section begins with the Norbert Beaujot and then broadens to include a Saskatchewan SME, the Canadian industry association for agriculture equipment manufacturing, the government, farm media organizations, and farmers.

### *5.2.1 The agriculture equipment manufacturing SME community*

The inventor of DOT™, Norbert Beaujot, is an entrepreneur in agriculture equipment manufacturing and founder and president of an SME located in the heart of the dryland prairie region, southern Saskatchewan. Born and raised on a family farm in Saskatchewan, Beaujot is a farmer and professional engineer who saw the destructive nature of tillage first hand on his own farm and set out to find a better way for precisely planting seed without having to till the land.

By 1992, Beaujot pioneered a unique row opener for no tillage (conservation agriculture) seeders that provided accurate placement of seed and fertilizer placement in a one-pass operation, saving input costs and reducing risk compared to placement of inputs in multiple passes and different times. Ten years later, Beaujot built a manufacturing plant, SeedMaster, in a small rural community in the rural municipality of Edenwold, Saskatchewan, Canada. The company he founded, SeedMaster, has delivered several industry firsts, including large, 90 and 100 foot, no-tillage air seeders ([seedmaster.ca/bout](http://seedmaster.ca/bout), 2018).

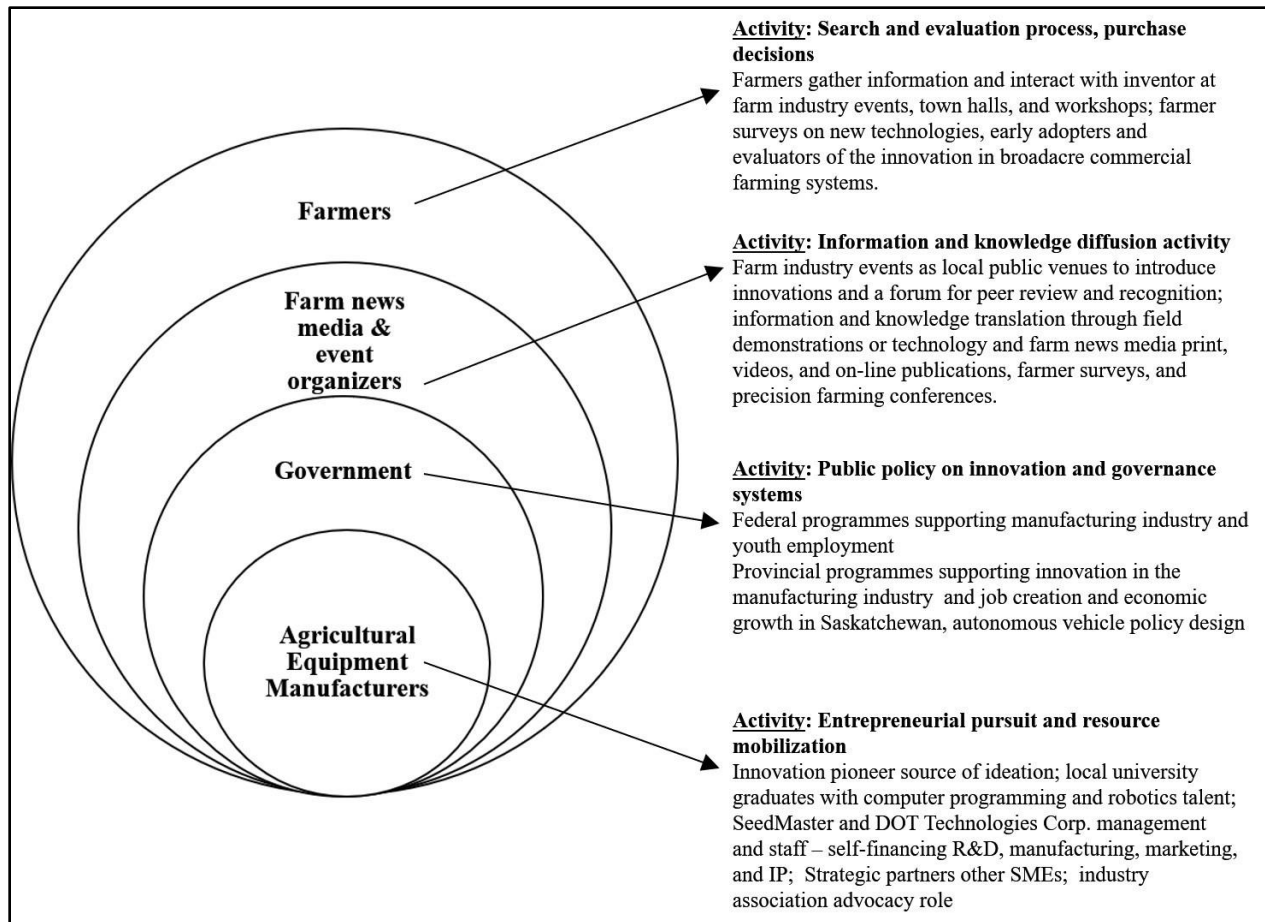


Figure 5.2: Actors and Activities in the DOT™ Innovation Opportunity Space

### SeedMaster, the SME

SeedMaster is a global exporter of conservation tillage equipment, notably air seeders. The design, crafting, production, and assembly of DOT™ is done at the SeedMaster facility. SeedMaster invested CA\$1.6 M toward the production of the first prototype (Saskatchewan, 2018a, b). Field-testing DOT™ with multiple implements was conducted at the SeedMaster research (family) farm. SeedMaster also provided technical support, customer insight (marketing) and engineering talent in support of DOT™. Dot Technology Corp. then formed as the sister SME to SeedMaster.

### New sources of talent

When work began on the autonomous platform, a decision was made to access a new pool of skills to develop the software and sensors and incorporate the ‘smart’ functionality into the U-shaped platform. A decision was made to hire a person to work at the SeedMaster facility with Norbert and develop the software and sensors needed for robotic systems.

Finding talent was a challenge noted by the management team. SeedMaster and Dot Technology Corp. actively scouted for talent at competitions such as the agBot competition in the United States (agBot Challenge n.d.).

The students they hired to develop DOT™ won the 2016 AgBot Seeding Challenge, and coincidentally; they were from the University of Regina, less than 50 kilometers away from the SeedMaster facility. The coding for software and sensor development was all done in-house with support from the new talent pool. The management team noted that the two young computer science students did not have agriculture backgrounds, although they grew up in Saskatchewan. The management team explained how they found this university-trained computer programming talent.

*[T]hey were displaying at shows, and we went to talk to them .... They're Saskatchewan boys- I don't know if they all have farming in their roots or not... they are just guys who like making things move by themselves. I'm sure they have, or will continue to, gain more and more appreciation for the ag world, but they're coming into it from a very pure kind of programming robotic head space. I think that's been great though. They've been very receptive and thinking about it from a different perspective than perhaps a farmer would (Interview participant).*

The two students scouted at the 2016 agBot Challenge Seeding Competition, C. Friedrich and S. Dietrich, remain active in Dot Technology Corp. and this talent group will likely expand as DOT™ production scales up and the smart functionality of DOT™ progresses.

#### **Other professional network SMEs and shortlines**

Strategic partnerships were formed with other providers of mobile hardware, software and information products in order to have DOT™ *conceptually designed to control our machines in the way that we wanted to* (Interview participant).

Dot Technology Corp. entered a strategic partnership with Raven Industries (McIntosh 2018), bringing Raven's decades of expertise developing technology for space exploration and agriculture (Raven Industries 2006) for the development of DOT™. Raven Industries, founded in 1956 with a focus on space exploration and high-altitude balloons, is based in Sioux Falls, South Dakota. In the mid 1990s, Raven Industries entered the precision agriculture market by manufacturing a controller for variable rate product application with GPS technology (Raven Industrie, n.d.). By 2004 they manufactured autosteering technology (SmartTrax) and in 2005,

Raven Industries purchased, Montgomery Industries (United States Security Commission 2005).<sup>7</sup> Their product, Slingshot, is available on equipment commonly used on prairie farms, including SeedMaster products, and provides high speed wireless Internet connectivity in the equipment cab by leveraging Raven's high altitude balloons (Raven Industries n.d.). Raven Industries became the supplier of mobile hardware and software custom designed to control DOT™ machines.

Cummins, a manufacturer of engines commonly used to power agriculture equipment, brought a century worth of expertise in engine manufacturing, plus expertise in autonomous technology (Cummins 2019; Garvey 2019). Cummins worked with Beaujot to supply the diesel engine that powers DOT™. The engine meets Tier 4 emissions standards described in the United States *Environmental Protection Agency (EPA) Regulations*, requiring that emissions of particulate matter (PM) and nitrogen oxides (NOx) be further reduced (by about 90%) to meet the same standards for diesel engine farm equipment engines as highway engines (EPA 2019).

SeedMaster and Dot Technology Corp. are also members of the agriculture equipment industry association, AMC. The purpose of AMC is to “foster and promote the growth and development of the agricultural equipment manufacturing industry in Canada” (AMC n.d.). Headquartered in Regina, Saskatchewan, AMC was active in coordinating industry support to secure funding for R&D on advanced manufacturing technologies, specifically artificial intelligence as part of a national competition to establish an industry-led consortium and an innovation supercluster. The president of the AMC, Ms. Leah Olson, was hired as Chief Executive Officer of Dot Technology Corp. in spring 2018 (SeedMaster 2018 a, b).

### ***5.2.2 Government***

The next group of actors is government and activities directly related to financial support of R&D in the manufacturing sector. This group is divided into different levels of government, federal, and provincial.

#### **Federal government agencies**

The National Research Council of Canada's Industrial Research Assistance Program (NRC-IRAP) administers the Youth Employment Program (YEP). The YEP support for wages,

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<sup>7</sup> Montgomery Industries is based in Stockholm, SK and is an SME established by Monty Shvak. Shvak developed Autoboom™, automatic boom height control system for agricultural spray booms and was agriculture equipment Inventor of the Year in 2003 (Canadian Cattleman, 2009, <https://www.farm-equipment.com/articles/4269-feature-articles---timeline-of-ag-equipment-firsts>).

targets companies such as SeedMaster and Dot Technology Corp. to hire the talent they need and YEP will cost-share a portion of the salary costs of an eligible youth candidate (Canada 2016). The program is part of the Government of Canada's policy (commitment) to help Canadian youth obtain career information, develop skills, find good jobs, and stay employed. Eligibility for youth in this program must meet an age criterion of 15 to 30 years, be a Canadian citizen, a permanent resident of Canada, or are a person who has been granted refugee status in Canada. They must also be legally entitled to work according to the relevant provincial legislation and regulation. YEP is geared towards work experience programs targeted at post-secondary graduates and internships must last a minimum of six months to a maximum of twelve months. There is a diversity in types of eligible projects. In this IOS, projects with relevance include R&D, engineering, and business development related to science and technology activities. The SME is responsible for other expenses such as benefits and overhead costs. The SME must be incorporated and for-profit, have 500 or fewer, full-time equivalents, be ready to enhance their innovation capacity, and be willing to establish a trusting relationship with NRC-IRAP (NRC-IRAP 2018). YEP was used to hire the students SeedMaster had found when they scouted for talent in the agBot Challenge (agBot Challenge n.d.).

### *Provincial government programs*

At the provincial level, about one year after DOT™ was first revealed at farm events, the Saskatchewan government announced it would provide direct financial support to further the development of autonomous functionality for use in the agriculture sector. The Saskatchewan Advantage Innovation Fund (SAIF) committed CA\$ 230,000 to Dot Technology Corp. in support of collaboration with University of Regina researchers and further develop the tablet device for improved user interaction (Saskatchewan 2018b). The policy support enabled industry-academic collaboration of Dot Technology Corp. with the University of Regina's program where the students in the YEP program were trained.

Prior to the SAIF program, the Patent Box program, first-of-its kind 'patent box style tax incentive' was offered by the Government of Saskatchewan under the authority of *Saskatchewan Commercial Innovation Incentive Act* (SCII). Patent Box is available to companies that will create new jobs, provided the company headquarters in Saskatchewan and R&D is done in the province (Saskatchewan 2017). The province implements the program in partnership with IRAP, who will provide technical assessment services for the SCII application process. The SCII is a new growth

tax incentive that offers eligible corporations a reduction of the provincial Corporate Income Tax (CIT) rate to 6%, for a period of 10 consecutive years. Companies can extend the CIT benefit period to 15 years, if 50% or greater of the related R&D has been conducted in Saskatchewan; companies may choose when to begin their 10 or 15-year, reduced CIT period. In order to qualify for the program, the SCII scientific eligibility evaluation must be assessed. Next, the eligible corporation must establish that it's only sources of revenue are related to the commercialization of the qualifying IP. If these conditions are met, the eligible corporation must then demonstrate new economic benefits accruable to the province and meet two of five economic benchmarks including spending a minimum amount of R&D in Saskatchewan (CA\$ 3 M including labour costs ), creating and retaining ten net new full-time employees, generating \$10 M in net new capital expenditures and contributing \$ 3.5 M in new provincial CIT taxes. Once the eligible corporation meets these conditions, it will be issued an SCII Certificate and the successful applicants can begin claiming their CIT benefit over a 10 to 15-year period (Saskatchewan, 2017).

Dot Technology Corp. qualified for the Patent Box program. An official announcement was not made, although government sources confirm that DOT™ had indeed qualified for the innovation incentive. At the time of writing, Dot Technology Corp. had not accessed the Patent Box program and CIT benefits.

Outside these programs, the government's role in the DOT™ IOS has mainly been indirect and private industry has taken on an increased role of knowledge transfer about new smart farming technologies. For example, equipment dealerships and manufacturers of specific brands of equipment provide technical support on a one-on-one basis to their customers. Government's role in knowledge transfer (extension) about agriculture is typically sponsorship of organizations hosting events such as farm trade shows or conferences. The gap of smart farming knowledge transfer to the farming community and the public is being filled primarily by farm news media groups, mainly Glacier Media and Farms.com.

### *5.2.3 Farm news media*

Farm news media play an increasing role in the organization of farm industry trade shows. Admission to these venues is not exclusive. Individuals or groups that may not be directly connected to farming have equal opportunity to attend these multi-day events (listed in Appendix Table A.1), although attendance typically includes those with personal ties to the agriculture community.



Articles are published in traditional subscription-based newspapers and magazines as well as internet-based dissemination of farm news (Appendix Table A.4). Journalists working for the major farm media organizations in western Canada are generally hired as staff members and according to a chief editor, as an employment requirement, there are expectations of objectivity in journalist's articles, and following in-house and/or international code of ethics including the American Agriculture Editors Association (AAEA) Code of Ethics which applies to all members, and any medium used to communicate their work (AAEA n.d.). Many of the articles related to DOT are related to live or post event reporting of farm industry trade shows.

#### *5.2.4 Industry trade shows*

The agriculture industry has a long-standing tradition of organizing trade shows or agriculture fairs that serve a purpose of showing new technologies to farmers and recognizing excellence in the industry (Ellis 1970). Three major trade shows are reported in the next section as representative venues relevant to the DOT™ IOS. Events such as this are social events for the agriculture community, and they are also venues for knowledge gathering. Farmers can meet face-to-face with the manufacturers, other agribusiness, and agtech providers.

The first venue, Ag in Motion, Western Canada's Outdoor Farm Expo, was hosted by the farm media group, Glacier Media. It is organized by the rural community of Langham, Saskatchewan and staffed by hundreds of local volunteers. This event is unique in that it allows farmers direct interaction with the inventors and observe the performance of innovations in real-time under field conditions. The event allows farmers to compare brands, and the new technologies offered. The third annual Ag in Motion event was held in July, 2017, and it was this venue where DOT™ made its global product launch and was revealed to the farming community (Rance 2017; Myers 2018a). Over the duration of the three-day event, 25,787 show visitors were able to watch daily demonstrations of autonomous technology as DOT™ was used to hook up to and propel a seeder, unhook, and switch over to a land roller implement. The management teams from Dot Technology Corp. and SeedMaster were on-hand to speak to farmers over the course of the three-day event. In October 2017, the Ag in Motion organizers announced that DOT™ had won two awards, Innovation in Agriculture Equipment Technology and the People's Choice Award (Ag in Motion 2017). As a follow-up to these events, other farm news media groups provided reporting of the newest innovations, featuring interviews with Beaujot and other family members (employees of SeedMaster and/or Dot Technology Corp.). The event coverage had a substantive

reach. Glacier Farm Media has a broad readership base of over 100,000 users and 1.2 million page-views per month and reports on farm innovations ([glaciermedia.ca](http://glaciermedia.ca)). The event organizers observed the following,

*People couldn't walk away from the DOT over the three days of Ag in Motion, and there was a constant flow of people around the DOT booth and machines to see live demonstrations. Being one of the most popular items at this year's show, it wasn't a shock to see DOT Technology win the People's Choice Award as well as the award for Innovation in Agriculture Equipment Technology.*

*While the DOT has been officially launched, it will be a while before we see them scattered throughout the prairies. This year six pre-selected buyers were picked to help DOT and their sister company SeedMaster fully test the DOT Power Platform and its different implements. Plans for further distribution are in motion for the upcoming year.*

The Western Canadian Farm Progress Show venue in Regina, Saskatchewan was the second major trade show to feature a competition for innovations as a mechanism to encourage competitiveness in the agriculture sector (<https://bit.ly/2p90OpS>). The 41<sup>st</sup> show was the largest (indoor) show to date for this annual event with 200 exhibitors, 22 Innovation Program entries this year and three major product launches from equipment manufacturers, AGCO, Morris Industries and Salford Group (Postey 2018). That year, the farm media organization, Farms.com, became a major sponsor. Attendance was approximately 35,000 with over 700 international visitors and buyers, and CA\$ 345M in sales (Ibid).

Nominations for the awards are accepted by the event's innovation committee and evaluated by a panel of expert (industry) judges. Among the 22 innovations evaluated by the innovation panel judges in June 2018, Norbert Beaujot and Dot Technology Corp. received the highest ranking, Gold Standard Innovation Award, one for DOT™ and the other for a new seeding system developed by SeedMaster (Briere 2018b). The innovations competition has recently expanded to include farmer-made innovations, and a hackathon competition has been added for 2019.

Farm news media is expanding their activities to include organizing conferences featuring experts from the government (policy), academia (R&D), industry (technology developers), and farmers (technology consumers) participate as session panelists. Farms.com provided a venue for the agriculture community to be made aware of the latest innovations in farming. The first Precision Agriculture conference was held in Saskatoon, Saskatchewan, October, 2017. It was attended by 350 senior agribusiness executives, government, and researchers from academic

institutions, students, farmers and agronomists. Beaujot was a key note speaker at the plenary session and hosted a breakout session later that day. The event was held again in 2018, and management from DOT Technologies was once more featured at the event (farms.com, 2017, 2018). The newly appointed Chief Executive Officer, past president of the AMC, was a keynote speaker and provided an update on commercialization (Koerhuis 2018). In 2018 the audience was augmented by a group of international agricultural journalists sponsored by Global Affairs Canada. The new CEO of Dot Technology Corp. was a keynote speaker at and gave an update on commercialization activities in 2018 (Ibid). The owner of an SME delivered a presentation profiling a new DOT Ready™ implement (Farms.com 2017, 2018). DOT™ and the DOT Ready™ opportunity for manufacturing autonomous farm equipment caught the attention of the African journalist, who wrote:

*With Africa on the precipice of its own agriculture revolution technologies like these could speed up the process of putting the continent's 60 per cent of the world's uncultivated arable land to use (Vanek 2018).*

Based on the response to the autonomous option for the industry, keynote speakers representing DOT were invited to the London, Ontario location for another Farms.com Precision Agriculture conference event in January 2018. (p.comm. Joe Dales, Executive Vice President, Farms.com).

### ***5.2.5 Farmers***

The final group of actors identified are the farmers as consumers of smart farming innovations. Early indications are that prairie farmers are not opposed to autonomous agriculture equipment, and in fact, farmers are making their own equipment autonomous, for example, a Manitoba farmer made his tractor autonomous out of necessity in order to pull a grain cart at harvest time when labour was not available (Hackaday.io n.d.). Tractors can be made autonomous using AgOpenGPS mapping software for units equipped with CAN-Bus and much of the necessary information is found through on-line farm hacker forums (Booker 2018b).

Glacier Farm Media (2017) conducted a post-event survey after DOT™ was revealed in 2017 to gauge opinion on the new technologies. Results were published in a special innovation edition of The Western Producer, December, 2017. Sample size was 428 respondents, evenly distributed between the three Prairie Provinces; 84% owned their own farms; 3% were farm employees; 5% farm managers and 6% were third party consultants. Seventy percent ranked it as

a low priority, however, autonomous vehicles were actively being tested by 3% of respondents; 10% felt they would be ready in one to two years, and use of an autonomous vehicle on the farm was possible three to five years distant for a vast majority (75%) of respondents (Lyseng 2017b; Glacier Media 2017). Cultural, lifestyle and safety objections were the concerns of the autonomous technologies, although survey rankings for these factors were not provided in the report. Top mentioned barriers were as follows: budget (45%); ‘too complicated’ (28%); ‘don’t know how to use the technology’ (22%); ‘I understand equipment but not an autonomous operation’ (16%), ‘I can’t get help when I need it’ (16%) and ‘other’ barriers were 18% (Glacier Farm Media 2017, available at <https://bit.ly/2DSeWgb>). Over half indicated time savings would be their main benefit, but that the future of autonomous technology hinged on rural labour shortages and 45% indicated budget constraints as the ‘top barrier’ (Lyseng 2017b; Glacier Media 2017).

Farmers have observed and read about DOT™ and Dot-Ready™ technologies since the first field demonstration of DOT™. Field tests were done at a facility in Arizona, United States in 2018 and 2019. In addition, SeedMaster and Dot Technology Corp. management actively engaged with farmers at the trade show venues, Master Seeder workshops (October 2017), town-hall meetings (2017/2018), and on social media (Twitter). Management was observed as always being readily available for in person conversations with farmers and the public at numerous farm events.

In the interviews, Beaujot was asked what qualities they were for in the farmers who will be trialing DOT™, he replied:

*We expect to get the ones that are comfortable in the electronic world for sure and to start with, ones that are not too far from Regina. We’ve kind of set it at 100 miles from Regina and the ones that are bigger farmers who would test this on a portion of their land so that we’re not exposing their livelihood overall. ... [I]n my estimation, [they would] typically start with keeping all of their present equipment for one year and testing one unit. Quite a number have approached us within that distance and outside of that distance. We’ll probably interview them, talk about it, and show them what we expect to provide and what we expect out of them. We hope they will financially commit to it as well. So, it’s not just a demonstration piece. We would ideally not own these pieces. The farmer would own these pieces. There’s a bit of a transition- translation happening.*

As of July, 2019, DOT™ was used for field operations on approximately 6,500 ha (Relf-Eckstein 2019). The early adopters feature six farmers who used DOT™ on their farms in the spring of 2019. ). The DOT Power Platform™ is sold directly to farmers at US\$ 260,000 and the full package of DOT™ with a seed drill and a sprayer is available for \$500,000 (Garvey 2019b).

### 5.3 Aftershock

The aftershock element is defined as the “impact and outcomes of the actions taken place by the actors within the opportunity space” (Flowers et al. 2017, 209). Analysis of the fourth IOS element, the Aftershock, is based on what is currently happening while writing this thesis, which focuses on three main aspects of the aftershock, plus an added fourth aspect related to success in adoption of the smart farming DOT™ technology.

The main impact is the uptake of manufacturing DOT Ready™ implements and the decreasing time from design to field testing of a new implement with autonomous functionality, commercialization and acceptance by farmers. The second potential aftershock is the impact at the farm level and on the biosphere and environmental outcomes. The ex-ante analysis is based on aggregate values of farm inputs available from Statistics Canada and the estimated economic impact through marginal reduction in these inputs and socio-environmental outcomes for society.

The third aftershock therefore relates to government policies and according to Maru institutional and social-organizational changes “must precede technological change”, however, it is often the case that changes are contested as actors compete for the required resources (2018, 354). As a predictive tool for aftershock of the innovation, data for such changes simply does not yet exist. Data captured in this area is therefore, speculative in nature, focusing on the ‘putative aftershock’ including socio-economic benefits accruable to society, for example, how does this technology address environmental sustainability and soil health? The aftershock element therefore considers *potential* barriers to the IOS, including associated risks, public perceptions, farmer adoption of these smart-farming innovations, and industry acceptance of the business model. Beyond these aspects, it is premature to identify industry impact or outcomes as the aftershock is rapidly unfolding and predicting what the ‘next shock’ might be (Flowers 2017, 64), now is speculative (e.g. what is promoting or inhibiting the innovation).

#### 5.3.1 A new equipment manufacturing opportunity space

Potentially, the most impactful aftershock is the licensing of autonomous technology and Dot Technology Corp. new business model for creating and managing the IP assets of DOT™’s technologies. Licensing, or obtaining permission to use someone’s IP is typically done through a contract between the licensor (IP owner) and a licensee “who wants to use the IP is associated with a product or service” (Arrasvuori et al. 2017 101). Contract terms include, for example, specific regions or market area, time period and conditions for renewal or invalidation of the contract.

‘Brand’ licensing may be used to extend the IP (trademark, copyright character) for productions manufactured by another company. In the case of Dot Technologies Corp, the new Dot-Ready™ equipment is manufactured through a licensing agreement, collaborations and vendor partnerships between Dot Technologies Corp. and other equipment manufacturing companies.

The first major outcome of the new business model put in motion by the Dot Technology Corp. is commercialization of specialized agricultural equipment with autonomous functionality by two shortline manufacturers, Pattison Liquid Systems and New Leader Manufacturing. The first shortline manufacturer, Pattison Liquid Systems, is a Saskatchewan SME that specializes in liquid fertilizer application equipment, liquid handling products, and spray management systems (Pattison Liquid Systems 2019). The second shortline manufacturer, New Leader Manufacturing, is a large size agribusiness enterprise established in the northern United States with production facilities located around the world. New Leader is manufacturing a precision fertilizer applicator and supplies other full line agricultural equipment OEMs.

The autonomous sprayer, made by Pattison Liquid Systems, is uniquely branded as CONNECT™. The SME was established by two brothers, Rick and Larry Pattison, in 1979 in Lemberg, Saskatchewan. Rick Pattison is now the sole owner. The idea for an autonomous sprayer was talked about over 25 years ago between Rick Pattison and Dr. Guy Lafond, a local scientist highly regarded by the local farming community for work in conservation agriculture (p.comm. R. Pattison 2018a). With the creation of DOT™, Rick Pattison, present day owner of Pattison Liquid Systems, was finally able to create the autonomous sprayer. The company has assigned their own trademark to their product line of autonomous agriculture equipment known as the CONNECT™ system. Reflecting the cultural fabric of the conservation agriculture movement and Lafond’s impact on the agriculture community, the sprayer is named, ‘Guy’ (Pattison 2018b).

The CONNECT™ PLU (Pattison Liquid Unmanned) S120 is available for purchase as of summer, 2019. The time from design to field testing was rapid. Development began in March/April 2018 and by June 2018 the CONNECT™ PLU had been manufactured and was revealed at the June 2018 Western Canada Farm Progress Show (Heppner 2018). Rick Pattison was a key note speaker at the 2018 Precision Agriculture Conference organized by Farms.com, and indicated that field testing is well underway and additional trials will be done in Arizona, March, 2019. The CONNECT™ PLU incorporates state of the art individual nozzle controls developed by Raven Industries that will deliver cost savings to the producer, including individual nozzle controls over

the 120-foot (36.5-meter) oscillating aluminum boom. This will provide highly precise application of product, reducing input costs and these studies are underway. Pattison also highlighted the environmental benefits feature of having a spray tank loaded with exactly the amount of product needed. A unique auto-rinse feature accommodates a ‘spray out’ and cleaning of the implement on the field or roadside ditches. Combined with the concept of an autonomous, mapped field path, and very accurate application, there will be added cost saving in comparison to a tractor-pulled sprayer.

A second CONNECT™ implement that will have autonomous functionality is a 12.2 m coultter-based fertilizer applicator for mid-row banding and fall application (Wiens 2018). The fertilizer spreader and was demonstrated at the July 2018 Ag in Motion venue (Ag in Motion 2018). Pattison reflected on the opportunities for short-lines to step up to the world stage and autonomous, robotic farming. When interviewed by farm media, Pattison reflected on the opportunities for short-line manufacturers to step up to the world stage and autonomous, robotic farming:

*It's very difficult for a small company to be able to build all of the automation that needs to go into it [product development], so for a short-line smaller manufacturer like ourselves, being able to partner with the DOT™ folks; it's amazing because we can collaborate and collectively build something where individually we would not probably do that (Rick Pattison, president of Pattison Liquid Systems and Connect, July 5, 2018, as quoted in Heppner 2018).*

In the same article, Beaujot re-iterated his statements of a year prior, and the ideation of Farming Reimagined. He comments about the outcomes of the licensing agreement approach,

*Having a significant company such as Pattison working on implements for DOT is a significant milestone.... All around the world it's the short-line manufacturers that really led advancements in agriculture. ... they don't get the recognition they should, and with DOT they can be leaders in autonomous farming, which we fully believe is the future. (Norbert Beaujot, president of SeedMaster and Dot Technology Corp.)*

The second shortline manufacturer participating in the Dot Technology Corp. licensing agreement is New Leader Manufacturing. Based in Cedar Rapids, Iowa, New Leader has been producing equipment for over 80 years, and operations have expanded with an international facility established in Brazil (New Leader Manufacturing n.d.). Similar to the experience with Pattison Liquid Systems, the time from discussions to prototype was only six months and commercial sales are planned for the 2020 field season. New Leader added autonomous functionality to their product line-up of fertilizer spreaders traditionally mounted on chassis for OEMs including Deere &

Company, Case IH and AGCO (Booker 2019). The Dot-Ready™ spreader will be sold as a NL5000 G5 implement and it offers precise and VRT application of multiple dry-fertilizer products. The innovation was revealed at the July 2019, Ag in Motion venue (real agriculture 2019). Journalist Kara Oosterhuis discussed the scale of testing and uptake of DOT™ new Dot-Ready™ implement with the management of Dot Technology Corp (Ibid).

Several early adopters are using DOT™ and Beaujot told the audience gathered for the field demonstration of the Dot-Ready™ equipment that approximately 2,023 ha were planted using a DOT Ready™ SeedMaster no tillage seed drill. The CONNECT™ PLU has sprayed over 11,000 acres (4,451 ha) and a strategic partnership with xarvio™ Digital Farming Solutions was announced which will combine the human-less application of pesticides and singulation (single nozzle) technology of the CONNECT™ PLU with an AI-driven weed identification system developed by xarvio™ Digital Farming Solutions, delivering product *only when a problem weed* is identified by xarvio's sensors, cameras (Relf-Eckstein 2019). At the demonstration, Beaujot and the management team announced that Dot Technology Corp. has also been working with the Government of Saskatchewan and more recently, the Alberta government, to develop safety regulations for use of autonomous farm vehicles.

In essence, this major aftershock of the IOS is partially an old world 'ethos of control'; driven by defending IP with patents on a 'technological innovation' in combination with a 'ethos of openness' and new world of IP strategy reflective unfolding in the IT sector and systems recognition of 'artistic innovation' not unlike Copyleft software licenses, which are considered protective or reciprocal, as contrasted with permissive free software licenses. As noted by Arrasvuori and colleagues (2017, 107), there will be tensions between the old and new world of IP and defending territory.

Potential benefits of the 'old word' of IP protection are easier to grasp than the potential gains for the new world of IP. In the manufacturing of agriculture equipment, details of monetization of the IP associated with DOT Technologies Corp. licensing (e.g. royalties) remains undisclosed at the time of writing; however, there is plenty of room for smart farming innovation for both technological and artistic models of IP. Commercialization is not limited to Canada and as reported by international visitors to the November, 2018 Precision Agriculture Conference, *Africans have the opportunity to build their own implements that could be added to DOT* (Vanek 2018). The journalist from Africa has reported in the CNBC Africa media, that the Dot-Ready™



30' air seeder, 41' land roller and a 500-bushel grain cart by SeedMaster and the 120' CONNECT™ PLU sprayer by Pattison Liquid Systems will be commercially available in the first half of 2019 and the potential use on farms in Africa was highlighted.

### *5.3.2 Farm level cost savings and environmental benefits*

The highly anticipated benefits derived from the DOT™ IOS are hard to quantify. Estimating the impact of DOT™ at the farm level is particularly challenging as individual farm operator data is reported in aggregate by Statistics Canada. Information is not cross-referenced to a piece of equipment, operation, or task, and the actual cost savings to farmers will vary based on farm size, wage rate, and type of farm operation. The following impacts and outcomes are therefore maximum theoretical estimates based on available government statistics.

The first farm level aftershock is related to the technologies of smart farming and the vision of DOT™ and its autonomous functionality - it will solve producer problems by saving on labour requirement while also reducing fuel costs. The large-equipment inventory problem addressed by DOT™ will potentially impact dealerships, and the affordability of the innovation makes it affordable for farmers wishing to purchase new technology.

The cost savings impact by removing the labour requirement of a tractor operator position will vary between farms and the potential outcome of improved health and wellbeing would also vary with farm operation, age of farmer, and mental stress factors other than labour shortages (e.g. succession, financial). The near-term impact of reduced labour for a tractor operator, however, will need to be balanced with a longer-term view and outcomes of new skill sets for farming. Agriculture is experiencing shortages of workers with necessary skills and experience. While autonomous functionality in agricultural equipment would reduce the absolute number of workers required, a new set of skills is essential. Autonomous technologies will require a re-thinking of operations planning including time for route planning, and task scheduling such as refueling (Bochtis 2013; Bochtis et al. 2014). The value of autonomous technology in addressing the labour problem in the agriculture sector is recognized by the Canadian labour council (CAHRC), but there will be social costs and re-adjustments required. The executive director of the organization cautions that,

*[I]t's a double-edged sword. You have to then train the workforce; you have to adapt to those new production techniques and technology, and in order to maintain those systems; you need different skills moving forward (MacDonald-Dewhirst quoted in Blair 2019).*

Aftershock on the biosphere is linked to reduced fuel emissions and usage, and improved soil health. The new Cummins engine with Tier 4 emission standards powering DOT™ could displace older (fuel emissions) technology tractor engines with less stringent environmental regulations. Reduced fuel requirement and emissions are related to the decrease in (horse)power required per acre from less weight, and the basics of a propulsion versus pull-type system. A fully ballasted 400 hp tractor weighs approximately 18,100 kilograms (kgs). In comparison, a DOT™ unit, weighs 5,570 kgs. As explained by Beaujot, a comparable ballasted tractor requires between 20 and 30% more horsepower than a DOT™ unit, thus requiring between 20 and 30% more fuel, and in addition, the weight travelling the field is substantially reduced and this may have an impact on soil compaction. Furthermore, with the lighter weight from agricultural robots (such as DOT™), Danish researchers suggest that in times of above average rainfall, an agbot is less likely to get ‘stuck’ in wet soils, a factor particularly important in coastal Europe where global warming is anticipated to have the effect of increased precipitation (Berggreen 2018).

Soil compaction caused by heavy tillage equipment is recognized as “one of the most severe degradative processes in mechanized agriculture” (Blanco-Canqui and Lal 2008, 402). Soil chemistry changes with compaction, impacting the mobility of elements, biotic activity of roots and earthworms (Whalley et al. 1995). With pore space compromised, the increased anaerobic conditions can lead to higher production of methane, a greenhouse gas (Nawaz et al. 2013). Change in soil structure also affects physical processes of the soil, reduces root and shoot plant growth and impacts crop yield, and impedes water infiltration, which in turn increases runoff of water, nitrates, and pesticides into groundwater (Soane and van Ouwerkerk 1995; Hamza and Anderson 2005).

Measuring the impacts and outcomes is not an easy task and beyond the scope of the SME to quantify. Some suggest the impact on the biosphere may be larger than the fuel savings, although long-term experiments will be required to understand the environmental aftershock. Such experiments could include for example, head-to-head testing of Dot-Ready™ implements with tractor-based systems, measuring the environmental affect using different land management practices, and testing on farms representing a diversity of soil types and structures, climate and weather conditions. Similarly, quantifying the value of decreases in soil compaction has a long-time horizon, and metrics will vary by soil type, crop kind, and management strategy and adoption of implanting controlled traffic practice, retaining historical records and adjusting field path patterns through deep learning and field-specific algorithms.

### 5.3.3 Government policy and changes

Four policy aftershock areas with direct relevance to the DOT™ IOS were identified in this study. The first policy aftershock relates to Canada's agriculture policy platform which continues to undergo substantive changes reflecting the ongoing dynamics of the role of government and non-government organizations and the shared jurisdictional authority between the provinces and the federal government in matters relating to agriculture (Carew 2001; Hedley 2017, Atkinson et al. 2013). The Canadian Agricultural Partnership (CAP) is the latest iteration of the policy and is backed by a five-year, CA\$ 3 B investment program to help the sector grow, innovate, and prosper. The Canadian Agricultural Strategic Priorities Program (CASPP), within the CAP policy, was announced in February 2019. Government investment of \$ 50.3 M over five years will focus on the adoption of new technology, environmental sustainability, strategic development and capacity building, and emerging issues (Canada 2019b). Dot Technology Corp. was one of the 55 projects chosen as lead applicants for CASPP, although it was not advanced to the full application phase of the competition (Canada 2019b). While it is unlikely the IOS created by DOT™ had a direct impact on this policy aftershock - DOT Technologies is *not* among the 15 projects moving forward after initial submission - it may have had a role in illuminating the potential of digital technologies when applied to the agriculture sector.

The second aftershock relates to innovation. The national Innovation Supercluster program is Canada's flagship policy platform and a budget commitment of CA\$ 950 M. Funds support R&D and commercialization clusters in advanced manufacturing, agri-food, health/bio-sciences, clean technology, and digital industries (KPMG 2018). Canada's Supercluster program supports work by researchers spread across the country and leadership teams to coordinate the projects. Dot Technology Corp. is part of the Innovation Supercluster (KPMG 2018, slide 11). The SME's role in the Supercluster was not disclosed during the interviews, although the inclusion of Dot Technology Corp. in the Supercluster may signal Canadian government interest in multi-sector autonomous equipment innovation. At the provincial level, the aftershock of the Saskatchewan innovation fund program, SAIF, is evidence of a movement towards provincial government supporting industry-academic collaboration and an outcome of advancing smart farming innovations that support ease-of-use of the new technologies. As the program is in early stage of implementation, the impact of the policy and encouraging cross-disciplinary training of computer science and agriculture equipment manufacturing is uncertain at this time.

During the competition of candidate proposals for the cluster initiative advancing innovation, a group of 17 educational institutes, combined with private industry multi-national corporations, not-for profit groups and non-governmental organizations, proposed a project to create an explicit smart farming cluster in Canada. The cluster, known as the Smart Agri-Food Super Cluster (SASC) had a broad-based (farm-to-fork) communities model approach to smart farming that was cross-sectoral (crops and livestock) and included data and big data analytics along with advanced artificial intelligence applications in the agriculture equipment manufacturing sector, and testing of technology at a de-commissioned federal research farm in the nation's capital (Johnson 2018b; Cheater and Blair 2018; SASC 2018). The proposal did not receive support in the Innovation Superclusters Initiative. However, the Advanced Manufacturing Supercluster received funding with a purpose to build up the next-generation manufacturing capabilities and position Canada as a leadership in innovative manufacturing, however, the SAIC proposal did *not* receive support in the Innovation Superclusters Initiative (Innovation, Science and Economic Development Canada 2018).

The Strategic Innovation Fund (SIF) and a new program stream introduced in early 2019, National Ecosystems, was added to the Canadian government's approach to innovation. SIF awards grants based on a competitive process and National Ecosystems is specifically geared toward supporting innovation by Canadian SMEs (Canada, 2019cd). Several entrepreneurs involved in the SASC initiative mentioned above re-organized when the proposal was not selected as a SuperCluster. The group formed within the Alberta Innovates program and received CA\$ 49.5 M of federal funding through the Canadian Agri-Food Automation and Intelligence Network (CAAIN). The CAAIN project aims to build smart farming capacity by implementing a 'platform' to test, demonstrate and scale up smart farming technologies. This is a SIF-funded project that will support "private sector, academia and research institutions to drive automation and digitization of Canada's agricultural sector" through collaborations with: not-for-profit organizations; private firms in resource management, automotive and industrial manufacturing of aerial platforms telehandlers and agricultural equipment' Dot Technology Corp.; TrustBIXS (based in Alberta); and two college-level agriculture-based academic institutions in Alberta (Alberta Innovates 2019). While the Innovation Fund Stream 4 governance (policy) approach is not as comprehensive as the EU Internet of Farming and Food model (IoFF, 2018), it does signal a first 'smart farming view'

of innovation supported and implemented by multiple jurisdiction (i.e. federal funding and Alberta provincial policy).

The third aftershock is that Canada lacks a regulatory framework and regulations for safe use of autonomous agriculture equipment and Dot Technology Corp. is working with government to shape policy for autonomous farm vehicles. Prior to the introduction of DOT™ in 2017, Dot Technology Corp. engaged in conversations with the Saskatchewan Government Insurance agency and Transport Canada to understand the rules for transport of DOT™ (Garvey 2018b). In the absence of rules, Dot Technology Corp. created a trailer platform to transport DOT™ and the SME became part of the process to design policy for autonomous farm vehicles. CCMTA confirmed a pilot program in Saskatchewan is in the works, and Dot Technology Corp. is taking a leadership role (p.comm. CCMTA 2019). The outcome of this activity is thus far not public information.

The fourth policy aftershock is related to IP issues including the ownership, security and third-party use of agricultural data and control of the life cycle of equipment using IP rights and systems lock-out to make repairs. These are areas of growing global concern and in other jurisdictions and there are pressures for governments to engage with these issues. Canadians are no different and they are anxious about how their data is being used and the impact of digital technology in their daily lives (Canada 2019a). In May 2019, Canada's new Digital Charter was announced by the Minister of Innovation, Science and Economic Development, signaling government's intent to develop industry-wide governance standards including the modernization of *PIPEDA*. However, neither 'agriculture' nor 'farm' is indicated in either the visualization of the Charter or the text form descriptions. Furthermore, there is no obvious action in Canada on the ability of a farmer to repair equipment and provincial legislation regulating equipment providers, dealerships and manufacturers does not address access to software-based operating systems.

In the absence of government regulations on farm level information, or Canadian industry codes similar to the ADT principles or Right to Repair legislation, firms such as Dot Technology Corp. which manufacture equipment that generates data, will need to establish one-on-one trust relationships with farmers, provide clarity and transparency on the use of machine data collected by DOT™ and provide assurances on measures the firm has taken to address cybersecurity of their proprietary Cloud systems. The aftershock of using existing provincial statutes which prescribe relationships between equipment industry actors and farmers remains unknown until specific cases are brought forward for review by government oversight boards.

## 6.DISCUSSION AND CONCLUSIONS

The breadth and depth of the research questions introduced in Section I, benefits from taking a multi-dimensional perspective to this policy research, drawing on the literature to study what is known about smart farming innovation, applying the Innovation Opportunity Space analytical framework, and then extending the framework to focus on a *new thing* and the *opportunity space* it is creating in the agriculture sector and equipment manufacturing in Canada. In this section, I discuss my answers to each of the three research questions and parse out the conclusions I have arrived at.

In the following sections, I argue these conclusions by discussing different three aspects of the IOS framework. I draw on the Architecture element of the IOS and problem aspect of smart farming which DOT™ may, or may not solve, which answers my first research question. The second aspect is a policy lens, and applies it to the Actors and their Activities related to participation in public policy and/or industry policies (codes and principles), which answers my second research question. Finally, the third aspect uses the Aftershock element of the IOS to focused on the risk of equipment-related smart farming innovations, which answers my third research question.

The final area of the Discussion concludes that Farming Reimagined is an Unstable Innovation Opportunity Space, based on the criteria of types of IOS suggested by its authors.

### 6.1 Smart farming as solutions to farm-level problems and societal concerns

Smart farming is a logical path to sustainable intensification of agriculture because it solves farm-level problems identified and experienced by many prairie farmers.<sup>8</sup> This research found that a field robot such as DOT™ is best suited to broadacre farming on the prairies and farm types where the direct and indirect effects of the labour problem is most severe. If DOT™ and Dot-Ready™ equipment continues to be priced as indicated by Dot Technology Corp., the general acceptance of field robots by younger farmers, and farmers with medium-sized operations is a ‘no-

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<sup>8</sup> Sustainable agriculture, defined as, “the ability of farmers to continue harvesting crop and animal products without degrading the environment or the resource base while maintaining economic profitability and social stability” (Struik and Kuyper 2017:39). It is the author’s own interpretation that sustainable agriculture is an ongoing process, whereas the sustainable *intensification* of agriculture is outcome-oriented, meaning more food produced (intensified production). In the Prairie Provinces, however, climate remains a primary constraint to the yielding ability of crops, given the use of adapted and disease resistant crop cultivars.

brainer' (Melchior 2018a), and will support sustainable farming especially for these farmer-farm combinations. Moreover, adoption of autonomous equipment as a smart farming innovation will likely 'shift the production function' (Schumpeter 1939) in support of Canada's many, medium-size, sole proprietorship or a family corporation type of farms (Statistics Canada Table 32-10-0433) which are presently operated by educated farm operators (Ibid Table 32-10-0011). These operators and others before them, have established a culture of embracing technological change to improve productivity (Darku et al. 2016). By applying their skills, talents and aptitude for innovation, present farm operators are well-equipped to learn new processes required to effectively integrate field robots into their line-up of equipment, particularly in the next decade of farmer retirements and transfer of billions of dollars in farm assets (Diamond 2019).

Based on this research, I draw four conclusions in response to the first research question; *how does smart farming address problems at the farm level while also supporting sustainable intensification of agriculture and delivering public good benefits?*

1. DOT™, the field robot, addresses a major farm level problem that is experienced and well known at the farm level, namely the dilemma of shortage of labour to complete crop operations, and the high occupational levels of mental stress in the farming community that is related to the trend of a widening labour gap impacting in broadacre farming in the Prairie Provinces.
2. DOT Technology Corp. has introduced to the farming community one solution that addresses the problem of the lack of ICT systems infrastructure and connectivity in rural areas by using Real Time Kinetic (RTK) base stations and unused broadband frequencies.
3. A new licensing business model for the agriculture equipment industry that is introduced by DOT Technology Corp. addresses: farm level problems of lack of interoperability between proprietary operating systems and lock-in to equipment brands, copyright based operating systems restricting a farmer's right to make basic repairs to the piece of equipment they purchased, and erosion of trust and uncertainty regarding ownership rights to agricultural data.
4. There is limited attention and resources demonstrating that smart farming will solve broader societal problems connected with agriculture such as maintaining social stability and economic profitability of farming without degrading the environment or the resource base.

### *6.1.1 Closing the agriculture labour gap*

First and foremost, this research found that in the context of prairie agriculture, smart farming technology must maintain economic profitability and social stability of the farming community. Observations on new digital technology innovations and venture capital funds. Yet,

this case study found only a few examples of a demonstrated economic return on investment in the form of data-driven smart farming innovations or new revenue streams for farmers based on market place willingness to pay for digital-based farm input and production records for crops (e.g. Tatge 2016; Decisive Farming 2019; Hart 2018; Booker 2018a), or traceability and social assurance systems supporting environmentally sustainable livestock production (e.g. TrustBIXS n.d). Furthermore, software solutions for improving the decision-making processes for farmers and the big data prospect of smart farming tend: to neglect farmer's tacit knowledge of their land (Lindblom et al. 2017; Lundström and Lindblom 2018), favour large commercial operations (Bronson 2019; Fleming et al. 2018; Jakku et al. 2018) or high value crop kinds (Pivoto et al. 2018), and threaten the livelihoods of older farmers and those with smaller size farms (Regan 2019). Conversely, this research demonstrates that machinery-based applications of digital are leading the way of agtech innovation as suggested by Rogers (2018a), and moreover, smart farming using autonomous agriculture equipment can support sustainable agriculture simply by making it easier for farmers to continue farming and reducing input costs.

Equipment is a major expense for prairie farmers (Statistics Canada Table 32-10-0437-01); reducing this capital and related maintenance and operation cost, including the expense of labour to drive a tractor, will save farmer's dollar and cents in the long run. Moreover, digital technology innovations in equipment such as GPS and auto-guidance navigation systems and automatic sectional control are widely accepted because these technologies offer substantial farm-level benefits, mainly by reducing farm input costs and making the difficult working conditions for the equipment operator safer and easier (Cavallo et al. 2014, 2015; Bashiri and Mann 2015; Adams 2013; Mulla and Khosla 2015; Ashworth et al. 2018; Smith 2013; Mulla 2013; Schieffer and Dillon 2014; Schmaltz 2017; Bennett et al. 2016).

In terms of autonomous equipment, the field robot, DOT™, will eliminate the labour cost and the cognitive and physical demand of operating a tractor for long hours over a compressed time frame available to complete crop operations on the prairies (Bueckert and Clarke 2013). With the DOT™, fuel costs will be reduced. DOT™'s inventor estimates a 20% reduction in fuel would be realized by transiting from the traditional large-size equipment and pull-type system, to smaller-sized equipment based on a propulsion system weighing 70% less than a comparable tractor. If this is true, based on Statistics Canada 2017 reporting of machinery fuel operating costs of CA\$ 1,475,779,00 (Statistics Canada Table 32100049) and a rough estimate of 75% of farmers as



potential adopters of autonomous vehicles within five years (i.e. the Glacier Farm Media post-revealing of DOT™ survey - Lyseng 2017b; Glacier Media, 2017), when aggregated over the potential 92,321 farm operators and 20% fuel cost savings (Beaujot 2017), an annual \$221.4 M savings could be realized by prairie farmers using DOT™ and Dot-Ready™ equipment. Cost savings on other input costs are speculative at this time as neither Pattison Liquid Systems (CONNECT PLU DOT-Ready™ sprayer) or New Leader™ have announced anticipated savings on inputs from precision application of pesticides, or use of an optimized line of travel based on DOT™'s field path plan.

In terms of user readiness for autonomous equipment, the transition to field robot-based system would happen in less than five years (Lyseng 2017b; Glacier Media 2017). From an educational perspective, the displacement of tractor operators must however be balanced with the development of new skills for 'DOT™ users' that integrates tacit knowledge of a field with satellite and drone based field imagery, topography and soil mapping, waterways etc., in order to map out the most efficient, safe and biologically friendly (i.e. soil health smart) path plan for travel. It is likely this transition will take time, which is not surprising as the transition to widespread adoption of conservation agriculture technologies occurred over several decades. Based on the work done by Micheels and Nolan (2016), the building of social capital to integrate robots into prairie farm operations and create absorptive capacity will benefit from peer learning and social networks.

Based on its present size of DOT™ is a particularly good fit for a sole proprietorship or a family corporation and grain and oilseed farm operations of medium size (e.g. 1,500 to 2,500 ha) where access to seasonal off-farm labour is a particularly challenging problem (CHARC 2019). Typically, these farms do not offer full time, year-round employment. Moreover, these types of ownership arrangements represent a major proportions of farm operations (62% or 55,634 farms) on the prairies (Statistics Canada 2016, Table32-10-0043-01). In comparison, this research concludes that DOT™ is *less suitable* for very large farm operations (10,000 ha or more) and non-family corporations representing only 1.8% of ownership arrangements (Ibid). The non-family corporation large farms generally have large fleets of large-sized equipment, offer year-round supply of full-time labour, and are the prime market for maximizing profit through economies of scale and agtech decision services (Bronson 2019), in addition to typically using one brand of equipment with service contracts. For these large-size farms, based on the size of DOT™ , it is

likely that purchase of *multiple* DOT™ units (Power Platforms™) would be a necessary expense in addition to the purchase of several transportation trailers required to ensure the timely completion of crop operations and transfer of equipment between fields connected by public roadways (CCMTA 2019, Interview participant data). Furthermore, the pragmatic aspect of having multiple DOT™ units working in one field will require collision avoidance strategy and the generation of multiple and complementary field path plans, enabling machine-to-machine (M2M) communication systems between DOT™ units to work together and perform equivalent crop operations as would fleets of large equipment directed by human to human communication. Presently, M2M is not available so DOT™ units cannot (yet) talk to each other, however, when this technology is available, the field robot may be a prospect for large farm operations with fields distributed across numerous locations.

### *6.1.2 Addressing limited rural cellular infrastructure*

Addressing the challenge of poor rural connectivity is a vital aspect of a smart farming IOS in Canada and beyond, where the farm area is vast and the cost of widespread building-up of connectivity capacity would extract a major toll on treasury resources (Pivoto et al. 2018; Coble et al. 2018; Bennett et al. 2016). The limited market of rural compared to urban customers and spectrums set by federal regulators is a disincentive for the few, major Canadian telecommunications providers to expand rural intranet (Bickis 2019). While Husain et al. argue the current lack of capacity is forming a gulf between “what is possible and what is feasible for smart farming” (2019, 4), and Tzounis et al. (2017) claim poor connectivity limits network capacity, connectivity services and the use of digital technologies incorporated into machinery, this research demonstrates otherwise.

Rather than holding back innovation and waiting for major rural communications infrastructure upgrades advocated by farm organizations and rural municipalities (FCM 2014; Duhatschek 2018), Dot Technology Corp.™ devised an entrepreneurial solution as a necessary response when DOT™ underwent testing by farmers in fields and the harsh reality of limited internet and cellular coverage became evident. The connectivity solution adds expense to the equipment investment, but it does allow DOT™ to operate within a 15-km boundary - an area of approximately 1,500 ha (3,700 acres or 23 quarter-sections of land - by leveraging the technology of RTK base stations and unused broadband frequencies. The local (micro) solution to the much larger rural ICT problem of lack of infrastructure issue will likely be a ‘jumping off’ point for other

entrepreneurial approaches for improving connectivity in rural and remote areas, without waiting for government policy-makers and telecommunications firms to resolve the rural ICT *access* issue in a timely and cost-effective manner.

### *6.1.3 Empowering farmers for equipment access*

The third conclusion from this research is that several of the access concerns related to innovations in agriculture equipment of problems can be addressed using new business models. This case demonstrates the licensing business model developed by Dot Technology Corp.<sup>TM</sup> is an alternative strategy enabling interoperability between proprietary operating systems, intellectual property protection and ownership and rights to agricultural data. Presently, the protection of operating systems used by the OEMs agriculture equipment manufacturers is based on IT sector technology use agreements and copyright-based form of protecting innovation (Gordon-Bryne 2014). Norbert Beaujot and Dot Technology Corp.<sup>TM</sup> acknowledged the interoperability constraint to smart farming. Commercialization of the DOT Power Platform<sup>TM</sup> is done using traditional patent-form of IP protection in combination with a (technology) licensing business model approach. With a minimal purchase of one DOT<sup>TM</sup> unit and use as a propulsion system, a farmer is empowered to have a brand-agnostic line-up of autonomous equipment licensed as Dot-Ready<sup>TM</sup>. This research demonstrates a first step towards a different way of addressing the interoperability problem by using of a universal hardware and software-based platform approach for development of field robots. The Dot Technology Corp.<sup>TM</sup> licensing approach is evidence of an SME-forged pathway to the democratization of Agriculture 4.0 innovations as proposed by Yahya (2018). The business model democratizes the incorporation of autonomous functionality into agriculture equipment and creates opportunities for existing firms, or new entrants, in agricultural equipment manufacturing to rapidly incorporate robotics into their products while foregoing in-house R&D costs to develop their own system (Pattison 2018a; New Leader 2019). Although, it remains to be seen if licensees will continue with the Norbert Beaujot's philosophy of the industry moving forward to more open systems, which is a key aspect of Yahya's principle principle for democratization of Agriculture 4.0 innovations.

Presently, with the major OEMs, licensing approaches such as Total Maintenance and Repair Agreements (TM & R) restrict a farmer's right to make basic repairs to the piece of equipment they purchased, especially if the technology-replacement-cycle is out of sync with the operator's equipment-use-cycle (Gordon-Bryne 2014). It is often the case that IP protecton of

source code and digital locks built into the software operating systems for smart equipment prohibit a farmer from accessing the computer diagnostics and identifying an error code when a machine fails to operate at full capacity (Lyseng 2018 a,b; Right to Repair 2018). Conversely, this research demonstrates that Equipment Use Licensing Agreements (EULA) can be written to accommodate access, diagnostics and allow the farmer to make basic repairs. For example, if DOT™ breaks down, through provisions in the licensing agreement, the error code can be identified by equipment diagnostics provided through a virtual service provided by Dot Technology Corp.™. A purchaser of a DOT™ unit is required to take training sessions, providing the owner with the skills to make quick, on-site repairs through the replacement of the faulty sensor (plug-n-play) if the error code is related to a basic sensor malfunction. It must be noted however, that management of Dot Technology Corp.™ made it clear that the ‘plug and play’ ability to repair (replace) a faulty sensor is limited to basic repairs, commenting that it is unlikely that the average farmer would want to do extensive sensor-based repairs and fix the sensor itself. As an added benefit, by providing an alternative to the need for a farmer to hack a system, diagnose the error code and make a repair using pirated software, the ‘access risk’ and cybersecurity threat identified by (Boghossian et al. 2018) is reduced.

Based on the evidence in this research, the smart farming challenge of ownership of machine-type agricultural data identified by Dowell (2015a,b), Dowell and Ferrel (2015), Ferris (2017) and Janzen (2018b), may be handled using terms of access and ownership of machine data defined in the equipment use agreement, and reviewed with the owner at the time of purchase. The management of Dot Technology Corp. explicitly indicated they are not interested in the data related to field inputs, asserting the farmer owned the data collected by the sensors on DOT™, and what they did with that data, is up to the farmer. There is however, one exception. Due to insurance liability reasons for autonomous vehicles, terms for the capture and ownership of data relevant to information such as the location of the DOT™ unit, her travel path and speed, must be accessible to Dot Technology Corp. for the purpose of monitoring the safety of autonomous equipment and incident investigation and insurance liability responsibilities linked to the manufacturer. These results were not unexpected considering there is neither policy on use of autonomous vehicles, nor provision for any type of agricultural data in Canadian or provincial privacy legislation (CCMTA 2018; Garvey 2018b). Dot Technology Corp. devised its own safeguards that address the liability risk for autonomous vehicles noted by Yeomans (2014) and Janzen (2019b).

#### *6.1.4 The need for environmentally and socially sustainable farming systems*

The fourth and final, conclusion to the first research question is that smart farming as a solution to broader societal problems connected with agriculture, is presently, speculative in two aspects. First, there is scant evidence in the literature or elsewhere, that argues the use of smart farming (e.g. a field robot) is one solution for maintaining social stability in farming by improving mental health and wellness or reducing the incidence of farm-related injuries and deaths in the farming community. Yet, based on the evidence in this research, health and safety issues of farmers must be a consideration for maintaining social stability in farming.

When off-farm labour is not supplied by the market, labour shortages are impacting the quality of life of farmers in Canada, and as indicated above in Table 5.1 of the Analysis section, the problem is acute on prairie farms and is costing the industry in terms of lost revenue and is limiting farm expansion plans (CAHRC 2019). As reported by Jones-Bitton to the Canadian Senate (Canada 2018d; University of Guelph 2018 ,b), the high rate of mental stress amongst farmers and their families is also having a negative impact on sector growth and innovation. Farm stress stemming from labour shortages is arguably a component of social stability for sustainable farming, must therefore be resolved. Furthermore, many prairie farmers are close to, or beyond, the standard retirement age in Canada (CAHRC 2019). Accidents and deaths among the senior farmer population is recognized as a serious problem (Canadian Occupational Safet, 2018) and autonomous equipment is one step in reducing the physically demanding and long working hours, minimizing the risk of accidents involving senior farmers and farm equipment, and improving the mental health and well-being of farmers and social sustainability in prairie, broadacre farming.

Second, the use of smart farming technologies as a solution for socially responsible use of the land and water resource base remains (highly) speculative at the time of writing up this research. The environmental benefits are beyond the scope of an SME such as Dot Technology Corp. to prove in statistically controlled and long-term field trials. This would include, for example, research studies and evidence of reducing fuel usage and emission with smaller and propulsion-based equipment, lessening soil compaction by using lighter weight farm implements, or gaining efficiencies through application of crop inputs based on an optimized field path plan.

Unfortunately, there is a noted absence of prioritization for this work by Canadian institutions including government and other public, or not-for-profit research organizations. These institutions and organizations are well equipped with physical and human capital resources to

perform independent evaluations, critically assess and/or demonstrate the public good benefits and costs of smart farming technologies. Furthermore, there are no indications that the government has identified a problem for which smart farming is a solution as was the situation with deteriorating soil health and conservation agriculture (Senate of Canada 1985; Lindwall and Sonntag, 2010). Moreover, there is no evidence of leadership or government-facilitated coordination by farmer groups to demonstrate smart farming or host accessible and affordable information sessions (e.g. town hall meetings) that could educate farmers and provide a forum where they share peer experiences with the new technologies. This is a very serious problem for smart farming in Canada, and contrasts with the Australia initiative of a national (smart farming demonstration farm (Lamb, 2018), or the IoFF2020 in the EU. If past behaviours of transformation of farming practices hold true today, until the input cost savings and environmental benefits of smart farming are demonstrated, it is unlikely that most farmers will adopt smart farming practices as with zero tillage and conservation agriculture. Furthermore, until evidence of the greater social and environmental benefit of smart farming is provided to the public, and the cost of inaction explained, there is little justification for allocation of treasury resources for policy measures incentivizing a change towards smart farming behaviours. A field robot such as DOT™, therefore has *anticipated, but not demonstrated potential* to address social, economic, and ecosystem (environmental) problems that go beyond the farm gate.

## **6.2 Smart farming and government policy choices ‘to do’ or ‘not to do’**

Policy-making may be viewed from a problem perspective. In this context, Laver suggests that policy is necessary because of the “existence of social conflict, the need for social cooperation, and the necessity of reconciling these two contradicting pressures experienced by citizens as individuals or groups” (1986, 10). Scarcity, real or imagined, and incompatibility, or divergent needs and wants, create social conflict. Social cooperation impacts productivity both are essential for an organized, well-functioning society. Yet, cooperation requires coordination which includes setting standards generally accepted as beneficial by citizens, versus a ‘free-for-all’ or uncoordinated society where “groups of individuals are worse off” (Ibid, 24).

In this research, public policy is differentiated from policy. *Public policy*, according to Dye, may simply be defined as “anything a government chooses to do or not do” (1987, 3). There are three pillars to Dye’s definition: (i) public policy involves a conscious choice with consequences and rewards, (ii) government is the primary agent responsible for public policy-

making and has the authoritative power to compel or incentivize citizens to change their behaviour, and (iii) policy-makers may choose to identify a problem, or an opportunity and ‘do something’ about it, ‘do nothing’, or maintain ‘status quo’. In comparison, *policy* may be conceptualized as “the most important choices made either in organized life or in private life, applicable to government policy, business policy or private life” (Laswell 1951, 5).

Canadian public policy is having a positive, but at the time of conducting the research for this thesis, there is little evidence that policy is having a minor impact explicitly on smart farming innovation. On the other hand, the research about DOT™ revealed a series of emerging problems that warrants the policy attention of government and non-governmental organizations. The market approach to smart farming innovation is creating conflict in the farming community (Right to Repair 2018; Raine 2018; Lyseng 2018 a,b,c; Higgins et al. 2017; Wiens 2015; Sydell 2015; Wiens and Chamberlain 2018; FCC 2018). Lawyers, rural sociologists, and industry leaders are also expressing concerns (Janzen 2017,2019a; Dowell 2015 a,b; Ferrel 2016; Ferris 2017; Trail 2018; Wiseman et al. 2019, Stočes et al. 2018; Carolan 2017a,b; Bronson 2019; Fleming et al. 2018). In Canada, the survey data gathered by FCC is a harbinger that if emerging tensions are not addressed, the unanticipated consequences of the present (industry) policy approaches to capturing value from the digital technology-based innovations will stall widespread use of the new technologies.

Coordination and cooperation will be key to sustaining a culture of innovation based on the digitization of agriculture and ultimately in order to achieve a ‘shifting the production function’ (Schumpeter 1939) that is inclusive of equipment manufacturers, the farming community, and society in general. However, policy intervention in Canada will be a challenge. The *Constitution Act*, 1867, section 95, created a unique challenge for implementation of public policy in Canada. Under this statute, agriculture became one of the few areas of governance with concurrent jurisdictions (Hedley 2017) meaning that federal and provincial governments have “related (though not identical) jurisdictions” (Atkinson et al. 2013, 5). Transportation policy, which impacts autonomous vehicles is shared authority, whereas the area of manufacturing is governed by federal policies and other international standards such as fuel emissions, or ISO-type hardware and software systems. Recently, a federal innovation platform enters the policy mix to create a ‘one-stop-shop’ for innovators and innovation programs (Canada 2019e). However, this research found distinct provincial and federal program approaches at play in the DOT™ IOS, neither of

which are considered agriculture policy (i.e. Canada youth skills development program and Saskatchewan technology innovation grants).

Based on the evidence presented in this case study research, I offer three conclusions to answer the second research question; *how is a smart farming innovation such as DOT™, enabled or limited by public policy, or advancing in the absence of state or industry-made governance models?*

1. Federal government innovation policy supporting industrial R&D by SMEs, enabled the conditions for a synthesis of essential skills and talents needed to develop, manufacture, and commercialize DOT™ and DOT-Ready™ technologies in less than less than three years-time. Beyond the financial assistance through the youth employment program, SeedMaster™ provided the R&D capacity and financed DOT™ from creation to commercialization.
2. There is limited update of industry-made governance models that prescribe principles for data sharing, ownership, and third-party use of agricultural data.
3. Three policy gaps are identified. The first is related to agricultural data, and the second concerns insurance schemes for use of autonomous vehicles. The third concerns the lack of unbiased and timely information on the scale of adoption of smart farming technologies or user concerns, and coordinating mechanisms to support the demonstration and evaluation of the new technologies.

### *6.2.1 Advancing innovation with public policy*

The first evidence of public policy support for DOT™ was the federal policy supporting the advanced manufacturing sector. The youth employment program (YEP) targets skill development and training of high-quality personnel. YEP, administered by the National Research Council, Industrial Research Assistance Program (NRC-IRAP, 2018) enabled innovation in equipment manufacturing by an SME.

This research concludes that co-creation (synthesis) of new knowledge is an essential component to the rapid development of DOT™ and furthermore, it helped create legitimacy of the innovation. YEP brought together locally trained university students who had computer programming skills and talents and a passion for robotics but had minimal knowledge of agriculture, with an equipment innovation pioneer who had tacit and artisanal knowledge of dryland agriculture and broadacre farming, Norbert Beaujot, and an agriculture equipment manufacturer, SeedMaster. Both the individual and the SME are recognized and acknowledged by the local and international community as industry leaders in agriculture equipment designed for



domestic use and global export. Several of the Dot Technology Corp. and SeedMaster management felt the federal program brought good value for them and the graduates, and was “a feather in the IRAP cap” (Interview participant) and commented,

*What we have seen is the Silicon Valley [pool of talent], the programmer nerds that are coming into an Ag sphere. We're seeing it even in our own industry. Like these young guys from Saskatchewan that are City kids that like robotics, don't have a lot of farm background at all aside from growing up in Yorkton. But when they are given a problem, they are interested. We teach them a lot...they will become farm experts very very quickly (Interview participant).*

The trained students became employees of the Dot Technology Corp. and are active participants in the search process for new ideas/uses of the technology as production scales up (AIMday 2018). An example of this is the Academic Industry Meeting (AIM) forum sponsored by NSERC, Western Economic Diversification and Innovation Saskatchewan. Specific industry challenges are ‘tackled’ at AIM day where academics discuss with industry leaders, options for co-creating pathways and finding solutions for industry problems (Ibid). The YEP students from Dot Technology Corp.<sup>TM</sup> led the session on autonomous farming (Relf-Eckstein, 2018).

At the provincial level, two policies will *potentially* enable innovation in smart farming. Both are new programs targeting R&D in the manufacturing sector. The Saskatchewan patent box program was launched in March, 2016 (Saskatchewan, 2017), which positioned Saskatchewan with a major policy-leadership position for improving Canada’s innovation competitiveness (Gowling WLG, 2016). Fulfilling the requirements of the Patent Box program can occur over a ten to a fifteen-year time frame, therefore, the impact on policy that enables smart farming innovation remains uncertain at this time. Next, the Saskatchewan Advantage Innovation Fund (SAIF) was launched in March 2018 through Innovation Saskatchewan (Saskatchewan 2018a). The grant provided a financial bridge that strengthened the social network of SeedMaster, Dot Technology Corp. and the YEP students with their computer science professor and research team at the University of Regina. Both policies came into effect *after* DOT<sup>TM</sup> was developed, tested, and recognized as an award-winning innovation, but nonetheless, they have still been useful. Beaujot publicly commented on the policy,

*It is great to have organizations like Innovation Saskatchewan that keep innovation rooted in the province... [T]he government's continued support for entrepreneurs and innovation is critical in helping companies like DOT Technology succeed locally (Norbert Beaujot, 2018 in Innovation Saskatchewan News Release, June 27, 2018).*

A second public policy impacting the DOT™ IOS are the Canadian guidelines for autonomous vehicles. The policy encompasses the following areas: data privacy and security, including personally identifiable information, cyber security, enabling infrastructure, socio-economic implications, economic development, and environmental impact (CCMTA, 2018, 15). Jurisdictional authority is shared across federal agencies and in January 2018, the Canadian Senate Standing Committee on Transport and Communications reported government departments “may be working at cross purposes” and advised creation of a joint policy unit to coordinate federal efforts and implement a nation-wide strategy (Senate of Canada 2018, 11). The report included recommendations that Canadian government agencies should ‘work with’ provincial and territorial governments through the CCMTA to design a ‘model provincial policy’, and put a priority on developing vehicle safety guidelines for the design of autonomous vehicles. The report did not mention autonomous farm vehicles.

Rural sociologist, Bronson (2018), claims Canadian government programs such as those mentioned above are driven by ‘productivist values’ which tacitly promote smart farming innovations that target more production and agricultural product output by large-scale capital-intensive farms. Government policy is benefitting the existing and powerful players in the industry and those who can pay for the technology, at the expense of small to medium sized, ‘labour-intensive’ farms. Based on the evidence in this case, Bronson’s claim (conjecture) is subject to challenge when two aspects are considered – a Saskatchewan-based SMEs in agriculture equipment manufacturing and the context of changes in prairie farming.

First, Neither Dot Technology Corp., nor the sister company, SeedMaster are ‘powerful players’ in equipment manufacturing. Both are small-in-size and being located on the prairies, the SMEs are far away from political influence on federal policy-makers. Furthermore, they did not receive seed money from government programs to fund R&D, rather, SeedMaster provided CA\$ 1.6 M in funds and self-financed the R&D, production and commercialization of a DOT™ unit which is well suited for broadacre farms of any type or size where labour is a constraint.. Moreover, this research documents that Dot Technology Corp.™ sought out Transport Canada to proactively develop policy for autonomous agricultural vehicles (Raine 2018). The effectiveness of their so-called ‘powerful player’ position and influence on policy is evident - Canada still lacks policy in the area of autonomous agriculture vehicles. In response to ineffectively capturing the attention of federal policy-makers, Dot Technology Corp. refocused its efforts to work with Saskatchewan

regulators to develop a made-in-Saskatchewan pilot policy for autonomous agriculture vehicles (CCMTA 2018, 2019, p.comm). However, until progress is made on the Saskatchewan pilot project and insurance scheme and there is a starting point for policy discussion about autonomous agriculture vehicles, there remains a high level of regulatory uncertainty for new entrants to the market. Moreover, guidelines for liability and public safety remain ‘out-of-scope’ for operation of autonomous vehicles in Canada (Ibid) and cellular and wifi connectivity problems remain a major challenge in rural areas.

Beaujot commented on the federal policies and how he experienced a ‘disconnect’ between what the government bureaucrats understood about smart farming equipment innovation, and what SMEs need to drive ‘agriculture’ innovation forward,

*There are decent incentives I suppose from a technology investment standpoint. But really, what I find is holding us back is the level of understanding. So, the policy I think is solid, but the people that are, I guess, enacting that policy are limited in their ability to do so. I wouldn't identify the government as a barrier to what we've achieved to this point - though we may be wishing about having government money. If there was a more organized way for us to access talent in a subsidized manner, that would have propelled us further than we are today. But it wasn't a massive pinch point by any means (Interview participant, Norbert Beaujot, 2017).*

Second, although it is not documented in the 2016 Agriculture Census, many prairie farms are large (i.e. 5,000 to 10,000 acres). These farms are both conventionally (using agrochemicals) and organically farmed and sell their production to meet market demand. Both types must be considered productivist, yet presently, smart farming policy is not benefitting these larger operations who ‘can afford’ the technology. For example, Saskatchewan organic (agroecological) farming operations that are family farm operations export commodities similar to conventionally operated farms (i.e. not organic, commodity based); both struggle to find labour and gain efficiencies with economies of scale with larger farms, bigger equipment (Bickis 2018). Moreover, some of the largest sized farms such as Calgary’s Andjelic Land Inc., have 210,000 acres of lease holdings across Saskatchewan operating under sustainable land management (<https://andjelic.ca/about#lease> ). In 2018, Andjelic Land operated 40,000 acres of farm land and produce organically certified commodities (Bickis 2018). Organic farms in particular must therefore also be considered both productivist intensive and would benefit greatly from autonomous agriculture equipment such as robotic seeding and weeding as a form of smart farming (Sharp 2018). Yet, the crux of policy is that conventional and organic (productivist) farms in rural

areas of the western Canadian prairies are exposed to several of the access challenges identified in Section 2.2 above; both could benefit from smart farming policy action.

In conclusion, public policy has enabled the creation of smart farming innovation, however, it falls short of advancing smart farming innovation in broadacre agriculture on the prairies. Cellular and wifi connectivity problems remain a major challenge in rural areas and the \$250 M pan-prairie Smart Agri-Food Supercluster proposal (Cheater and Blair, 2018) did not receive government support (European Cluster Collaboration Platform n.d.)

Consequently, this study demonstrates that smart farming is advancing rapidly in the absence of policy and is doing so in two aspects; agricultural data, and a strategy for evidence of adoption used to inform decision-making by public policy-makers. Other aspects of the story of smart farming with respect to intellectual property protection such as Right to Repair and protection of source code for equipment is only just beginning in Canada.

### *6.2.2 Advancing innovation using industry governance models*

The most impactful policy aspect shaping a smart farming IOS for Canada is lack of clarity on public policies regarding agricultural data privacy, ownership and third- party access, including agricultural equipment (machine) data. This study provides evidence that market mechanisms for governance of data are not working efficiently (Wall, 2018).

Industry governance mechanisms such as the Ag Data Transparency (ADT) principles developed in the United States (Janzen 2015, 2017) are, at best, weakly adopted by the North American agriculture industry product and service providers (Ag Data Transparent 2018). In other regions, industry-developed codes are voluntary, including the New Zealand Data Code and the EU Ag Data Code - and like the ADT principles, the codes are non-binding (Janzen 2018a). Furthermore, the few Canadian agribusinesses which were signatories to the ADT principles in 2018, did not include SMEs or large-size equipment manufacturers (Ag Data Transparent 2018)<sup>9</sup>, and while SMEs such as Dot Technology Corp.<sup>TM</sup> are not interested in the collection of agricultural data, they acknowledged that is not the case for all equipment manufacturers.

The impact of market governance for agricultural data is just beginning to surface in Canada, manifesting itself as an erosion of trust by farmers in what is being done with their farm level data (Wall, 2018). Contractual agreements such as that used by TrustBIXS may be an

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<sup>9</sup> John Deere Operations Centre is included on the current (spring 2020) list of ADT Certified Companies.

exception to this trend and terms of the data use agreement are posted for public access and align with provincial (Alberta) and federal information privacy regulations.

Reflecting on Micheels and Nolan (2016) research, social capital and absorptive capacity are key aspects of farmers adopting innovation in Canada. Following this, if trust is broken, the unravelling of social ties between agtech industry providers and farmer customers will weaken absorptive capacity for smart farming. In a situation such as this, government intervention is legitimate, particularly as Turland (2018) has found that farmers will be willing to provide data to academic institutions, although, they would like to see some form of compensation.

Scholars writing in the area of smart farming innovation suggest public organizations take a leadership role by creating standards to ensure responsibility for data integrations (Eastwood et al. 2017). Business world views suggest agricultural data is being used like data gathered by Facebook and Google and government could act as ‘information fiduciaries’ A government oversight body could be created to act in the best interest of farmer’s natural rights to personal data and contractual rights with agtech product or service providers, while ensuring that monitoring and dispute arbitration instruments ‘won’t crush the industry’ (Bloomberg 2018). This however, will be a policy challenge in Canada in two aspects. First, there are already both provincial and federal policy frameworks, the federal *PIPEDA* and provincial statutes in Alberta, British Columbia and Quebec (Kardash and Kosseim 2018). Agricultural data is not part of these policies. Furthermore, each Canadian jurisdiction has an Information and Privacy Commissioner to oversee data protection laws in the respective jurisdiction. Until agricultural data is deemed worth protecting, it is unlikely the Commissioner would have authority to act in the interest of farmers.

### *6.2.3 Innovation is advancing sans public policy*

This research identified two additional areas where lack of policy framework will negatively impact smart farming innovation in Canada. There is a lack of unbiased data that provides timely information and evidence of adoption behaviours including the scale of digital technology adoption and data sets representative of a diversity of farm types and sizes as well as capturing data from different farmer demographic groups. In addition, a critical area concerns (lack of) government strategy for communication and information exchange on digital technology-based innovations as an unbiased source of research evaluation and extension (knowledge transfer) on smart farming innovations.

The first area where smart farming innovation is advancing (rapidly) in the absence of policy, was identified during the data-gathering process for this study, namely data used to measure the degree of digitization of agriculture. Presently private and other organizations are the main sources of information about digital technology behaviours and concerns of users (Steele, 2017; Slade and Turland, 2018; McLean, 2018; FCC, 2018). This signals that the industry policy will likely be preferentially shaping smart farming innovation in the absence of government policy on statistical evidence of farmer smart farming behaviours.

Currently, the national (mandatory) agriculture census is implemented every five years in Canada. This timeline of information to inform policy-making is sluggish in comparison to the technologies being introduced to the markets. In-between these five-year cycles, surveys are being done by professional for-profit and non-government organizations. This information is generally not publicly available and as Bronson (2019) alludes to, industry has its own vision of designing products and services for their target customer base, which is generally larger commercial farm operations. Evidence of current smart farming technology adoption behaviours and underlying drivers was available only through private sector, consultant-executed line agency studies (i.e. Agriculture Canada), or non-governmental agency (e.g. FCC 2018) or farm media (e.g. Glacier Media) surveys. The issue is ‘what evidence’ is being used to advance smart farming innovation in Canada when industry survey data falls far short of representing a diversity of farm sizes and types, or operator ages ownership arrangements.

Consequently, there is a need to re-examine the role of government and statistics that could be used to inform Canadian farmer’s use of digital technologies. With this evidence, public policies could be designed to support the widespread use of technological changes in Agriculture 4.0, and sustain the widespread prairie farmer culture of farmer adoption and use of innovations.

### **6.3 Risks**

The purpose of the third research question was to draw on the evidence, and analysis of the Aftershock element in the IOS to answer a third research question, *what are the potential risks associated with this innovation opportunity space created by smart farming innovations?*

This research provides evidence to answer this question and discrete areas of risk that are identified for each of the four groups of actors and activities in the DOT IOS: SMEs and agricultural equipment manufacturing, government and policy-making, farm news media and smart farming knowledge extension, farmers and smart farming technology consumers. For the

purpose of this discussion and linking a broader, reflexive and inclusive innovation space, a fifth group is now added – the general public as part of the global environment of food consumers and tax payers. Risks are identified for each group and discussed below.

### *6.3.1 Regime capture of Dot Technology Corp.*

Beginning with the first group of actors as originators of the smart farming innovation of DOT, I conclude that an SME, as an entrepreneur, can build the social capital, or R&D capacity as proposed by Yahya (2018), which is required to create a new product and new form innovation as suggested by Flowers and colleagues (2017). However, the tractor-less form of (autonomous) smart farming innovation of DOT is at risk of scaling up challenges described by Maru (2018) and value capture (Flowers et al. 2017) in the form of ‘regime capture’ (Pigford et al. 2018) including corporate acquisition by global agribusinesses (Cosgrove 2018) with vested interests in the tractor-based system of large scale agricultural equipment.

The ‘user community’ of shortliners, including SMEs or larger-sized manufacturers of specialized equipment must engage in the technology licensing model offered by Dot Technology Corp.™ in order for DOT™ to gain enough market power to challenge the tradition of pull type systems for agricultural equipment and the broadacre agriculture trend of progressively larger farms with larger size and heavy weight tractor-based equipment line-ups.

Two years after the revealing of DOT™, only two shortline manufacturers, Pattison Liquid System, and New Leader, of potentially 535 Canadian equipment manufacturers, have captured the opportunity of having autonomous functionality as part of their products and foregoing the cost of in-house R&D (Canadian Industry Statistics, 2018).

At best, the DOT™ IOS is presently an *ecosystem niche* described by Pigford et al. (2018) and an agriculture innovation system populated by a group who shares a common objective that reflects a culture of shared knowledge and skills. The shortline agriculture equipment manufacturing community is shaping an ecosystem's niche with similar values - a vision of an autonomous agriculture equipment that challenges the major OEM strategy in particular Deere & Company, a major equipment provider for the North American and global tractor market whose smart farming strategy reflects “the T in IoT stands for tractor” (Brody 2018). But an ecosystem niche that challenges the tractor-based pull type system norm - “why do we need a tractor” (Beaujot 2017 in Rance 2017) - is not enough to transform agriculture because, first and foremost, a complete set of specialized equipment must be made Dot Ready™ before the full benefits of labour

savings, interoperability of equipment and reduced fuel input cost can be realized on any individual farm operation. An autonomous seeder with one type of opener/packer made by SeedMaster, one sprayer made by Pattison Liquid Systems, one fertilizer applicator made by New Leader, does not offer enough product diversity to impact the retailing of agriculture equipment. If uptake of Dot-Ready™ technology licensing business model by the shortliner user community is limited to the above three mentioned manufacturers, then two pathways are foreseeable.

The first risk to the DOT™ IOS is capture of an ecosystem niche by a larger ‘regime’. In this case study, regime capture could involve multi-national agribusiness and full-line OEMs. If Deere & Company (or other dominant manufacturers of tractors) determine that the market for autonomous, tractor-less equipment is large enough, they are well positioned to capture the value or acquire the innovation, just as Deere & Company did with Blue River Technologies (Deere and Company 2017). With Blue River, the technology, autonomous irrigation systems, while lacking revenue to justify the approximate purchase price of US\$ 300 M, had ‘market traction’ prior to its acquisition and demonstrable return on investment (ROI). Similarly, the acquisition of Granular by Dupont- (Corteva) at 100 times its revenue, signalled the agtech growth strategy of larger organizations such as Deere & Company and Corteva with both acquisitions viewed as atypical of the prototypical exit of VC software-based startups (Cosgrove 2018). The DOT Power Platform™ now has traction, however, demonstration of ROI and market traction is in its infancy and therefore, the new IOS is ripe for value capture by the OEMs.

If regime capture and corporate acquisition happens, the innovation space being shaped by DOT™ may take on a very different look and feel for smart farming. All the best intentions of the innovation pioneer with ‘no interest’ in machine data beyond liability purposes, locking out equipment repair due to a faulty sensor, or vision of open operating systems, may be forfeit. Once again, farmers would be left with little control over repairs, ownership of data gathered by their machines and frustrations with interoperability between brands of equipment.

Alternatively, a second scenario of regime capture would be a multi-national such as AGCO. In this case, the risk of lock-down access and constraining equipment interoperability between brands could be minimized given the OEM’s open systems (ADAPT) strategy for equipment (Internet of Food & Farm, 2018), their relationship with shortliners such as New Leader, and the diversity of brands of equipment in their portfolio (i.e. Massey Ferguson, Fendt, Challenger).



### *6.3.3 Media-based knowledge brokering of smart farming innovations*

This research identified that open knowledge transfer (i.e. anyone can access) about smart farming is dominated by industry actors, primarily farm news media (e.g. Glacier Media, Farms.com, Real Agriculture). In addition, agribusinesses target knowledge transfer services and product support to individual customers. These two groups are rapidly becoming the sources of information about smart farming and filling the gap of research and extension activities which was traditionally filled by government researchers and extension specialists. This is not unlike what Rhodes (1997, 2007) described as ‘hollowing out’ of the role of the state, and there are risks with this approach to the sharing of information about innovation.

As reported by Carew (2001), the Canadian government played a vital role in R&D and the economic and social development of agriculture in Canada. Institutions, such as the federal research farms (experimental stations), fostered “greater competitiveness through the development and transfer of innovative technologies” (82). Provincial government employees were hired for extension work and to disseminate knowledge of the new technologies. Over time, the level of extension support is eroding and presently, in Saskatchewan, for example, there are ten regional offices that serve as knowledge centres and of the 50 extension specialists, two serve as resources for precision farming (Saskatchewan n.d). Academia or commodity check-off-funded organizations have filled the gaps for R&D and extension services, but this research found the check-off organizations are silent in the area of precision agriculture technologies, or smart farming. This is in stark contrast to the American Farm Bureau Federation (AFBF), the national farmer organization, who is active in advocating for issues such as farmer access to technologies (AFBF, 2014).

In response to the gap of knowledge transfer of new digital (smart farming) technologies, agribusinesses and lending institutions are playing a role in information transfer by offering customized farm management agronomic (production) and marketing support services to their customers, while dealerships and manufacturers of equipment provide brand-specific technical support. However, the dominant actor is without question, the farm media who are well on their way to becoming de-facto ‘innovation brokers’ (Klerkx et al. 2009) representing a network of ICT actors whom neither create, nor implement, innovations; instead, they enable others to innovate (Ibid), for example, farmers or local SMEs. In a study of farm events (field days, tours, trade shows) in the United States, Heiniger et al. found that farm show venues are a long standing

tradition where farmers “hope to find answers to their problems regarding use of technologies”, and event attendees are introduced to new technologies and techniques and learn it may be applied to their farm operations (2002, 310). Knowledge transfer in forums such as farmer panels, or side-by-side software demonstrations are ranked with high importance by participants (Ibid). Through the farm shows, conference forums, innovation competitions, and news media coverage, this network of industry actors is providing (brokering) information and knowledge flow between SME entrepreneurs, OEMs, farmers and indirectly, the public. Consequently, the farm media, as innovation brokers, are well on their way to being important actors defining the smart farming innovation IOS in Canada unless the traditional role of unbiased information dissemination, and agriculture research and extension (R&E) is resumed by the government. Fortunately, existing farm media firms are held to an ethical standard in their reporting of events.

#### *6.3.4 Access and trust barriers for farmers*

The digitization of agriculture inherently generates multiple forms of agricultural data and access to the IoT enables its long-distance transmission. Rural ICT systems infrastructure and connectivity capacity, combined with unreliable access to the Industrial Internet, upload and download speeds (Mark et al. 2016) for transmission of machine-data are unquestionably a serious risk for a smart farming future in western Canada (Lyseng 2017c) and Australia (Lamb 2018), two broadacre agriculture systems with strengths in primary production and global exports. Solving the infrastructure problem for the Canadian smart farming IOS requires an expansion of broadband coverage, but the scale of the system for the rural prairie area is beyond the scope of the agrifood sector or the government to resolve alone. With a combined population of nearly 6.79 million people in 2017 and land area of 1.96 M square kilometers, there are about 3,400 people per km<sup>2</sup> in the prairies and coverage at 4G or 5G is limited to the majority of the population which is concentrated in urban centres service (Lyseng 2017c). This is the classic example of the ‘urban-rural digital divide’ with slower-speed broadband and fewer providers identified by Prieger (2013). Interim solutions have been developed including construction of towers, but this is viewed as a band-aid solution to a bigger problem in rural areas. Bell-MTS (Manitoba), SaskTel (Saskatchewan), and Telus (Alberta), the major cellular carriers the three prairie provinces, were approached by farm media to respond to farmer questions and propositions to donate land for construction of towers, boosters or repeaters for improved service (Lyseng 2017c). The challenge of improved connectivity, however, has not yet been resolved in Canada or Australia (Ibid; Lamb,

2018). New ways of thinking about connectivity are required and this study has demonstrated that finding alternative solutions for farm level connectivity for autonomous agriculture equipment is possible, but that much more work is needed in this area.

Cybersecurity system attacks by malicious actors create an agriculture system-level vulnerability for operation of ‘connected’ agricultural equipment and while not identified in the evidence of the DOT™ case study itself, the cyber security threats to precision farming identified in the United States DNS 2018 report are applicable to the Canadian situation, and, in particular, to this case, machine operation and control.

Cyber security risks are very real in a ‘connected’ world. Ramachandra et al. (2017) surveyed the literature on Cloud computing security with results supporting a 2015 study by Forbes, concluding Cloud computing is a ‘severe risk to all of the four groups of actors they identified who are using Cloud computing, yet there is very limited research on training and the ‘people’ impact on security; threats exist at every layer of Cloud-based platforms, and the security issues need to be resolved urgently. The farmer is an example of a Cloud consumer, and they are part of a broader system of Cloud deployment models (private single-tenant cloud, public, hybrid public and private cloud) and cloud providers, auditors, brokers and carriers. In a 2018 industry survey involving 1,400 IT decision makers around the world, data theft and compromise were named as the top concerns with security controls, and lack of skills identified in the previous year (McAfee 2018). Twenty-eight percent of respondents indicated they experienced incomplete control over who can access sensitive data and accounts were being created outside of IT visibility; 27% reported theft of cloud-stored data by malicious actor and additionally, the severity of attacks is evolving rapidly.

The issue of cyber security recently became an item on the agenda of government. The Canadian Centre for Cyber Security was created in 2018 (the announcement was June, 12, 2018) and a series of documents are available to mitigate threats, including those on cyber security controls for SMEs (Canada 2019d). However, there has not been reference made to cyber security for agricultural data and systems controls of agricultural equipment.

### *6.3.5 Unintended consequences*

With each revolution in agricultural there are major and disruptive shifts in farming and the agriculture and agri-food systems and each shift impacts society. The technological changes in agriculture have increased global food availability substantially. In 1965, 33% of the world

population accessed a sufficient daily supply of food (2500 kcal/cap/d) and by 2005 this had increased to 61% (Porkka et al. 2013). Nevertheless, the innovations also had unanticipated consequences (Ruttan 2002). Yet it is difficult to predict how smart farming will shift the production frontier, or how changes such as having field robots operating in farms situated along major transportation corridors or in rural, remote areas will be viewed by society. Fortunately, there is opportunity to build on lessons learned from other times of profound change in agriculture, and map an anticipatory planning approach for Canada based on a modified version of the EU-Responsible Research and Innovation strategy (Long and Blok, 2018; Bronson, 2018).

The Industrial Revolution brought the replacement of oxen and horses as farm power sources with mechanical engines, and this was but one, of many changes which profoundly affected societal dynamics, income growth, and the distribution and regulation of the labour force (Gibson 2012). The Green Revolution technologies gave the world higher yielding wheat, maize and rice varieties, and the invention of fertilizers; more food was available in developed and developing economies and there was a world-wide decrease in food prices (Borlaug 2000). But the benefits were much lower in marginal production areas and inter-regional disparity widened (Pingali, 2012). In Sub-Saharan Africa use of the technologies were constrained by the state of knowledge, and institutional and political failures (Evenson and Gollin 2003). There were environmental consequences as cropping patterns shifted (Singh 2000). The increased use of chemical inputs (e.g. fertilizer, pesticides) to feed the higher yield crops, combined with inefficient water use (i.e. irrigation) and limited supply, led to degradation of soil health, deterioration of water quality, and deforestation (Ibid). The Biotechnology Revolution opened the political and economic debates of the regulatory regime, agriculture policies, and intellectual property rights (Phillips and Khachatourians, 2001). Society initially had concerns about the consequences of DNA based innovations, cloning and the creation of transgenic plants (Cohen, 1977), which later manifested also as loss of trust in the technology and views of lack of (corporate) accountability of the innovations (De Beer, 2007). Despite the substantive body of evidence and stringent regulatory systems governing development and commercialization of the agricultural (food and feed) products, the safety of the technologies associated with innovations in biological systems is questioned (McNaughton 2003; Knudsen 2011). The long-term sustainability of agriculture is at risk when the biophysical, economic, environmental and information costs of seed production associated with the biotechnology innovations are considered (Rótolo et al. 2015). Others assert

the few higher-yielding recombinant DNA based crops which came to dominate world-wide agriculture, now threaten biodiversity and resilience of food production systems (Tsatsaskis et al. 2017).

At this time, this research found few indications of concerns about unintended consequences of smart farming such as regime capture of technology, inter-regional disparity (the digital divide), or how the Canadian society will perceive smart farming technological change. Bronson (2018, 2019) and Pigford et al. (2018) are noteworthy exceptions, however, the evidence in their research did not include participants external to the agriculture industry. In Ireland, however, there are farm-level concerns about the re-shaping of the public image of farming and these views foresight some of the intended and unintended effects of other revolutions in agriculture. Smart farming will increase food production and support new job creation, however, there will be a re-shaping of the traditional image of an Irish farmer (Regan 2019). For example, by scanning the bottle, consumers will have nutritional information about the product, while also revealing other information including the story of milk - the farm, the cow, and the agtech-farmer. The images of robots milking cows and displacing the Irish farmer, for example, may not necessarily be a good thing for the Irish agriculture industry.

Potentially, with Agriculture 4.0, or the Digital Revolution, smart farming technologies could be responsive (i.e. pulled by) to farm-level problems, as well as consumer concerns. In Monitor Deloitte's review of agtech drivers transforming the agriculture industry, Laugerette and Stöckel, (2016) concluded new consumer preferences could drive disruptive technological change in agriculture. They found contemporary consumer preferences include an aspiration for personalized food products and production practices and on-demand services and products, expectations of reduction of agriculture's ecological footprint, demand for sustainability, increased health awareness in food consumption and supply chain traceability. Considering the push-back of the Biotechnology Revolution technological change in agriculture, and the early stages of the Digital Revolution, taking account of the consumer and social trust may pre-empt unintended consequences associated with the technological change.

## 7.POLICY IMPLICATIONS

This research presented bridged the gap in evidence-based scientific knowledge about machinery-based applications of digital technology, specifically *smart* equipment. The Innovation Opportunity Space framework proved useful to understand Agriculture 4.0 innovations, demonstrating that DOT™ is a New Form Innovation which creates “entirely new sources of value that sit alongside more traditional forms of innovation”, according to Flowers, Meyer and Kuusisto (2017, 214). The evidence presented in the case study shows that DOT™ has traditional commercial value for Dot Technology Corp and equipment manufacturers in Saskatchewan. The design and manufacturing of the high-tech agriculture equipment using a new business model developed by an SME creates new market opportunities for shortline equipment manufacturers DOT™. The new licensing business model opens the door for specialized equipment manufacturers to quickly provide (within six months) autonomous functionality into the product line-ups without investing in the R&D costs to develop a robotic platform in-house. However, DOT™ will challenge the tradition of equipment providers and powers held by the few and major OEM manufacturers of pull-type, tractor-based equipment systems.

As a New Form Innovation, DOT™ also has the potential to contribute to a socially responsible food system by creating and capturing the non-commercial value of innovation. Dot Technology Corp.™ demonstrates the concept of SMEs democratizing smart farming innovation by breaking down the proprietary software-based operating system barriers of intellectual property (IP) restrictions on the use and repair of agricultural equipment. DOT™ users will be empowered to make basic repairs. When faulty sensor error codes are detected remotely, the malfunctioning sensor can be unplugged and exchanged for a replacement sensor stored in the farmer’s toolbox.

Other non-commercial value in the DOT™ which necessitates recognition includes the social value of making agriculture interesting for a new generation of employees with talents in computer programmer. The challenge of creating a field robot can attract them to work in smart equipment manufacturing. Other non-traditional forms of value in this case is the reputational value for smart farming equipment made by Canadian shortline industry. There will be capacity building for smart equipment and development of made-in-Canada new routines and processes that build on technology-based business models for autonomous motor vehicles such as Tesla and

business to business B2B relationships. However, as the authors of the IOS emphasize, a ‘different mindset’ is essential for the actors to mobilize resources and capture the value of the IOS. The question is, will the Actors in the IOS have, and hold, this different mindset? This research suggests in the affirmative for the shortline equipment manufacturers.

The subsidiary argument introduced at the beginning of this dissertation was that smart farming innovation is a ‘new thing’ and public policy, in addition to industry-wide standards, will be vital to the second iteration of transformation of prairie landscapes. Considering all the institutional (policy) mechanisms that are available in Canada, one could conclude that government policy has enabled smart farming innovation. However, this view must be treated with caution.

Based on the analysis of evidence presented in this research, the DOT™ IOS is presently an Unstable IOS, noted by Flowers (2017) as a complex phenomenon, riddled with high levels of uncertainty. Capturing the IOS necessitates its understanding while identifying potential opportunities and the goals of the existing Actors or new Actors entering the IOS.

In terms of public policy, this research concludes that a fresh approach to a ‘smart farming’ policy future requires a ‘policy conversion’ and a change in the policy instrument mix to a “more tractable policy domain” (Howlett and Rayner, 2007). To start with, this will require Canadian policy-makers to (i) identify emerging problems for smart farming, (ii) gather information to inform policy design, (iii) consider and evaluate policy means used in other sectors (e.g. finance, health) and jurisdictions (e.g. ADT, GDPR, Data Code), and (iv) set goals in support of building trust and stabilizing the Unstable smart farming IOS. Incremental changes to the existing *PIPEDA* policy framework could explicitly reflect agricultural data, or alternatively, the Canadian government facilitates industry-wide governance standards and take an active role on the international Digital Council (Richter 2019, Rural21 2019).

Yet, the path forward to capture the DOT™ IOS presents a series of challenges when one considers the three narratives and the different governance institutional mechanisms and processes poised to shape smart farming innovation spaces. Walter and colleagues opine in the Proceedings of the National Academy of Sciences, that although smart farming is the key to developing sustainable agriculture production systems and networks across all actors within the agri-food sector, “there is no single policy approach” to achieve this outcome (2017, 6149). Rather, a

governance lens is appropriate, where governance is viewed as the “total effort of a system to govern itself; governability is the outcome of this process” (Kooiman 2000, 160).

The first, collective-benefit narrative, focuses on a collectivist political ontology, engaging a comprehensive value chain equity view of smart farming as a means for the ends of an environmentally sustainable agriculture system. This is a difficult narrative to map onto a governance lens and value creation and capture of smart farming in Canada, especially regarding mobilization of resources, partially due to the nature of the Canadian policy system in agriculture and blurred lines of governance and provincial/territorial authority. An example of this narrative is the European Union governance system and policy framework of CAP. The EU member nations, as a collective, can operate under the IoF2020 to develop, evaluate and demonstrate smart farming technologies through the lens of food production, distribution, consumer engagement. Tömmel (2016) draws on Kooiman’s concept of orders of governance and argues the CAP policy framework is an example of *second order governance* and political ‘steering’ in a non-hierarchical and a complex system multi-level governance system which establishes institutional settings that structure governance processes at a national level (EU member nations). These indirect ‘steering’ mechanisms shape a hierarchical and non-hierarchical of governance, adding they are ‘not soft’ in implementation or impact. While the EU common policy cannot directly intervene in the EU member nations following their own policy objectives, the umbrella framework for agriculture ‘can significantly constrain’ their maneuverability, furthermore, it can ‘compel them’ to follow the European policy path, including establishing market mechanisms (2016, 408). CAP and the IoF2020 platform is a striking example of using smart farming technologies to gain a competitive advantage in agriculture innovation systems and positions the EU member states as a potentially serious challenger for intensification of food production using a socially and environmentally responsible research and innovation approach.

This case found no evidence of second-order governance mechanisms in the Canadian system that structure coordination of smart farming R&D or research and extension. The approach to innovation in smart farming starkly contrasts the second-order governance approach used during the shift behaviour towards acceptance of innovations for conservation agriculture farming. Instead, with smart farming, innovation programs in Canada have a narrow focus on policies with a technological focus, in contrast to preparing for ‘governability’ and an outcome of a behavioural



shift and systems-level (collective) ‘value capture and hold’ of the smart farming opportunities for all Canadians.

The prospect narrative of smart farming (section 2.1.2 above) with its neoliberal political ontology, brings into play property views that are aptly exemplified in the ‘digital wild west’ view of smart farming. This is a classic market-based approach and self-governing, which, unfortunately, is presently falling short of governability outcomes of fair and equitable practices and fails to “provide an efficient or optimum level of production of goods and services desired in society” (Howlett, 2009, 79). The failure of market governance in smart farming is a new problem, more evident in the United States than Canada, and it is creating social conflict in the form of erosion of trust based on industry approaches for governance of agricultural data. In the prairie farming culture, the trust factor as a component of social capital and social networks, is core to farmer acceptance of new technologies. Failure to have industry-wide standards that address the lack of clarity about agricultural data ownership, access and third-party use of data will stall smart farming innovation, continue the erosion of trust and forestall the benefits of farmers and firms contributing data for public platforms for predictive big data analytics that could benefit all Canadian farmers.

A farmer’s loss in trust in the data aspects of smart farming would unquestionably compromise Canada from realizing the potential value of big data analytics in the public domain. In this aspect, Canadian policy-makers are overlooking new approaches to inform policy-making. Lessons could be learned from the governance taking shape in United States under the American *Ag Data Act* of 2018, also aligning with Kooiman’s description of *second-order governing* where “the maintenance and design and renewal of social-political institutions” are dealt with (Kooiman 2000, 158). As part of the US *Farm Bill*, the United States Department of Agriculture (USDA) will be empowered to aggregate and anonymize farm level data (Janzen 2018b). Big datasets will be provided to university researchers and used to benchmark and inform conservation agriculture practices for sustainable agriculture systems. In effect, this approach ‘sets the conditions’ for first-order governing (Kooiman 2000) and opportunity creation for value from public domain big data analytics. In comparison, Canadian socio-political institutions are laggards in demonstrating any level of ‘data’ leadership. If farmers lose trust in the present mode of governance of agricultural data, this will potentially influence desired sharing of data with the private industry or the state, especially if there is no compensation for use of their data as suggested by Turland (2018).

The third smart farming access narrative (section 2.1.3) and related access challenges (section 2.2) highlights government *and* market failure to resolve the emerging social conflict over availability and security of ICT systems. Farmer response of hacking operating systems using pirated software to circumvent digital lock restriction and gain access over use of their equipment, further adds to the need for government to reconcile contradicting pressures between farmers and equipment manufacturers. Public policy must be generated in advance of backdoor access to equipment operating systems. Failing to act to address cyber security threats may result in policy failure if the pirating of essential agricultural equipment by malicious actors elevates from a present threat-status identified by state security and defense agencies to a future reality status.

Finally, this research provides evidence that industry policy-makers, that is equipment manufacturers as a whole, can work with government help to stabilize (capture and hold) the Unstable IOS by “drawing on a range of resources to create and maintain systems and processes that engage actors external to the firm” (i.e. Dot Technology Corp.) and ‘bind them’ to internal R&D and new product development (Flowers et al. 2017, 220) of smart agricultural equipment and new ways of improved connectivity and cyber security. Industry policy-makers can do this, for example, by choosing new business models that address farm level concerns of equipment interoperability, incompatibility of data exchange systems, copyright protection of equipment operating systems, access barriers, and providing clarity on third party use and security of machine data. If, however, existing and dominant suppliers chose not to address these concerns, then considering the opportunities made possible with advances in digital technologies and ICT systems, the emergence of new entrants, including SMEs, will continue to challenge the dominant suppliers. Dot Technologies Corp. is an example of a first, a challenger for the pathway to autonomous farming and a vision of an agriculture equipment future based on a tractor-less propulsion system. The success of the innovation led by an SME and the DOT™ IOS will impact all the actors in the innovation space, whereas the failure to capture and hold the innovation space will impact the reputational and commercial value of the New Form Innovation of DOT™, the first tractor-less field robot suited to broadacre farming on the prairies of western Canada.

The policy approach for the smart farming access challenges identified above in section 2.2, and arguably, the first step policy approach to stabilizing the Unstable IOS, is, the question of what type of governance is needed to give voice to farm-level problems? The policy means must consider (i) ICT systems connectivity and security; (ii) data rights (iii) trust: of the technology and

third party use of data and linkages with personally identifiable information; (iv) gathering evidence that supports/rejects a smart farming IOS as a socially, economic, and environmentally sustainable shift of production function.

In the new world of innovation, the authors of the IOS framework emphasize the need to ‘mobilize external resources to capture the IOS. In other words, the Canadian government need not act alone, nor should the market alone need to shape the IOS. For as the SME case study has demonstrated, individual actors have the capacity to invent and create smart farming innovations, however, it is critical to recognize that smart farming really does go beyond the farm gate as suggested by Wolfert and colleagues.

The evidence in this case study research suggests there is a need for the government to ‘steer’ or at a minimum, coordinate the shaping of the IOS on a *multi-jurisdictional* basis, and furthermore, based on the history of shift in farm behaviour and landscapes transformed with conservation agriculture innovations, farm groups must be engaged in the process. Kooiman (2000) offers the governance lens view, emphasizing, governance is not just ‘how’ the system governs itself but also how it “*wants to govern itself as a whole*”. This is the concept of *third-order governing*, where the “whole is more than the sum of the constituent parts” (Ibid, 161). Will the multiple actors identified in the DOT IOS, however, purposely choose *third-order governing to advance smart farming in Canada*? With evidence of lack of coordination across levels of government, lack of adoption of voluntary industry standards regarding agricultural data, silence by Canadian farm groups (commodity or other organization types), the answer would suggest action in the negative, or as Dye (1987) suggests, chose to ‘do nothing’.

In the present and dominant market governance approach to smart farming in North America, this research demonstrates innovation is thriving, but Canada must now strive to achieve better rural connectivity is needed and address the erosion of trust regarding use of agricultural data. The risk of sustaining a smart farming future is therefore, questionable until the issues of data, right to repair and ‘smart-ready’ infrastructure are addressed. However, building high-speed internet service and providing greater cellular coverage given the present technology is cost prohibitive for the government. Under the current system of how ICT infrastructure expansion is assessed (i.e. number of users), the rural farming market size is not enough to attract service providers to extend and expand their present rural ICT coverage infrastructure.

This study has demonstrated there are small-scale solutions for coverage at an individual farm level, for those farmers who choose smart farming. This opens the possibility of a new policy frontier in how Canada could capture value from improved smart farming connectivity. For example, the value of coverage could be measured as returns per acre of increased production, profitability with increased farm income as tax flows back to the Treasury.

On the issues of data and ability to repair high tech equipment, there are governance options to be considered. Agribusiness which collect farm level data could be mandated to strip identifiable information prior to aggregation and analysis by the company, or third-party use. Governments could play an oversight role or use a soft approach such as an information tribunal if farmers suspect their data is being used inappropriately. This would improve the present system of one farmer/contract signatory challenge an agtech provider in the court of law (Booker 2018c). The Right to Repair concern may unfold differently in the prairie provinces than in the United States due to lack of a strong national farmer's organization such as the American Farm Bureau Federation and presence of provincial laws regulating 'timely' repair of agricultural equipment by the manufacturer or dealership and government-appointed legislative oversight bodies (Agriculture Equipment Statutes 2019). The existence of an oversight board created under the provincial statute presents a rare opportunity for hearing evidence of farmer complaints by potentially incrementally changing existing statutes and regulations without creating a new policy. It remains to be seen, however, if using the legislation and enforcing compliance is preferable to software hacking for farmer repair.

This study, therefore, offers a final conjecture that the smart farming future for Canada should *not* be primarily focused on the 'new thing' or technological change, for as this research has shown, smart farming 'things' will be made in presence or absence of policy, and in this case, the new thing is created in response to a problem recognized from within the (farm) technology user community. Yet, the new thing, or the artefacts it generates, reveal a new set of problems. The future of a smart farming innovation opportunity space will be therefore shaped not only by solving a problem at the farm level or solutions developed by SMEs or other shortline equipment manufacturers; it will be shaped by access to innovations, trust in the social networks and clarity on conditions of data ownership for farm-level data originators. Together, these complex aspects of Agriculture 4.0, frame stabilizing a smart farming innovation as an ill-defined problem in need

of a policy solution (Simon, 1973) and indeed, create exciting times for agriculture and policy research.

## 8.POSTSCRIPT

Following the completion of the data analysis for this research, a few key events are noted which are related to the evidence presented in this case study. The events published by the farm news and new press releases, are organized chronologically.

### *July 19, 2019. DOT part of Alberta Innovations*

Under the Strategic Innovation Fund Stream 4 award, a \$CA 49.5 million grant was awarded to CAAIN, the Canadian Agri-Food Automation and Intelligence Network based in Alberta. The purpose of the network is to bring together an ecosystem of autonomous processes, modules and machines to advance the use and value of automation and robotics in agriculture and food. The focus will be using a variety of technologies including artificial intelligence, advanced sensors, hyperspectral imaging, and blockchain.

According to a news press release (NPR) by Alberta Innovates, the “network will create and implement a smart farm platform that integrates partners and creates the context for testing, demonstrating, and scaling technologies.” (Alberta Innovates 2019). Alberta Innovates is one of the following partners in the Alberta smart farming, private sector, academia and research institution initiative: Vineland Research and Innovation Centre, Olds College, MDA Systems Ltd., Linamar Corp., Lakeland College, DOT Technology Corporation, and TrustBIX (Ibid).

Source: <https://albertainnovates.ca/impact/newsroom/transforming-farming-through-innovation/>

### *October 28, 2019. Dot Technology creates Edmonton branch*

The main location for the manufacture of DOT™ is Edenwold, Saskatchewan. However, in October, Dot Technology Corp. announced creation of an Alberta subsidiary, Dot Intelligence Inc. and an R&D centre will open in Alberta, December, 2019, based out of the Alberta Machinery Intelligence Institute in Edmonton. The NPR report from the management of Dot Technology Corp. indicates the objective of establishing the Edmonton subsidiary is to “build a team focused on adding artificial intelligence and machine learning to Dot”. While the Edenwold plant will continue production of DOT™, the new Alberta location will focus on developing transport options for moving DOT™ between fields, including refining the “Follow-Me” feature or developing a system to move in groups (platooning).

Source: <https://www.grainews.ca/2019/12/11/dot-technology-corp-opens-rd-centre-in-alberta/>

***October 31, 2019. Raven Industries buys autonomous DOT technology***

Raven Industries, one of the strategic partners involved in the early development of the sensors and autonomous functionality (the guidance system) and user interface of DOT, became the major shareholder of Dot Technology Corp. Traded on the NASDAQ, Raven Industries has social and physical capacity including infrastructure and talent for manufacturing ICT systems (i.e., high altitude balloons), digital technology platforms (i.e. sensors and guidance systems) and has well established international supply distribution systems for developing steering, machine guidance and control technology area. In the October news item in the Glacier-Media owned Western Producer, Raven Industries is reported to be “working toward autonomous agricultural approaches as part of its strategic growth plan”. An example of their latest technology is situational awareness, where row crop planters are guided by crop rows and integrated tools that recognize and identify plant presence.

Quoted in the news article, Rob Saik, Dot Technology Corp. management, said “the other benefit of Raven’s investment in DOT is the additional credibility that the company brings for short-line machinery manufacturers looking to build field tools for the autonomous platform.”

Source: <https://www.producer.com/2019/10/raven-industries-buys-autonomous-dot-technology/>

***December 19, 2019. Telus acquires Decisive Farming***

Decisive Farming, introduced in section 2.2.1, in the prospects narrative of smart farming, is one of the few examples where a decision support service agribusiness pays their farmer-customers for their data and uses the information to inform malt barley research. Owner and founder, Remi Schmaltz, is a farmer from Alberta and an industry leader in data platforms. In December, Schmaltz told AgFunder that Decisive Farming has joined the TELUS family. Burwood-Taylor reports of Telus that this is not the telecommunications giant’s “ first foray into agtech”, noting TELUS activities in: acquisition of FarmHand software solutions for tracking farm inventory and managing field records; investment in UK drone imagery analytics startup Hummingbird Tech and the proposed Smart Agri-Food Super Cluster (described in Section 5.3.3), and expansion of fiber-optic broadband in Alberta with a CA \$16 B commitment to infrastructure upgrades.

Source: <https://agfundernews.com/breaking-exclusive-canadian-telecoms-giant-telus-acquires-decisive-farming.html>

*March 29, 2020. DOT Technology Sells To Raven Industries.*

On March 29, 2020, Norbert Beaujot and the Beaujot family management team at Dot Technology Corp. announced the sale of their shares remaining after the initial October 31, 2019 purchase by Raven Industries, thus consolidating Raven's ownership of DOT™. Beaujot lamented that it was difficult to 'sell his baby', but acknowledged that it would take the resources of a larger company to move DOT™ forward now that the proof of concept and testing stages have demonstrated that DOT™ will work as he envisioned. Production capacity is increased and 25 DOT™ units will be ready for working in the fields in spring 2020. Other implements are being developed that will also be released in 2020. Other broadacre farming areas including Australia, Latin America, are showing interest in DOT™, as well as South Africa (see Section 5.3.1 above). Journalist, Glenda-Lee Vossler, reported that "Raven Industries will continue to manufacture DOT in Saskatchewan with SeedMaster."

Source: <https://okotoksonline.com/ag-news/agriculture-news-ab/dot-technology-sells-to-raven-industries>

See also <https://ravenind.com/news/raven-to-acquire-full-ownership-of-dot> and Raven's March 30, 2020 news release of the building of their capacity for smart farming innovation with ownership of the DOT™ power platform, combined with the newly acquired Smart Ag® autonomous perception and path planning technology.



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Table 32-100153, formerly 004-0202 Total area farms and use of land



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 Table 002-0005. Farm operating expenses and rebates, for Canada and the provinces (in thousands of dollars).
- Table 004-0005. Census of Agriculture, Farms classified by size of farm, 1976 to 2016  
 Table 004-0204 Census of Agriculture, tenure of land owned, leased, rented, crop-shared, used through other arrangements or used by others, every 5 years  
 Table 004-0230 Census of Agriculture, farms classified by operating arrangements, every 5 years (number)  
 Table 004-0232 Census of Agriculture, farms classified by total farm capital, every 5 years (number)  
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## APPENDIX

### Three Stages of Data Collection: Digital Technology Innovations in Agriculture

#### *Stage 1: Event selection and purposeful sampling for the CDO project*

The first methods stage focused on understanding the types of digital technology and scale of applications in commercial agriculture in western Canada. Events were chosen to answer the CDO project research question, *how does the diffusion of digital technology across all sectors of the economy contribute to the overall dynamism and competitiveness of the Canadian economy?*

A strategy of ‘purposeful sampling’ was used to “purposefully inform an understanding of a research problem and central phenomenon in the study” (Creswell 2015, 156). Primary and secondary data was gathered from sites where farmers (consumers of the technology) and agribusiness firms (suppliers and/or developers of the technology) gathered to observe, discuss and potentially purchase some form of digital technology application for farming. Trade shows and industry events were selected as representative venues which “bring together different groups of suppliers from a particular industry or technology field with the primary goal to showcase, promote, and/or market their products and services to buyers and other relevant target groups” (Bathelt et al. 2014, 4). A total of fourteen venues were attended from 2015 to 2017. The events, attendance and number of exhibitors is listed in Table A.1.

Primary (observational) data was collected on the innovation and on which exhibits/exhibitors were attracting the most farmer attention. These database entries were later cross-referenced to exhibits/exhibitors receiving peer recognition in the form of People’s Choice and panel-judged innovation awards. Information on acquisitions, mergers and new entrants was added to the database to reflect changes in the type and number of innovations being offered over the three-year time period. Secondary data included event brochures with information on exhibits. In addition, media coverage in the form of newspaper circulars and articles was collected to understand how innovations were reported to the farming community.

**Table A.1: Trade shows selected as sites for the CDO project and policy study**

Annual Event	Date		Impact	
			Attendance	Exhibitors, buyers
Canada Farm Progress Show (CFPS), Regina, SK <a href="http://www.myfarmshow.com">www.myfarmshow.com</a>	3 days in June	2015:	41,897	640 exhibitors; 146 international buyers representing 15 countries. Buyers spent about CA\$ 380 M
		2016	Similar attendance as 2015	700 exhibitors, C\$ 500 M in sales, 52 countries represented
		2017	38,000	\$360 M in sales; 65 countries represented
		2018	34,853	Over 700 international visitors and buyers
Western Canadian Agribition, Regina, SK <a href="https://bit.ly/2SQrMOZ">https://bit.ly/2SQrMOZ</a>	6 days in November	2015	130,200	CA\$ 3.4 M of livestock sales, 800 international guests representing 70 countries
		2016	123,000+	CA\$ 2 M in purebred cattle sales, 365 international buyers from 86 countries represented
Western Canada Crop Production Show (CFPS) Saskatoon, SK <a href="https://bit.ly/2VPL74MP">https://bit.ly/2VPL74MP</a>	4 days in January	2016	20,425	n/a
		2017	20,394	n/a
		2018	19,480	n/a
Ag in Motion Langham, SK <a href="https://aginmotion.ca">https://aginmotion.ca</a>	3 days in July	2016	About 23,000	n/a
		2017	25,787	n/a
		2018	30,335	459 agricultural companies.
Precision Agriculture conference <a href="https://bit.ly/2Fb2rNY">https://bit.ly/2Fb2rNY</a>	1 ½ days in November or December	2017	250 precision ag enthusiasts, featuring 22 international precision ag speakers	
		2018	25 exhibitors, attended by about 350 senior agribusiness executives, government, researchers from academic institutions, students, farmers and agronomists	



### *Stage 2: Opportunistic sampling for the CDO project and policy study*

The second stage involved ‘opportunistic sampling’ which relied on “taking advantage of unforeseen opportunities” at each event (Ritchie and Lewis 2012, 81). Criterion for sampling was incorporation of some form of digital technology for use in the agriculture sector, willingness of exhibitors to participate in the research and the innovation being either nominated or a direct recipient of an innovation award. The number of possible research participants ranged from 25 to 50 at each venue. There were also different levels of accessibility as not all exhibits were staffed by someone who could explain the genesis and development of each innovation. However, a broad diversity of types of technologies was available. Following communication with exhibitors, relationships were established, contact information was exchanged and individuals were formally invited to participate in the research project. Information was then provided (email or paper copy) to participants on the project’s goals, funding source, time required for interviews and the ethics statement.

Semi-structured interviews were conducted from June 2015 to July 2017 (Table A.2, Interview Guide 1). These were conducted either in-person, by telephone, or through the web (Skype/Facetime). Interviews were audio-recorded and summary notes prepared.

The 25 expert participants represented various sizes of firms (less than ten employees to several hundred) offering a diversity of technologies with a primary focus on Canadian and/or North American markets and a secondary goal of reaching global networks. Details are provided in Table A.3.

Participants represented a range of firm sizes, from one or two employees to several hundred employees, with operations headquartered in the prairies or the northern United States. Several firms had a customer distributed across North America, Australia, and the Slavic regions (dryland agriculture farming conditions). All participants were asked to explain the challenges (barriers) they experienced and the barriers and opportunities they envision for digital technologies in Canadian agriculture. They were also asked to identify policy areas or gaps that either supported or hindered the advancement of their innovations, or are on their radar as emerging areas of concerns related to digital technology-related innovations in agriculture and knowledge-based systems.

**Table A.2: Interview guide 1: Creating Digital Opportunities project**

<b>Theme</b>	<b>Probe/Question</b>
Who	Identify the person or firm, the organization strategy, and structure, the firm value and size, who or what influenced you.
What	Identify the innovation the firm is offering to the market, is it interoperable with other platforms, is it simply a better widget, or is it disruptive.
Why	Identify the motive for the innovation - problem-solving, shared values and interests, intellectual challenge, filling a market gap, import someone else's technology or bundle it.
Where	Identify the area the innovation was developed and target market, are their aspirations to be in a market niche, a local market or global.
When	Identify the timelines when the originator came up with the idea and protection of intellectual property, and when and/or how long did it take to acquire the knowledge and skills necessary to translate the idea to the commercial innovation.

**Table A.3: Technologies and number represented in the interviews, June 15 to November, 2017**

<b>Type of digital technology</b>	<b>Interview participants (number)</b>
knowledge-based systems (i.e. farm management decision support services)	4
agriculture equipment	4
commodity trading platforms	3
UAV (drones)	3
not-for-profit knowledge transfer, training and competition host organizations	3
policy/economic development	1
scanning technologies	1
customized software systems	1
sensor development	1
soil testing	1
cleantech	1
navigation systems	1
commercial production	1
<b>Total</b>	<b>25</b>

### *Stage 3: DOT™ Case Study Methodology*

#### *3.1 Purposive sampling for the case study*

Third stage purposive sampling, was initiated at a July 2017 outdoor farm event where DOT™ was unveiled and demonstrated to the public. Senior management of SeedMaster™ (owned by the inventor of DOT™) had been interviewed in an earlier phase of data collection for the CDO project. During the time of the CDO interviews, the development of DOT™ was confidential and not revealed. After the trade show demonstration, an informal meeting was granted at the SeedMaster™ exhibitor display. Based on this prior research relationship, further arrangements were made for a series of interviews with the inventor and five members of the senior management team representing SeedMaster and the newly formed sister company, Dot Technology Corp.™

#### *3.2 Interview guide and data collection*

An interview guide was designed as a specific series of theoretically-informed interview questions. Semi-structured interviews were conducted from October, 2017 to January, 2018 (Interview Guide 2), below. Individuals were not identified during the audio recording, therefore not identified in the transcriptions done by the Social Sciences Research Laboratory.

#### **List A.1: Interview Guide 2 - Smart Farming project**

1. How does this technology benefit Canadian agriculture in the long run?
  - a) From a farmer's perspective, what problem did you have in agriculture that brought you to this innovation?
  - b) How does innovation solve it?
2. How did you go about solving it?
3. What is the 'reach' of this technology? (global, or local) and the IP strategy?
4. Affordability – do you have a sense of willingness of producers to adopt this technology? (probe - is price holding it back)
5. What evidence do you have of the value proposition?
6. Does it make a difference to farmers that this technology is homegrown?
7. Do you have a plan as to how and where the data generated by the use of this machine is going to be stored? (e.g. inputs)
8. Will you aggregate the data generated by the innovation?
9. How do you see this innovation addressing sustainability and soil health?
10. Where is the R&D taking place?
11. If you were to change the things that have hindered this innovation, what would you like to see going forward? (probe: how might government policy/programs support future innovation for ag?)
12. How does this innovation support the social structure of agriculture? (rural centres, family farmers)

In-person interviews (primary data source) were conducted at the SeedMaster office, Edenwold, Saskatchewan. The three-hour interview was recorded and professionally transcribed using services at the Social Sciences Research Lab, University of Saskatchewan. Follow-up interviews were done over the phone, November to January, 2018. Interview scripts were imported into NVivo v10 software and coded for themes indicated in Appendix A.6. Observational data were also collected when the inventor and the management team of Dot Technology Corp. were featured as keynote speakers at industry events.

### 3.3 Literature review

After stage 3 interviews were undertaken, a literature review of material related to smart farming and autonomous technologies was conducted. Based on the Web of Science data analysis of search results, 121 articles are published in 80 journals. Authors have edited 49 books, however, the main source of smart farming literature appears primarily as conference proceedings (145), notably the IEEE (Institute of Electrical and Electronics Engineers) accounting for 27% of conference articles by IEEE institute participants including computer scientists, software developers, information technology professionals, physicists, medical doctors, addition to IEEE's electrical and electronics engineering core group (IEEE, 2019). In comparison there are only nine agriculture-specific conferences featuring smart farming in proceedings and individual (one-off) events each featuring the bioeconomy, meteorology, ICT, Big Data, machinery and sustainable agriculture, and autonomous systems; two agriculture engineering conferences have featured smart farming. A second database search engine, Agricola, returned 221 publications and the most common theme (approximately 13% publications) is related to agriculture systems. The earliest publications, from the northeastern United States academic research and government extension services featured spatial analysis technologies that authors believed would support sustainable farming practices. In 2008, a special edition journal was dedicated to computer technologies in farming and featured eight articles on smart farming applicable to crops and livestock operations. Both database searches document the rapid increase in publications since 2015, confirming the topic is only recently capturing the attention of academic and industry professionals preparing scientific publications.

Secondary data was also accessed for the literature review, including agriculture industry reports, blogs, and tech news magazines listed in Table A.5.

**Table A.4: Farm media as secondary data sources disseminating information on DOT™ Technologies, July 2017 to December 2018**

<b>Publication</b>	<b>URL</b>	<b>Information</b>
The Western Producer	<a href="http://www.producer.com">www.producer.com</a>	17 articles, supplementary videos
Alberta Farm Express	<a href="http://www.albertafarmexpress.ca">www.albertafarmexpress.ca</a>	6 articles,
Manitoba Cooperator	<a href="http://www.manitobacooperator.ca">www.manitobacooperator.ca</a>	4 articles,
Country Guide	<a href="http://www.country-guide.ca">www.country-guide.ca</a>	3 articles,
Grainews	<a href="http://www.grainews.ca">www.grainews.ca</a>	2 articles, supplementary videos
Farms.com	<a href="http://www.farms.com">www.farms.com</a>	2 articles,
RealAgriculture	<a href="http://www.realagriculture.com">www.realagriculture.com</a>	10 videos and podcasts
AgDealer.com	<a href="https://www.agdealer.com/articles">https://www.agdealer.com/articles</a>	2 articles, 2017, 2018
FCC AgKnowledge	<a href="https://bit.ly/2VOEI9U">https://bit.ly/2VOEI9U</a>	1 article

Thirty-seven farm media items were selected for importing into NVivo for additional coding, as well as announcements of innovation awards and government funding. Ten videos and podcasts were also accessed from an on-line farm news source. Two videos were uploaded to YouTube by Dot Technology Corp.™ (seedotrun) which described the operation of DOT™ and visualization of its utilization with farm equipment. The third video on YouTube was uploaded by Invest in Canada featuring DOT™ as an example of autonomous technology in farming (<https://bit.ly/2HbYOaH>).

### 3.4 Coding for themes

On completion of the coding, a search of the academic literature and government documents specific to the coded themes was conducted. Ninety-six articles were sourced using WebofScience™ and Google Scholar search engines. These articles were further imported into NVivo and coded to relevant nodes.

**Table A.5 Main and sub-themes coded from interview transcripts and secondary data sources, 2018.**

Theme	Sub-theme node
Adoption	Barriers to (economics, trust), best management practices, Canadian context (actors in ag innovation space, labour, social capital), drivers of (precision agriculture, ease of use, materials, and materiality), sustaining adoption (agricultural transitions, conservation tillage)
Government (policy)	Funding, governance, regulations, actors
Technology (IoT, ICT)	Sensors, clean tech, satellites, cloud systems, infrastructure IoT-connectivity, autonomous
Equipment	Additive manufacturing, interoperability, leasing, right to repair, service agreements, swarms, navigation systems, robotics, firmware, coding, sensing, skills development
	concerns of Big data