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December 2020

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Acknowledgement: The project was funded by the Agricultural Research Institute of Ontario (ARIO) and the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA).

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Executive Summary

This report serves as a knowledge synthesis focused on examining the social and spatial dimensions of disruptive technologies in the Ontario agri-food sector and beyond. The objectives of this research are to: 1) Determine the nature and extent of disruptive technologies in the agri-food context; 2) Examine how these disruptive technologies are reshaping the agri-food sector; 3) Identify what is driving the adoption of these disruptive technologies; and 4) Explore the impacts of these disruptive technologies on rural regions and the responses by various levels of government, organizations involved in economic development and skills training, postsecondary and research institutions, industry associations, and other stakeholder organizations.

Advanced technologies are reshaping the agri-food sector in Ontario and internationally. These technologies often fall under the categories of *smart farming, digital agriculture*, and *precision agriculture*. Digital agriculture has been described as "the application of big data and precision technology systems in agriculture" (Rotz, & Duncan et al., 2019, p. 204). The term "digital agriculture" is used to include precision agriculture and other digital transformation trends in agriculture, including: (1) the IoT (Internet of Things) and sensors in the field; (2) IoT and sensors in equipment; (3) drones and crop monitoring; (4) farming and robotics; (5) Radio-frequency identification (RFID) sensors and tracking; and (6) machine learning and analytics (Newman, 2018).

There is a small but rich international body of academic and policy literature (Fleming, 2016; Kamilaris et al., 2017; Kelly et al., 2017; Leclerc, 2016; Marowits, 2018; Pierpaoli et al., 2013; Strubenhoff et al., 2018; Tzounis et al., 2017; Wolfert et al., 2017) focused on identifying agri-food tech trends, drivers and challenges. However, there is very little academic and policy research examining how these technologies are changing the way the agri-food sector interacts with people and the communities in which they operate. To address this gap, this knowledge synthesis report focuses on the historical and technological shifts in the agri-food sector; current trends, including an overview of disruptive technologies; and a discussion of the drivers, barriers, and impacts of technology adoption on farms and stakeholders in rural communities.

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1. Introduction

In Canada, the agri-food sector represents 6.7% of GDP and is one of the top job creators with 2.3 million jobs added in 2018 (Barton, 2019). While agriculture is vital to the livelihoods of Canadians, the sector is facing major challenges to meet global food supply demands in sustainable ways, while also responding to grand challenges like the impacts of climate change and the depletion of natural resources (Klerkx et al., 2020). Critical supply-side constraints facing the agri-food sector globally include water (40% deficit by 2030), land (over 20% of arable land degraded), climate change (3-16% lower productivity by 2080), productivity (declined from 2.2% to 1.2% from 1960's to present), and energy (over 50% of cash costs are fertilizers and fuels) (Barton, 2019, p. 3). Compounding these challenges is the rapid growth of the global population, which is projected to reach almost 10 billion people by 2050. These trends will require a fundamental shift in the way food is produced – producing much more with much less (Deloitte, 2018; Food and Agriculture Organization of the United Nations [FAO], 2018).

As a result, agri-food industries are adopting new strategies to face these challenges in productive, sustainable, and competitive ways. At the same time, radical and potentially game-changing technological advances in the areas of robotics, nanotechnology, artificial intelligence and machine learning, and sustainable energy generation are positioned to lead the 'fourth agricultural revolution', or 'Agriculture 4.0' (Klerkx & Rose, 2020; Rose et al., 2018). These advances in technology have the potential to fundamentally disrupt the agri-food sector, raising questions about the future of work and development in rural communities across Canada. Internationally, investments in agri-food tech has been increasing substantially reaching almost $20 billion in 2019 (AgFunder Inc., 2019). A number of game changers have emerged including the DOT autonomous power unit programmed to seed, fertilize, spray, and till a field developed by a Saskatchewan farmer and inventor, or the Fendt Xaver swarm technology, a mini robotic autonomous corn planter system developed by AGCO in Germany (Ontario Ministry of Agriculture, Food and Rural Affairs [OMAFRA], 2018). Little is known, however, about the adoption of disruptive technologies in the agri-food sector in Ontario and its impacts on rural communities.

This knowledge synthesis is part of a broader research project, funded by the Agricultural Research Institute of Ontario (ARIO) and the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), focused on examining the social and spatial dimensions of disruptive technologies in the Ontario agri-food sector. The objectives of the research are to: 1) Determine the nature and extent of disruptive technologies in the agri-food context; (2) Examine how these disruptive technologies are reshaping the agri-food sector; 3) Identify what is driving the adoption of these disruptive technologies; and 4) Explore the impacts of these disruptive technologies on rural regions and the responses by various levels of government, organizations involved in economic development and skills training, postsecondary and research institutions, industry associations, and other stakeholder organizations. Overall, the goal of this research is to advance understanding of the challenges and opportunities associated with the adoption of disruptive technologies in the agri-food sector.

The purpose of this knowledge synthesis is to provide an overview of the international academic, policy and business literature exploring disruptive technologies in the agri-food sector and their impacts on rural workers and communities. Much of the literature on disruptive technologies in the agricultural sector focuses on explaining trends, as well as barriers and motivations for technology adoption. Overall, this literature argues that adopting disruptive technologies in the agricultural sector will likely lead to increases in productivity and efficiency. Disruptive technologies are also assisting the agricultural sector with adapting to the impacts of climate change and changing environmental conditions while minimizing the environmental impacts of the agricultural sector. There is, however, a significant gap concerning how disruptive technologies in the agri-food sector are impacting workers and rural communities. This knowledge synthesis begins with a discussion of the history of technological shifts in the agri-food sector. This is followed by a discussion of current trends, including an overview of disruptive technologies in the agri-food sector. Finally, the report outlines the drivers, barriers, and the impacts of technology adoption in the agri-food sector.

2. History of Technological Shifts in the Agri-Food Sector

The agri-food sector has experienced enormous shifts over the past century with the rapid introduction of new technologies. Early technological advances in the industrialization of food processing are associated with the shift from the mechanization of systems and steam-engine power in the nineteenth century (Agri-food 1.0) to the use of electrical machines increasing production capacities in the 1950s along with the “green revolution” that introduced pesticides and fertilizers (Agri-Food 2.0) (Miranda et al., 2019). The late twentieth century was marked by the digitalization of processes related to advances in robotics and automation (Agri-Food 3.0). More recently, the use of ICTs, smart technologies, and the rapid development of the Internet of Things (IoT) has led to the emergence of precision production systems, and what is now being called Agri-Food 4.0 (Miranda et al., 2019).

Shifts in the agricultural sector have included innovations from hand tools, to tractors and combine harvesters that expanded farm production, which was further driven by commercial fertilizers, pesticides and weed control practices, to more recent innovations with precision farming techniques facilitated by smart technologies (Pedersen et al., 2017). These precision farming techniques emerged with the development of GPS systems, yield mapping, smart sensors, and auto steering systems. Earlier technological advances (e.g., tractors and combines) focused on labour saving production processes and farm expansion, which meant that farms operated larger fields. Some have argued that this shift to expanded fields lessened the knowledge farmers had about their crops because the of the sheer increase in size of the farms they were managing (Pedersen & Lind, 2017). However, the emergence of smart technologies in precision agriculture (PA) has allowed farmers to harness detailed data and information about their fields and crops while also benefitting from expanded farm production.

This digitization of agriculture and agri-food production can be situated within the broader context of the Fourth Industrial Revolution (4IR), a defining feature that represents the digitization of all economic sectors worldwide (Klerkx & Rose, 2020). Used synonymously with the term Industry 4.0, 4IR is marked by "a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres" with the rapid development of technologies such as artificial intelligence, robotics, the Internet of Things, and quantum computing (Schwab, 2016, para. 2). While the application of these new and emerging technologies is disrupting almost every industry across the globe by creating increased efficiencies and productivity, there are serious debates regarding the implications of these advanced for the future of work. For example, will these innovations fundamentally restructure labour markets by replacing workers with machines, producing further inequalities or will this result in the creation of safer, more rewarding jobs?

3. Disruptive Technologies in the Agri-Food Sector

Advanced technologies are reshaping and disrupting the agri-food sector in Canada and internationally. These disruptive technologies often fall under the categories of smart farming, digital agriculture, or precision agriculture. Smart farming is an emerging term that relates to the adoption of technologies supporting agricultural practices including bio-technology, remote sensing, cloud computing and the Internet of Things (IoT) (Kamilaris et al., 2017, p. 23). Digital agriculture refers to "the application of big data and precision technology systems in agriculture" (Rotz, & Duncan et al., 2019, p. 204). The agricultural sector is increasingly using digital technologies for crop monitoring and measurement, which in turn creates large quantities of data (or big data), which can be analyzed and applied to improve farming practices. Finally, precision agriculture (sometimes referred to as precision technology or precision farming) is the most specific of the three terms used to characterize disruptive agriculture technologies. Precision agriculture is "the process of using satellite imagery and other technology (such as sensors) to observe and record data with the goal of improving production output while minimizing cost and preserving resources" (Meola, 2020, para. 8). The application of these technologies helps to "manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality" (Pierce et al., 1999, p. 4). Precision agriculture has four main features: 1) geographical positioning (GPS) for use with guidance and navigation; 2) information gathering (e.g. yield monitors); 3) decision support (e.g. crop scouting and remote sensing); and 4) variable-rate treatment, which refers to precise application of materials based on location and/or qualities that reduces waste and a cost saving measure (Aubert et al., 2012; Pedersen & Lind, 2017).

The term agri-food technologies is used in this knowledge synthesis to include precision agriculture and other digital transformation trends in agriculture, including those outlined by Newman (2018): the IoT (Internet of Things) and sensors in the field; IoT and sensors in equipment; drones and crop monitoring; farming and robotics; radio frequency identification [RFID] sensors and tracking; and machine learning and analytics. Each of these trends are described in more detail below.

3.1. IoT: Field and equipment sensors

The Internet of Things (IoT) describes the connection of computing devices and the transfer of data using the internet. Precision agriculture is enabled by the IoT by transferring and utilizing big data to make decisions and deal with specific problems (Middleton, 2017). More specifically, IoT is "based on three layers; namely, the perception layer (sensing), the network layer (data transfer), and the application layer (data storage and manipulation)" (Tzounis et al., 2017, p. 33). IoT and sensors in the field are providing farmers with real time information about their crops - anytime, anywhere - allowing farmers to increase food production while creating less waste (Newman, 2018). For example, SomaDetect Inc. of Fredericton, N.B. is using AI to assist dairy farmers in what's being called the "internet of cows". Sensors installed at milking stations can identify individual cows, test their milk, provide metrics like protein counts, and any markers of disease (Marowits, 2018). Elsewhere, IoT technologies have been used to address pest and disease control in crops. The Semios platform uses sensors along with a wireless network that is paired with its pheromones application system to assist cherry and almond orchards in responding to insects and disease (Turner, 2017). Likewise, equipment manufacturers are connecting their machines wirelessly as well as creating sensors and platforms to improve crop yields (Meola, 2020). Sensors in equipment are also being used to track the maintenance needs of equipment thereby reducing costly downtime (Newman, 2018).

3.2. Drones and Crop Monitoring

Drones are being used across the globe to view fields from the air to combat drought, predict soil quality, detect pests and diseases, track livestock, and plan seed planting (Coppolino, 2016; Newman, 2018). Japan and the United States have the highest adoption rates of aerial agricultural tools. In Japan, 70% of rice paddy dusting, seeding and crop management is facilitated by drone technology to address labour shortages, challenging terrain, small land plots and domestic food demands (Ipsos Business Consulting, 2017). Likewise, in the United States agriculture drones have been used for crop dusting efficiency and precision agriculture in farm management. AI technology is also being integrated with drones for precision farming applications which is producing more data that can be used to make informed decisions (Deloitte, 2018). For example, Toronto company Deveron UAS combines both drones and AI to help alleviate irrigation stress in California by watering pistachio and almond crops only where needed. In Canada, farmers from Veritas Farm Management partnered with Deveron UAS technologies in corn farming to target areas for fertilizer use (Marowits, 2018; Nederend, 2017).

Drones are also seen to be advantageous because they can cover large acreages and they can be used frequently with readily available data versus satellite imagery which usually requires more time before data is ready for use (Coppolino, 2016). According to Deloitte (2018), other advanced surveying technologies such as infrared mapping can gather information on crop conditions and provide information to farmers in a timely manner that not only reduces the cost per acre but can boost crops yields by 20%.

3.3. Farming Robotics and Autonomous Transport

Robotics and autonomous transportation systems are also being adopted in farming from robotic planters and pickers to the early adopters of GPS-guided tractors for autonomous transport. AGCO's Fendt Xaver, a mini robotic autonomous corn planter system, is a great example. Xaver is controlled by cloud technology through a smartphone that can "carry out tasks in the field such as to load up with seed, go [to] the field, plant the crop, tell the farmer where every single seed was planted via GPS, return for fill up when empty, return to the charging trailer when batteries get low, and communicate with each other so if one is disabled others come to take over" (OMAFRA, 2018, para. 8). The Xaver robot plants the seeds by poking them into the ground, which presents the possibility of no-till farming. No fill farming decreases the amount of soil erosion caused by tillage in certain soils. Another example of autonomous farm equipment is the Dot Seed Master, a technology developed by a Saskatchewan farmer and inventor, that could be "programmed to 'grab' an assortment of implements, lock on, fill up and head to the field without human intervention to seed, fertilize, spray, or till a field" (OMAFRA, 2018, para. 6). One of the greatest advantages of replacing large human-operated machines with several smaller autonomous devices that utilize modern IT infrastructure, is the reduction in crop compaction, waste, environmental pollution, and harm to beneficial organisms/ecosystems (Growing Produce, 2019; Saiz-Rubio et al., 2020; UK-RAS Network, 2018).

3.4. Radio frequency identification (RFID) sensors and Tracking

Another trend in digital technology adoption in the agriculture sector relates to the use of radio frequency identification (RFID) sensors, which can track food from field to fork (Newman 2018). RFID is part of a broader technology called Automatic Identification and Data Capture (AIDC), which allows for the automatic identification and collection of data about an object which is then entered into computer systems (Calderone, 2019). RFID in agriculture enables farmers to capture and store information about their products such as the date of harvest, the field/location of the harvested product, along with other physical data such as the temperature, weight, moisture level and the nutritional information. Farmers and distribution companies are using this technology to save time and money as well as reduce food waste. Benefits of RFID extend to the consumer by providing basic information about products along the supply chain from the origin to the destination, as well as helping consumers check for issues related to product safety (Calderone, 2019).

3.5. Machine Learning and Analytics

Overall, the adoption and application of these digital technologies in the agri-food sector is creating large amounts of data. As a result, machine learning and advanced analytics are being used to analyze large data sets to determine trends, predict markets, and identify crops that are ideal for specific climates and locations. Machine learning and advance analytics are also being used to recognize opportunities from plant breeding to tracking food sales and reporting supply and demand information to growers (Newman, 2018). For example, the Montreal-based company Motorleaf Inc., “acquires data from indoor growing operations and applies artificial intelligence and machine-learning algorithms to identify growing patterns in the greenhouse, which can then be used to predict the size of future harvests” (Marowits, 2018, para. 8).

Large imaging datasets have been especially important to farm managers. Studies are examining how the combination of aerial imaging from drones and machine learning can enable ultra-scale aerial phenotyping and precision agriculture (Bauer et al., 2019). Crop researchers, growers and farmers are already using aerial imagery to monitor crops, however by combining these advanced techniques with deep machine learning, high-quality measures of key crop traits can be produced. These outputs support farm managers to make real-time and reliable crop management decisions. For example, using AirSurf-Lettuce, an automated and opensource analytic platform that is capable of scoring and categorising iceberg lettuces with extreme accuracy, it was found that deep learning techniques can "enable growers and farmers to conduct precision agricultural practises in order to improve the actual yield as well as crop marketability before the harvest" (Bauer et al., 2019, p. 1). In addition, farm management software, biological inputs (bio-fertilizers and bio-pesticides), and gene editing are also disrupting traditional practices in the agri-food sector by helping farmers to improve efficiencies on the farm and use fewer resources (Leclerc, 2016).

4. Global Drivers of Agri-Food Technology Creation and Adoption

Interest in agri-food tech is being driven by several broad global trends, including: feeding the world's growing population; responding to climate change impacts from water shortages and contamination to soil degradation and extreme weather events; and growing interest in food security and food safety (Leclerc 2016; Fleming 2016; Kamilaris 2017; Kelly et al. 2017; Marowits 2018; Strubenhoff 2018). Wolfert et al. (2017) identify a number of other push and pull factors. Push factors include technological developments like the emergence of IoT and ag-tech companies; the development of sophisticated technologies, including drones and robots; increases in data generation and storage capacity; improved rural digital connectivity; and the creation of innovation possibilities for entrepreneurs. On the other hand, pull factors include business drivers (e.g. more efficiency and improved management control) public drivers such as food security, safety and sustainability, and wider desire and need for more and better information to inform public and private actors in the agri-food system. A number of these trends are discussed in more detail below.

4.1. Population Growth and Climate Change

The agricultural sector faces major challenges related to meeting food supply demands in sustainable ways, while also responding to grand challenges such as climate change and the depletion of natural resources (Klerkx & Rose, 2020). The World Bank identifies a number of major challenges facing the agri-food sector; these range from "greenhouse gas emissions, land degradation, water and air pollution, overdrawn aquifers, and biodiversity loss, to food borne diseases, growing anti-microbial resistance, persistent under- and malnourished children, and rising obesity" (World Bank Blogs, 2019, para. 2). These challenges are compounded by the rapid growth of the global population, which is projected to reach almost 10 billion people by 2050. To adequately feed this growing global population under these conditions will require a fundamental shift in how food is produced – producing much more with much less (Deloitte, 2018; FAO, 2018).

Barton (2019) suggest that meeting future global demand will require larger investments in multiple areas including "yield improvements, land expansion and loss reduction" (p. 4). In addition, many disruptive technologies are being created and adopted to improve productivity and efficiency as well as to adapt to changing environmental conditions and to decrease the agricultural sector's impact on the environment (Newman, 2018). Furthermore, the Food and Agriculture Organization (FAO) (2017, 2018) suggests that agricultural technologies have the ability to increase agricultural efficiency while reducing global issues such as climate change.

4.2. Food Loss and Food Waste

Another factor driving the adoption of agricultural technologies, especially in supply chain management, is that technologies can help address food loss and food waste challenges without needing to increase food yields. According to Fleming (2016), approximately 1.3 billion tonnes of global food is wasted annually; this is equivalent to about one-third of total production. Research by Second Harvest (2019) suggests that close to 60 percent of all food (or approximately 35.5 million metric tonnes) that is produced in Canada is lost or wasted annually. Food loss includes the disposal of food during production through to processing while food waste includes food that is discarded during distribution and by consumers at home (Second Harvest, 2019). While there are several reasons why food is lost and wasted, including aesthetics (e.g., 'ugly' produce) and a culture of accepting food waste, managing complex supply chains can also be a factor. As a result, some argue that new technologies and new business models are needed to increase efficiency and reduce food loss and waste (Fleming, 2016; Second Harvest, 2019).

4.3. Global Competition

Global competition is also one of the drivers for investment in agricultural technologies. For example, Innovation, Science and Economic Development Canada (2018) cites agri-food as one of the key sectors to support economic growth in Canada as part of its Innovation and Skills Plan. The ISEDCs (2018) *Economic Strategy Tables Report on Agri-Food* argues that, with a projected global population of 10 billion by 2050, Canada is well-positioned to take advantage of the opportunity to supply the rapidly increasing global demand for protein. The report provides a roadmap to make Canada more competitive, with the goal of becoming "one of the top five competitors in the agri-food sector" by 2025 (ISEDC, 2018, p. 2). Investing in innovation is seen as one of the key actions needed to further incentivize the creation and adoption of digital agriculture technologies and advance Canada as a global competitor in the agri-food sector.

5. Technology Adoption at the Farm Level

At the farm level, Wolfert et al. (2017) identify a number of business drivers motivating the adoption of digital technologies, including more efficiency and improved management control (see also Coppolino, 2016). Pierpaoli et al. (2013, p. 64) also enumerate a number of criteria influencing the adoption of new technologies, including: farm size; costs reduction or higher revenues to acquire a positive benefit/cost ratio; total income; land tenure; farmers' education; familiarity with computers; access to information (via extension services, service provider, technology sellers); and location. They found that non-adopters either lacked the skills and competences to utilize precision agriculture technology or the appropriate levels of financial resources to acquire new technologies. Difficulties with managing larger farm sizes can also influence or motivate technology adoption decisions, particularly with respect to monitoring soil quality over large areas (Pierpaoli et al., 2013). In their study of precision farming adoption in Germany, Reichardt and Jürgens (2009, p. 84) found that 50% of farmers perceived associated benefits with having "better knowledge of the field" and "the reduced need of fertilizers." In another study on the adoption of precision agriculture (PA) technology in Quebec, Aubert et al. (2012) identified how perceived ease of use and usefulness have a significant effect on PA technology adoption. It was also found that, while the age of the farmer and the size of the farm did not influence the adoption of new technologies, the education level of the farmer was positively correlated with adopting PA. Higher education is viewed as important to providing farmers with the necessary skills for experimenting with PA technologies. In addition, having knowledge of PA technologies had the highest impact on perceived ease of use. Aubert et al. (2012) argue that education and training programs for farmers and staff would enhance the required knowledge and skills for PA implementation and increase positive perceptions about the ease of use and PA adoption.

In a more recent study, Ruder (2019) examined the opportunities and challenges with digital agricultural based on the perspectives of grain farmers in Southern Ontario. Within digital agriculture, Ruder (2019) distinguishes between digital technologies and big data, including big data climate forecasts, robotic tractors, satellites that assist with pest control and drones used for precision agriculture. Farmers highlighted the operational and decision-making benefits associated with these two areas of technology and were optimistic about the benefits provided by both new digital technologies and big data (Ruder, 2019). However, the majority of farmers felt there were still several challenges including the high cost of equipment, the new skills required to benefit from the technology and the risk of technological failures. Despite these concerns, Ruder (2019, p. 75) argues that "many farmers feel that they have 'no choice' but to adopt" (p. 75) to remain competitive in the sector. Meanwhile, farmers in New Zealand view investing in new technologies as important rather than critical, such that they "perceive that change will be incremental, manageable, and supportive, in broad terms, of the status quo" instead of transformational (Kelly et al., 2017). That being said, Kelly et al. (2017, p. 3) argue that farmers are "prepared to invest in technology that has a proven operational benefit that can increase efficiency and effectiveness."

6. Barriers to Technology Adoption

A number of studies discuss the barriers to adoption and low adoption rates of new technologies on farms. These often include a lack of rural broadband connectivity, limited knowledge of new technologies, implementation costs, technical expertise requirements, and concerns over privacy and security of food systems data (Kamilaris et al., 2017; Kelly et al., 2017; Pierpaoli et al., 2013; Tzounis et al., 2017). To increase the adoption of new technologies in Ontario, Duncan (2018) argues that the 2021 Census of Agriculture should collect more data on precision agriculture adoption and that there should be more institutional support to assist farmers with adopting more technologies. More specifically, institutional support is important to expand the social relationship around precision agriculture beyond that of the farmer-retailer dynamic because many farmers are not using precision agriculture to its fullest extent to make data-based decisions due to limited knowledge, capacity, time and experience among other factors.

More specifically, Duncan and Fraser (2018) argue that there is a "pressing need for knowledge transmission and capacity development in precision agriculture as the vast majority of agriculture data collected is underutilized" (p. 1). Elaborating on this argument, they explain that their interviews revealed that the main form of education farmers received regarding their new precision agriculture tools came from retailers. Additionally, they explain that when it comes to the data collected by these new technologies, the farmers send the information to "companies for data analysis, however this in turn, leads to questions over data ownership, privacy, and being able to trust that the algorithms are actually providing them with the best management decisions" (p. 6). However, Duncan (2018) argues that there is a role for both the government (Wolfert et al., 2017) and educational institutions to play in building this capacity with farmers. For example, government organizations like OMAFRA could provide extension services where postsecondary institutions train the next generation of farmers, advisors, and technicians using the latest technologies to enhance farm management practices.

7. Impacts and Implications of Disruptive Technologies in the Agri-Food Sector

Overall, there is very little academic and policy research examining how these technologies are having an impact on rural communities, especially with regards to farm workers and rural development. There is also debate on how disruptive technologies will change the industry and at what pace. For example, Kelly et al. (2017, p. 2) argue that many "technologists believe disruptive change will impact the industry at an unprecedented rate, fundamentally and substantially changing business practices and models, while industry participants often perceive that technological change will be incremental, manageable, and supportive, in broad terms, of the status quo." As the Ontario Federation of Agriculture (2018, p. 4) argues, "Ontario's agri-food sector is a leading economic engine for the province" contributing $39.5 billion to the province's annual GDP, generating 822,000 jobs that support an annual $8.1 billion in wages and salaries. According to the Advisory Council on Economic Growth (2017), the agri-food sector is one of Canada's largest employers, accounting for 2.1 million jobs, in both urban and rural communities. They argue that, due to this spatial distribution, these jobs represent a new form of economic inclusion. They also note that some agri-food jobs are "increasingly sophisticated as a result of technological progress in the sector, requiring skilled workers with a high degree of digital literacy" (2017, p. 8). However, there is concern that new technologies could replace farm jobs or require significantly different skills (Marowits, 2018). Robots, for example, are increasingly agile with the ability to milk cows, carefully pick apples, and pluck weeds. A decline in farm-level employment is problematic because it may also contribute to population decline and an overall decline in community investment due to out-migration or limited in-migration due to the lack of jobs. Although technologies continue to advance, some exceptions to this are farming jobs that require some human intervention through the operation of machines that struggle with unpredictable environments or the need for physical human presence and activity.

Further implications surround who benefits from disruptive technologies in the agri-food sector. Rotz, & Duncan et al. (2019) argue that major corporations like Bayer, Monsanto and Dow are heavily involved in the expansion of digital agriculture technologies (Mooney, 2018). They argue that this concentration of corporate power is leading to the introduction and adoption of digital technologies that meet the needs of large-scale corporate farm rather than small-scale and medium-sized farms. Rotz, & Duncan et al. (2019) also provide critical insights into how the adoption of these different technologies may influence the composition of the on-farm workforce. The authors argue that automation and labour-saving technologies like precision-technology, robots, drones, and other sensors are beginning to displace some low-skilled migrant labourers (see also Dizikes, 2020; Frank et al.; Holzer, 2018; McKinsey Global Institute, 2017; Rotz, & Gravely et al., 2019). As a result, they argue that "these technologies are being deployed to advance [the firms'] economic profits, rather than to improve the lives of more precarious and vulnerable groups in the sector" (Rotz, & Duncan et al., 2019, p. 119). They also highlight challenges surrounding control over farm-level data, arguing that farmers have little agency in determining consent rights to their data, increasingly important with the rising value of farm data.

Overall, Rotz, & Duncan et al. (2019) offer a cautionary tale while at the same time acknowledging the need for Canadian farms to innovate in order to compete globally. Investing in innovation, technology development, and technology adoption can lead to new business opportunities, increased productivity, and economic growth (ISEDC 2018). As noted earlier, radical and potentially game-changing technological advances in the areas of robotics, nanotechnology, artificial intelligence and machine learning, and sustainable energy generation are positioned to lead the 'fourth agricultural revolution' (Agriculture 4.0), which may help to address large-scale grand challenges facing the sector and society (Klerkx & Rose, 2020; Rose & Chilvers, 2018).

Recognizing this potential, governments at all levels across Canada, postsecondary institutions, and other innovation support organizations are investing in innovation, technology development and technology adoption in the agri-food section. For example, the Canadian Agricultural Partnership is a five-year investment of $3 billion by federal, provincial and territorial governments targeted towards strengthening the agriculture and agri-food sector (Agriculture and Agri-Food Canada [AAFC], 2020). This includes the AgriInnovate Program, which aims to "accelerate the commercialization, adoption and/or demonstration of innovative products, technologies, processes or services that increase agri-sector competitiveness and sustainability" (Government of Canada, 2020). The federal government, through FedNor, also recently invested $588,744 in the Bioenterprise Corporation to create a Northern Ontario tech-hub to support agri-food companies through accelerator services focussing on technology and innovation (FedNor, 2020). Another example is the Agritech Innovation Challenge launched in 2019 by Agriculture and Agri-Food Canada (ACFC) and the British Columbia Ministry of Agriculture. The Agritech Innovation Challenge awarded a total of $150,000 to three projects aimed at enhancing efficiencies and addressing specific challenges in the agri-food sector (AAFC, 2019). Likewise, the Ontario and Canadian governments are investing $2.5 million in 28 projects that will enhance commercialization in Ontario's agri-food sector. This includes $100,000 in cost-share funding to Ontario Agri-Food Technologies to design and launch a pilot project called the Commercial Deal Accelerator (Government of Ontario, 2020).

Other initiatives, such as the Town of Lincoln's AgriTech Hackathon challenge, are aimed to bring individuals, businesses and educational institutions together to find solutions to address challenges in the agriculture, horticulture and ecotourism sectors (Agri Tech Hackathon, 2019). Similarly, Mentor Works, funded through the AgriInnovate - Canadian Agricultural Partnership, provides support for businesses to commercialize and/or adopt innovative agri-based products, technologies, processes or services (Mentor Works Ltd., 2020). Elsewhere, the Smart Farm at Olds College in Olds, Alberta represents a collaboration with industry and sector partners and involves converting the college's farming program into "a living lab for agri-food development". More specifically, the purpose of the Smart Farm is to:

- "Establish the most efficient way to collect and implement the world's best digital agriculture technologies for crop and livestock production;
- Demonstrate increased efficiency of farming operations through implementation of smart technologies and practices; and
- Utilize commercial and pre-commercial technologies for world class education, demonstration, and applied research" (Olds College, 2019, online).

The Smart Farm's projects include autonomous agricultural equipment, data, sensors, technology development and validation, and regenerative agriculture. They also offer a Technology Diploma in Precision Agriculture and a Post-Diploma Certificate in Agriculture Technology Integration (Olds College, 2019).Overall, these initiatives highlight the importance of investing in agri-food technologies to solve pressing challenges, create new business opportunities, increase productivity, and promote economic growth and competitiveness.

However, it is also important to understand that disruptive technologies and innovation can have an impact on rural communities, especially farm workers and rural development. As noted, new technologies could replace farm jobs or require significantly different skills. In addition, a decline in farm-level employment could lead to impacts on rural development including population decline and an overall decline in community investment. Little research exists that explores how disruptive technologies are changing the way the agri-food sector interacts with people and the communities in which they operate and the impacts on workers and rural communities; an area of research needed to better prepare policymakers for Agriculture 4.0 and developments into the future. As a result, more research is needed on how disruptive technologies in the agri-food sector are affecting rural workers and rural communities and how they might do so in the future. Research is also needed to better understand how various levels of government, organizations involved in economic development and skills training, postsecondary and research institutions, industry associations, and other stakeholder organizations are responding or can respond to these impacts.

8. Conclusion

This knowledge synthesis provided a brief history of the technological shifts in the agri-food sector. From the mechanization of production systems to the use of ICTs and smart technologies, agriculture and agri-food production has undergone enormous shifts and will continue to experience digital transformation linked to what is called the Fourth Industrial Revolution. As noted, digitization and the introduction of new, disruptive technologies are currently reshaping the agri-food sector, including: 1) the IoT (Internet of Things) and sensors in the field; 2) IoT and sensors in equipment; 3) drones and crop monitoring; 4) farming and robotics; 5) RFID sensors and tracking; and 6) machine learning and analytics (Newman 2018). Several global trends are driving technology creation and adoption including a growing world population, the need for improved food security, and climate change impacts such as water shortages and contamination to soil degradation, and extreme weather events. At the farm level, the adoption and use of these new, disruptive technologies is driven by several factors, including the desire for more efficiency and improved farm management control with increased farm sizes and pressures to remain competitive. However, barriers to technology adoption and use exist. These include the lack of rural broadband connectivity, limited knowledge of new technologies or technical expertise, implementation costs, and increased concerns over the privacy and security of food systems data.

While there is little academic and policy research examining how these disruptive technologies are having an impact on farm workers, rural communities, and their development, many of the disruptive shifts point to a fundamental change in business practices and models and the need for more education and institutional support. Governments and institutions can proactively prepare producers and businesses for the digital agriculture transformation that is fast approaching on a global scale. Digital trends in agriculture are creating benefits for farmers from increased crop yields to efficient management and farming methods, but new technologies also have the potential to reshape the industry at a new and unprecedented rate. Therefore, more research examining how disruptive technologies are changing the way the agri-food sector interacts with people and the communities in which they operate is needed to better prepare policymakers for Agriculture 4.0 and beyond.

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