THE IMPACT OF DIGITAL TECHNOLOGIES IN IMPROVING SUPPLY CHAIN RESILIENCE: AN EXPLORATORY STUDY IN THE AGRI-FOOD INDUSTRY

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ABSTRACT

Globalization, geopolitics, and socio-economic uncertainties increase supply chain vulnerabilities. Climate changes, natural disasters, and man-made accidents have increased the tension of disturbances. The COVID-19 pandemic has disrupted many supply chains worldwide, putting the agri-food supply chain at a higher risk than ever. Agri-food supply chains face severe and complex challenges due to industry-specific characteristics, such as perishability, short shelf life, long lead time production, and weather dependence. Consumer awareness of having healthy, traceable, and environmentally friendly food products has become an increasing concern, making sustainable development also a vital factor in the agri-food industry. To ensure sustainable development, firms must improve supply chain resilience by discovering, nurturing, and developing resilience capability and competitive advantage. Resilience describes the ability to respond quickly to disruptions and help the supply chain recover.

Recently, digital technologies have developed rapidly, supported by the Industrial Revolution 4.0, which plays a crucial role in a company's operations. Digital technologies help promote core resilience competencies such as visibility, collaboration, and agility through typical technologies such as blockchain, artificial intelligence, fifth-generation technology, big data analytics, additive manufacturing, tracking, tracing technologies, etc. This study uses a theoretical framework from dynamic capabilities and extant literature reviews to determine the research gap in the agri-food industry. The study uses mixed methods: a qualitative research method to examine and uncover the role of supply chain resilience in responding to disruptions in the agri-food industry, and a second study used a quantitative method to examine the influence of digital technologies on resilience

in the agri-food supply chain. This study confirms the critical role of resilience in the agri-food supply chain and the significance of digital technologies in improving supply chain resilience and firm performance. The study also suggests that a firm should proactively build its resilience capability rather than learn from past disruptions.

The findings are useful for academics and practitioners alike, in the acknowledgment of the significant effects of digital technologies on supply chain resilience in the agri-food industry. Some technologies are not agri-food specific but have a place in the industry, while others are tailor-made for farming applications. Parties in the agri-food industry must take advantage of Industrial Revolution 4.0 and digital technologies to flourish in the agri-food industry.

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TABLE OF CONTENTS

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION

Research Motivation

On November 15, 2022, according to the United Nations Department of Economic and Social Affairs (DESA, 2022), there was a milestone of human development that the world population was projected to reach eight billion, resulting in a need for more agricultural and food production to feed the population, which will reach an estimated ten billion by the year 2050. At the same time, supply chains face disruptions, and this is especially the case with agri-food supply chains due to their product characteristics.

According to the Food and Agriculture Organization (FAOSTAT, 2021), the total global value-added products from agriculture, forestry, and fishing grew by 73 percent between 2000 and 2019, reaching 3.5 trillion US dollars in 2018. The number of people working in the industry worldwide reached 874 million in 2020. They contributed 9.4 billion metric tons of primary crops and 337 million metric tons of meat production. In the U.S., agriculture, food, and related industries contributed 5 percent to the United States' gross domestic product with 1.055 trillion US dollars, and U.S. farms contributed 134.7 billion US dollars, according to the United States Department of Agriculture, Economic Research Service (USDA ERS, 2021). In 2020, 10.3 percent of total U.S. employment was in the agricultural and food sector, equivalent to almost 20 million full and part-time jobs. The U.S. household spending of 12.4 percent on food expenditures in

2021 increased from 11.9 percent in 2020. Food expenditure ranks third behind housing at 33.8 percent and transportation at 16.4 percent.

Since China joined the World Trade Organization in 2001, many firms have globalized their sourcing and production and have reduced costs by following lean manufacturing techniques. Global trade increased from 39% to 58% of the global gross domestic product between 1990 and 2019 (Lakovou & White, 2020). Moving toward globalization exposes a firm to supply chain risks, which can be defined as unpredictable events that increase vulnerabilities to the supply chain, such as natural disasters, climate changes, labor disputes, geopolitics, social unrest, cyberattacks, etc. According to Blackhurst et al. (2011), the supply chains are increasing in depth and complexity. In Asia, firms are more aware of unpredictability than in previous decades (Anbumozhi et al., 2016). Firms' concerns about supply chain disruptions, which lead to negative consequences, have greatly increased (Blackhurst et al., 2011).

While the COVID-19 pandemic is not the first disease outbreak to disrupt the supply chains, none have been more devastating or revealed nearly as many supply chain risks that, until then, lay dormant in our industries. The novel coronavirus pandemic and its variants, such as Delta and Omicron, have affected 210 countries and territories, at roughly 570 million confirmed cases, causing more than 6.39 million deaths as of July 2022 (World Health Organization, 2022). In its earliest stages, COVID-19 appeared to be an issue central to China. However, Chinese authorities decided on an early lockdown in several provinces and cities in China, which created unprecedented chaos in global import-export activities. Until mid-2022, the Chinese government continued to implement a Zero COVID policy, and travel restrictions led to severe limitations in the

supply of materials and finished products from China to the world and vice versa. These long lead times caused disruptions, and firms outside China were forced to find alternative sources and other logistic partners to secure orders.

The COVID-19 pandemic has challenged the viability and adaptability of supply chains on an unprecedented scale (Ivanov, 2021a). The flow of goods slowed due to a shortage of human resources to manage activities: loading and unloading, transportation, factory operators, etc., affecting most, if not all, commodities. Supply chains across Asia to Europe and the U.S. became perpetually overloaded. Flights were forced to stop operating, causing delays. The disruption caused many negative impacts on economies and society, such as inflation in the United States and increased poverty in developing and underdeveloped countries. After years of heavy disruptions, the world gradually adapted into a "new normal." Countries now respond more quickly, flexibly, and effectively to the changes as a result of the pandemic, and supply chains will likely focus on performance, cost management, stability, and resilience (Ivanov, 2021a).

The supply chain is becoming more complicated, resulting in increased risks; firms are reassessing their supply, demand, and process disruptions and many are encountering a lack of preparedness and the need to establish greater supply chain resilience needed addressing (Remko, 2020). Specifically, the supply chain in the agri-food industry, with its specific product characteristics, including short shelf life, perishability, seasonal supply, conditioned storage and transportation, and long production lead time – demands greater attention.

Research Questions

Food security remains a critical issue for all countries, given the problems associated with population growth, climate change, geopolitics, conflicts between nations, limitations of natural resources, disease outbreaks, and many other unpredictable events. In developing and underdeveloped countries, food security and safety are a perpetual concern of the government and people because they directly affect public health and social security. In this way, the management of the global agri-food supply chain has dramatically helped firms, consumers, and stakeholders in streamlining supply, demand, and cost management for global food chains.

An agri-food supply chain aims to build and maintain a safe and secure food supply. With the integration of agriculture into food processing, an agri-food supply chain is considered the most advanced and effective method to bring safe and secure food to consumers at the most reasonable price. An agri-food supply chain comprises members, procedures, knowledge, activities, and facilities involved in the agricultural product transition from farm to table. The agri-food supply chain includes four main stages: farming activities, processing phase, delivery activities, and consumption (Kumar & Singh, 2021).

Investing in supply chain resilience can increase the cost of an efficiency premium (Sheffi & Rice, 2005). Supply chain resilience and effectiveness are complementary, not contradictory (Tukamuhabwa et al., 2015). Resilience is crucial because agri-food supply chains feature different factors that need to be examined (Hobbs, 2021). The agri-food supply chain is susceptible to turbulence in the external environment, causing disruption and a significant impact on all stakeholders. Therefore,

building a robust and resilient agri-food supply chain is essential in a volatile market. Notably, the agri-food supply chain has all the features of Volatility, Uncertainty, Complexity, and Ambiguity (VUCA), or an abbreviation called the VUCA world (Bennett & Lemoine, 2014). Any disruption to an unsecured food supply has ripple effects, such as price increases that affect people physically and mentally.

The evolution of information technology is quickly, dramatically, and deeply impacting the world. The digitalization of the supply chain is being promoted as essential across industries, and agri-food should be no exception. The breakthrough of Industrial Revolution 4.0 and digital technologies have created a new impetus for the current supply chain digitalization process. Innovative technologies have impacted how supply chains are managed, affecting supply chain disruption and risk management (Ivanov et al., 2019). Industrial Revolution 4.0 and digital technologies contribute to changing business processes and supply chain operations, increased flexibility and big data analytics, and improved visibility in the supply chain (Ivanov et al., 2019). Digital technologies allow firms to collect and process information related to risks and disruptions in real-time and control ripple effects in the supply chain, enhancing resilience capability. Setting up the supply chain resilience of the agri-food industry is complex and challenging due to its distinct characteristics from other supply chains, which are discussed in the subsequent chapters. The contribution of digital technologies will improve resilience components, such as flexibility, agility, and collaboration (Lezoche et al., 2020). In addition, the study of the effects of digital technologies in the agri-food industry is limited, and this study will be highly applicable to firms. Thus, unresolved problems in the literature relate to supply chain resilience and the impact of digital technologies in the agri-food industry.

The research gaps in this study can be summarized in two statements. Statement one: There is a lack of full understanding of the resilience of the agri-food supply chain, which is different from that of other supply chains. The agri-food supply chain has many unique characteristics that lead to differences in the constitution of its resilience capabilities. Statement two: There is a lack of full understanding of how digital technologies enhance resilience capability in the agri-food supply chain. These two statements suggest that an investigation is necessary, leading to the primary research questions.

The research questions that guide the investigation of the benefits of employing digital technologies in agri-food supply chains are as follows:

RQ1: How do digital technologies assist the agri-food supply chain in responding to disruptions by affecting supply chain resilience?

RQ2: How does supply chain resilience affect the firm performance under the impact of digital technologies in the agri-food supply chain?

To answer these questions, the study aims to examine supply chain resilience and firm performance as enabled and enhanced by digital technologies following disruptions in agri-food supply chains. In this context, the study's main constructs include digital technologies, supply chain disruptions, supply chain resilience, and firm performance in the agri-food industry. The research gaps are addressed in two separate studies. The role of supply chain resilience and what distinguishes resilience in the agri-food industry from other industries was previously identified as a gap in need of investigation. Additionally, the improvement of resilience capability enabled and enhanced by digital technologies in dealing with disruptions and leading to firm performance has also been identified as a research gap.

Study one is a qualitative method using semi-structured interviews with industry executives, directors, and managers to answer the research question through their insights at a strategic level. This level is crucial to understanding the impact of supply chain resilience in response to disruptions. A comprehensive understanding of resilience capability is crucial to effectively absorb the shocks of disruption in reducing losses and maintaining business continuity, quickly adapting suitable business processes to the changes, and restorative actions to bounce back and consolidate its robustness to overcome future disruptions. Based on the research results, the study confirms the crucial role of resilience in the agri-food supply chain, a supply chain with all features of volatility, uncertainty, complexity, and ambiguity.

Study two examines the impact of digital technologies on firm performance. This study two uses a quantitative method by using surveys to explore the key elements of supply chain disruptions, resilience capability, and digital technologies in the context of the agri-food industry. The industry respondents provide their insights at the execution level in promoting collaboration in the agri-food supply chain, increasing visibility in the whole supply chain, and improving agility to increase the supply chain's absorptive capability. Furthermore, study two suggests which technologies will benefit the agri-food supply chain in dealing with disruptions.

Findings from the completed study include the crucial role of resilience in the agri-food supply chain, a comprehensive definition of the agri-food supply chain, a distinction between the agri-food supply chain and others, the positive impact of digital technologies in improving resilience capability and firm performance and suggesting a

list of digital technologies which benefits to the agri-food industry. Those findings will be helpful to both academia and practitioners.

CHAPTER 2

LITERATURE REVIEW

A resilient supply chain is considered a next-generation supply chain with integration and visibility of supply chain stakeholders. It can be viewed from raw materials to finished products, from resources suppliers to end users. A resilient supply chain is able to detect, respond to, and recover from disruptions quickly.

Supply Chains

The term of supply chain is often associated with supply chain management, especially related to a specific commodity. All goods have a distinct supply chain, network composition, and management methods. In this way, a supply chain is a network where participants manage the flow of goods and services through their procedures and operations to deliver to end-users by mobilizing other partners to be involved in this value-creation process (Christopher & Peck, 2004). Another way to look at a supply chain is as a system of individuals, entities, procedures, knowledge, activities, and facilities involved in moving a product from suppliers to producers to end-users (Mentzer et al., 2001). Nevertheless, what defines a supply chain is the presumption of transforming components into a finished product for end-users. A typical supply chain begins with raw materials exploited from natural resources, includes many production links, moves to many layers of storage facilities with progressively smaller and larger geographic distances, and ultimately ends with consumers as a finished product. Hence, the definition of a supply chain is the flow of goods from its creation to the end-users; the

number of participants required is more than two parties (Mentzer et al., 2001). A supply chain including suppliers, focal firms, and customers is a directed supply chain, while an extended supply chain includes upstream and downstream suppliers, and an ultimate supply chain includes the extended supply chain and third-party engagement (Mentzer et al., 2001).

Generally, a supply chain is geared toward meeting demand and keeping inventory to a minimum. Many aspects of value chain optimization include sourcing and procurement strategy to balance the lowest cost. Using just-in-time processes optimizes production flows and maintains optimum production and distribution locations to serve customers with the highest satisfaction.

The Agri-Food Supply Chain

The agri-food supply chain (AFSC) describes the activities that produce, process, and distribute agricultural products from farm to table (Aramyan et al., 2007). Like other supply chains, the agri-food supply chain is a network of members coordinating and moving a product to provide satisfactory products and services to end-users (Peck, 2005). There are several unique characteristics of an agri-food supply chain: limited shelf life, perishability, seasonal supply, long production lead time, conditioned storage and transportation, and volatile markets, which renders the agri-food supply chain more complex to manage (Van der Vorst, 2000). Typically, an AFSC comprises one or two supply chains that can be distinguished as either an agricultural supply chain or a food supply chain (Aramyan et al., 2007). In order to examine an agri-food supply chain holistically “from the farm-to-table” perspective, this study reviews definitions of the

agri-food supply chain in the extant literature review and proposes a new definition of an agri-food supply chain that considers the chain as an integrated value chain. This proposed definition of the agri-food supply chain is as follows:

> A collaborative network includes individuals, households, and firms involved in producing, processing, distributing, retailing, and consuming agricultural or food products.

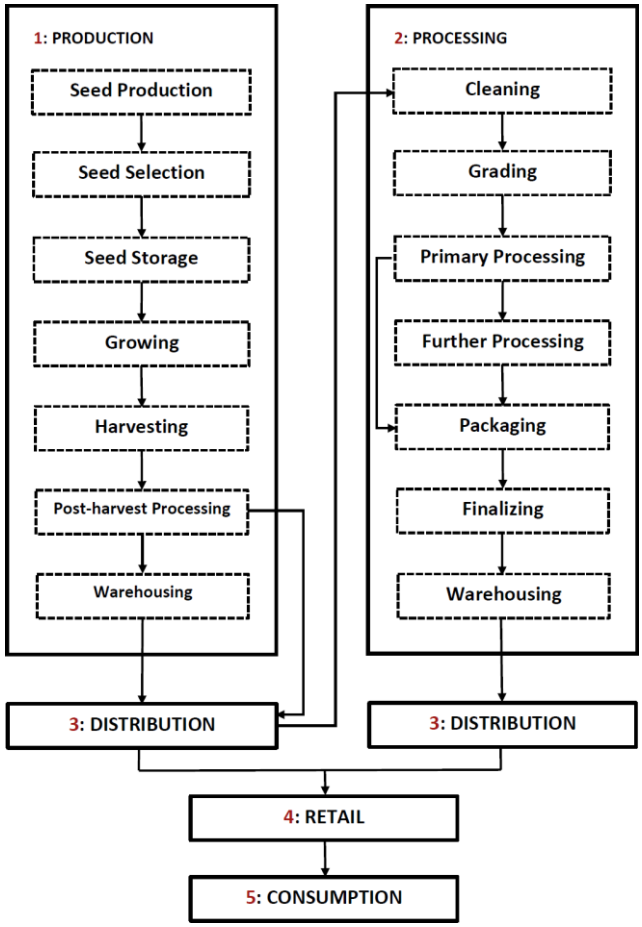


Figure 1. Typical Flow of Diagram of an AFSC

This study examines the supply chain as an integrated chain from agricultural production to food production to provide new insights into this business phenomenon. There are five phases of the AFSC, including two collaborative supply chains: 1) Production phase: Agricultural supply chains for fresh products such as livestock, flowers, fruit, fresh vegetables, and horticultural products. Due to fresh products with limited shelf life, the product can be delivered from production locations to distribution after post-harvest processing and then delivered to end-users; 2) Process phase: Food supply chains for processed food products. This food supply chain has primary processing and further processing, e.g., wheat from the farm can be delivered to the processing plant to produce wheat flour as primary processing or to produce bread and cakes as further processing; 3) Distribution phase: This includes warehouses, farm elevators, wholesale centers, etc.; 4) Retail phase: This includes supermarkets and other types of retailers; 5) Consumption phase: This includes individuals and firms qua end-users.

Agricultural products and their processing have received significant attention from public health officials (Ahumada & Villalobos, 2009). The changes in consumer preferences about health consciousness and traceability lead the firm's operation to meet higher standards such as environmental, social, and governance (ESG) criteria. These requirements will add more regulations and standards to the agri-food supply chain, adding to existing complexity and uncertainty.

Supply Chain Disruptions

Nowadays, in turbulent and uncertain environments, the agri-food supply chain is highly vulnerable to disruption events. A supply chain disruption (SCD) is defined as a disrupted incident of the flow of goods and services in a specific supply chain (Craighead et al., 2007). Supply chains inevitably face the risk of disruptions, which are largely unavoidable in the long run and can have severe short and long-term negative consequences on financial, operational, and market performance (Hendrick & Singhal, 2003; Tang, 2006; Bode & Wagner, 2015). These disruptions stem from natural disasters, man-made accidents, pandemics, political and economic uncertainties, social unrest, cyber and terrorist attacks, or simple disequilibrium between supply and demand. Moreover, disruptive events are no longer located solely in only one firm or within a country, given the nature of a global supply chain integration. For example, the tsunami that hit Japan in 2011 which resulted in the world auto industry staggering for several months. Thailand suffered floods in the same year, which affected the hard disk supply in the world's computer industry (Chopra & Sodhi, 2014). General Motors experienced an 18-day labor strike at its brake plant, which caused a stop in another 26 factories and caused a decrease in quarterly earnings of 900 million US dollars. In 1996, a delivery failure at Boeing for two critical parts led to an estimated loss of 2.6 billion US dollars (Blackhurst et al., 2005). Hendrick and Singhal (2003) analyzed how the stock market reacted to firms' supply chain negative announcements, which decreased shareholder value by 10.28 percent.

Notably, despite understanding how to protect their supply chains from costly disruptions, firms have done very little to prevent the incidents or mitigate their negative

impacts (Chopra & Sodhi, 2014). This is because of the source of supply chain disruption is largely unpredictable. Instead, firms should focus on improving resilience and the capability to cope with the next supply chain disruption that comes its way.

Supply Chain Risk Management

There exists a possibility of risk of disruption to the flow along all elements in the entire chain (Mentzer et al., 2001). Events can disrupt the supply chain, affecting one or all members. Disruptions are a typical consequence of risks, and firm performance can be affected when the risks do result in disruption. For example, a fire at a Royal Phillips Electronics, N.V. plant in Albuquerque, New Mexico, in March 2000 disrupted the semiconductor supply to two major customers of the plant, Nokia and Ericsson. Nokia immediately began switching to other suppliers, while Ericsson continued to pursue a single-sourcing policy; the shutdown caused Ericsson to lose 400 million US dollars in sales (Chopra & Sodhi, 2004).

Supply chain risk management (SCRM) plays a crucial role in effectively managing supply chains in volatile market situations to prevent these kinds of scenarios (Ho et al., 2015). The definition of SCRM that most scholars and industry practitioners agree on is that SCRM is an integrated collaboration to identify, mitigate, and monitor any uncertainty that might negatively impact a supply chain. SCRM aims to maintain business continuity by frequently evaluating the entire supply chain through collaboration between members to develop effective solutions for managing the outcomes (Manuj & Mentzer, 2008). SCRM usually consists of four processes: risk identification, risk

assessment, risk mitigation, and risk control (Ho et al., 2015). A brief explanation of each process is given in the following paragraphs.

Risk Identification: Firms identify risks through designed tools and scientific processes to identify potential losses and the likelihood of their occurrence (Manuj & Mentzer, 2008). Firms must collect the supply chain's operational data, including internal and external data.

Risk Assessment: This stage assesses the potential risks and predicts the impact levels on the supply chain. The assessment process will provide insights into the potential risks and predicted circumstances (Manuj & Mentzer, 2008).

Risk Mitigation: Supply chains become more complex, leading to increased supply chain risks and challenging a firm to reduce risks (Christopher & Peck, 2004). With risk assessment and different degrees of damage caused to the supply chain, firms implement appropriate mitigation strategies before a disruption occurs and subsequent actions during and after disruption (Manuj & Mentzer, 2008). Results obtained from this process will be an essential reference for the following process and improve the firm's risk identification and assessment capabilities.

Risk control: The risk control process reduces losses and systematically implements control processes on preparedness to respond and employees' awareness of supply chain risks (Manuj & Mentzer, 2008).

Supply Chain Resilience

Supply chain resilience (SCR) is considered a primary factor of SCRM to ensure the supply chain can effectively cope with the disruption (Ponomarov & Holcomb, 2009).

Disruptions are classified into three types: inside the firm, within the supply chain network, and environmental disruptions (Christopher & Peck, 2004). Disruptions such as disease outbreaks, trade wars, and unforeseen events, to name a few, are causing volatility and increasing risks for firms and countries. Firms must reduce risk by creating a resilient supply chain that can respond quickly to uncertainty and limit vulnerability. Resilience is the capability of an organization to recover from a disruption to normalcy or a desired state (Christopher & Peck, 2004). Resilience allows firms to adapt supply chain preparedness for uncertainties, responsiveness, bounce back, and maintain business continuity (Ponomarov & Holcomb, 2009). In this way, resilience is a competitive advantage that facilitates the responsiveness of the firm's supply chain (Sheffi & Rice, 2005), and resilience enhancers are those factors that assist firms in promptly and efficiently recovering from disruptions (Mentzer et al., 2001).

Christopher and Peck (2004) described the four principles of a resilient supply chain as (1) reengineering, (2) collaboration, (3) agility, and (4) setting up a risk management culture from the executive board to their subordinates in the supply chain. Sheffi and Rice (2005) state that a firm can be resilient in building extra resource reserves (i.e., redundancy) or increase flexibility in place of redundancy as a response means. Juttner and Maklan (2011) considered the main factors for improving resilience: capabilities of (1) collaboration, (2) velocity, (3) visibility, and (4) flexibility. Stone and Rahimifard (2018) employed a different lens; their perspective is based on phases of disruptions, including organization resilience and SCR with (1) redundancy, (2) flexibility, (3) collaboration, (4) visibility, (5) agility, and (6) adaptability. An additional proposal by Pomaronov and Holcomb (2009) recommended dynamically integrated

logistic capabilities. Researchers commonly recommend six elements in the relevant literature: (1) flexibility, (2) redundancy, (3) collaboration, (4) reconfiguration, (5) agility, and (6) visibility as primary components of building SCR (Chopra & Sodhi, 2004; Juttner & Maklan, 2011).

Flexibility plays another crucial role in SCR; most scholars recommended flexibility as their first-choice element in supply chain resilience. Flexibility is the ability to quickly adjust the firm's operation (Pettit et al., 2013). Flexibility promotes resilience in the firm, and it is considered a competitive advantage and an organic ability to screen risk and respond quickly (Sheffi & Rice, 2005).

Redundancy is a strategy to set up a stock reserve higher than usual as a safe solution to cope with disruptions and diversify sources by increasing suppliers to prevent any undesirable shortage (Sheffi & Rice, 2005).

Collaboration is the ability to mobilize participants to cooperate effectively (Pettit et al., 2013). Supply chains are often associated with many participating stakeholders, so there is a need for high collaboration, including collaborative planning between supply chain participants and supply chain intelligence, that can effectively mitigate the risk (Christopher & Peck, 2004).

Reconfiguration recognizes supply chain structure and design principles to reconfigure the supply chain to a resilient model with a supply-based strategy (Christopher & Peck, 2004). The risk may lead to a supply chain disruption that needs the supply chain to be reconfigured to tradeoff between cost optimization versus redundancy.

Agility is the capability to cope promptly with uncertainties, such as responding promptly to unexpected changes (Christopher & Peck, 2004). The main component of

agility is velocity. Supply chain velocity is the product's speed to the end-users or how fast the supply chain responds to changes in the entire chain (Christopher & Peck, 2004).

Visibility is the capability to see the whole chain from beginning to end. The supply chain risk will decrease if demand is increasing in visibility across the entire supply chain (Chopra & Sodhi, 2004)

SCR will be enhanced if a corporate risk management culture is implemented in the organization. Implementing SCRM at the focal firm by a team that maintains business continuity, including senior management, and developing SCRM principles is essential (Christopher & Peck, 2004). SCR can be enhanced by building information management capabilities inside the focal firm (Ponomarov & Holcomb, 2009).

Resilience in Agri-Food Supply Chains

The resilience of the agri-food supply chain is a vital area of research because of the nature of the business, which has perishable and short-shelf-life products, causing increasing volatility in the supply chain. Stone and Rahimifard (2018) identified new definitions of the resilience of AFSC, ultimately suggesting that the resilience of AFSC is the collaborative capability of all participants to ensure adequate and timely stability in the food supply and rapidly detect disruptions with appropriate strategies to respond, recover, and learn post-disruption. Tendall et al. (2015) described resilience is the ability of a multi-layer system to respond to food demand and supply changes in case of uncertainties. Regarding production and ecosystem perspectives, Macfadyen et al. (2015) implied resilience reduces the variability of production causes from outside, which may significantly impact the economy and society.

The COVID-19 pandemic severely impacted the agri-food supply chain through its impact on perishable products (Kumar & Singh, 2021). A dependable agri-food supply chain is significant for society and countries that are deeply involved in global supply chains. The effects of supply chain resilience on the agri-food supply chain are impacted by the firms and each country's specific social, economic, environmental, and political structures. Understanding the resilience of the agri-food supply chain will help firms better adapt to and overcome challenges from internal and external environments.

Digital Technologies

Digital transformation (DX) is a process of adopting new technologies into the firm. When applied correctly, this activity will completely change how a firm is doing business; it helps it create new businesses or improve performance. DX transcends traditional roles such as sales, marketing, and customer service. Instead, DX begins and ends with the way firms think and engage customers in a different direction. DX is a business model of the digitalization process that starts with the digitization phase, transforming information from analog to digital (Verhoef et al., 2021). While data stored in physical form (analog data) is usually more stable, digital data can be more easily shared and accessed and can be transmitted indefinitely, with no loss over time and through data duplication (Verhoef et al., 2021).

The next stage is digitalization, which is the application of digital technologies (DTS), automation, and digital data to simplify how firms operate and change how organizations work (Li et al., 2016). Digitalization is not about changing the way of doing business or creating new types of firms; it is about getting the firm to perform

better and faster. Data can be accessed quickly through digital technologies, verification, and more effective solutions (Li et al., 2016). As digital technology evolves, we can generate ideas for using digital technology to do business in new, faster, and more efficient ways.

Digital transformation is a comprehensive change of business models and organizations by applying digital technologies, advanced technologies, and digital information and developing novel business models. DX improves productivity and creates business value (Verhoef et al., 2021; Ebert & Duarte, 2018). DX is a journey with multiple interconnected intermediate goals, continuously optimized across the hyper-connected era of business processes, departments, and ecosystems. DX aims to create the ability to take full advantage of digital technologies and automation that brings novel business models to firms with better positions in the industry and in a more innovative way. In this study, we focus on applying digital technologies to change and improve business processes and the impact of digital technologies on supply chain resilience.

Industrial Revolution 4.0 and digital technologies offer many promising opportunities, mainly through improved service quality and transparent and cost-effective operations. Ivanov et al. (2019) summarized previous studies that showed the application of DTS has an association between digital technology and SCRM. DTS positively impacts supply chain management and reduces the ripple effect; DT applications also create new supply chain models. Typical digital technologies include tracking and tracing technologies (T&T), the Internet of Things (IoT), integrated automation, machine learning (ML), and big data analytics (BDA) (Ivanov et al., 2019). Industrial Revolution 4.0 technology can improve manufacturing flexibility. Notably, big data analytics will

enhance visibility and play a crucial role in data veracity. This can apply to many fields, such as inventory management, customer demand forecasting, production process optimization, quality management, and SCRM (Ivanov et al., 2019). Tracking and tracing technologies include scanning and monitoring barcodes, quick response codes (QR), radio-frequency identification (RFID), global positioning system (GPS), blockchain technology, and others. These technologies capture real-time commodity information, enhance visibility, and mitigate supply chain risks (Ivanov et al., 2019). Tracking and tracing technologies also play a crucial role in authenticating supply chain participants, thereby enhancing the collaboration and visibility of all supply chain participants. Blockchain promotes supply chain resilience by reducing transaction costs and time and improving partners' connectivity and visibility of supply chains (Min, 2019). Firms use DTS frequently to gather real-time information to cope with the propagation of disruption and promote resilience (Ivanov et al., 2019). In addition, some digital technologies applied to the agri-food industry, such as smart farming, precision nutrition, and aerial imaging technology, will promote collaboration, redundancy, and visibility.

The AFSC is characterized by short shelf life, perishability, and specialized logistic conditions. Achieving a resilient agri-food supply chain is complicated because they face more risk impacts than other supply chains (Lezoche et al., 2020). Therefore, the AFSC is under huge pressure to manage and mitigate predictable and unpredictable risks. DTS will help firms track good flows in real-time, identify risks early, and have an immediate response plan. The main contribution of DTS is to improve flexibility and agility, thereby enhancing the resilience of AFSCs (Lezoche et al., 2020).

As supply chain risks become more frequent, devastating, and unpredictable (Blackhurst et al., 2011). SCR helps the AFSC overcome disruptions quickly and minimize losses. DTS plays a significant role in SCR, such as enhancing visibility in the supply chain (Ivanov, 2021b). Hence, this study examines the role of DTS in AFSC through its impacts on SCR and explores whether and how specific digital technologies affect each component of SCR.

Firm Performance

In the business environment, firms pursue to improve their performance in any way possible. A firm faces severe competitive pressure to conquer by doing better and moving faster and more efficiently than competitors. Firm competition in the changing environment is necessary to measure and monitor firm performance (FIR); through performance, a firm can gain experience, learn from setbacks, and ultimately progress forward (Taouab & Issor, 2019). Firm performance is a prominent notion in organizational study, and the definition of firm performance has been diversely interpreted over the years (Miller et al., 2013). Firm performance was considered in terms of organizational efficiency and the ability to exploit its environment by using limited resources. The criteria to measure performance are productivity, flexibility, adaptability, conformity, and institutionalization (Seashore & Yuchtman, 1967). Firm performance measures the effectiveness of an organization and the ability to create values to maintain firm stakeholders' satisfaction (Harrison & Freeman, 1999). Performance is the ability to exploit the available resources efficiently to achieve the firm's objectives (Peterson et al., 2003).

Performance measurement can provide valuable information to allow management to monitor performance and progress. Lebans and Euske (2007) suggest that performance is a group of financial and non-financial measures that provide information on the extent of accomplishments of objectives and results. Traditional measurement is mainly financial, and non-traditional measures are mainly non-financial (Ghalayini & Noble, 1996). According to Gimbert et al. (2010), performance measurement is a group of financial and non-financial measures that help decision-making by collecting and analyzing quantified performance information data. This research firm performance is a context-specific construct in the agri-food industry, supply chain disruptions, supply chain resilience digital technologies, and both financial and non-financial outcomes can measure firm performance.

This literature review exposes a lack of literature related to supply chain resilience as enabled and enhanced by digital technologies in the agri-food supply chain. The research gaps for this study include the need to understand how agri-food supply chains differ from others and the lack of full understanding of resilience capability and firm performance in dealing with supply chain disruptions via the aid of digital technologies in the agri-food industry.

CHAPTER 3

SUPPLY CHAIN DISRUPTION MATTERS: A QUALITATIVE ANALYSIS OF THE ROLE OF SUPPLY CHAIN RESILIENCE IN THE AGRI-FOOD INDUSTRY

Background

The study contributes to a greater understanding of the nature of supply chain disruptions and resilience in the agri-food industry and the role of resilience capability in addressing disruption and improving firm performance. In order to answer the research questions, a qualitative study (study one) examines the basics of supply chain resilience in the agri-food industry, the differences from other supply chains, and respondents' perceptions of potential enhancements to firm resilience through deploying digital technologies. Study one used a qualitative method to investigate whether supply chain resilience plays an important role in the industry and which elements are considered the most important effects. Key elements and codes from this analysis will be further developed and examined in study two, which will use quantitative research.

The existing literature on the agri-food supply chain describes the supply chain with its unique characteristics: perishability, limited shelf life, long lead time production, weather dependence, etc. The agri-food supply chain is complex, with at least two supply chains, which are the agricultural supply chain and the food supply chain; the supply chain also possesses a huge number of participants from upstream to downstream. The extant literature has also suggested that volatility, uncertainty, complexity, and ambiguity (VUCA) in the agri-food supply chain and the disruption is unavoidable, and the

consequences are more and more fatal. Thus, building supply chain resilience is crucial, and enhancing resilience capability and effectively dealing with disruptions is a vital mission of firms in the agri-food industry.

This chapter is organized with the literature and a discussion above, as well as the following sections. A theoretical framework is discussed, then methodology, data collection, and analysis methods are provided. Data analysis and results are presented, including the coding process, first-order codes, second-order codes, and key themes. The last section describes the findings and proposes research propositions and concept models of digital technologies to affect supply chain resilience. Limitations and recommendations for future research are discussed at the close.

Theoretical Framework

The theoretical frameworks used in this study are dynamic capabilities theory and resource-based view theory. Firm resources are the main factors that bring competitive advantages and business efficiency (Wernerfelt, 1984; Barney, 1991, 2001a). Firm resources that possess valuable, rare, inimitable, and nonsubstitutable characteristics (VRIN) are competitive advantages (Eisenhardt & Martin, 2000). Thus, the resource-based view is the premise for dynamic capabilities. Dynamic capabilities are capabilities that rapidly respond to uncertainties from the outside through efficient reconfiguration and integration of internal and external resources (Teece et al., 1997). They are the basis of creating competitive advantages and bringing business efficiency and a means by which firms distinguish themselves (Barney, 1991, 2001b). In addition, dynamic capabilities are the ability to upgrade core competencies to cope with changes in the

external environment and gain a competitive advantage (Wang & Ahmed, 2007). Dynamic capability is not only the process but also the agent that creates the process. Therefore, a firm's capabilities are often built through reciprocal actions of the firm's resources. Dynamic capability is formed through the perception of opportunities and challenges of enterprises, and it is used to solve problems in a systematic, timely, and market-oriented manner (Barreto, 2009). Considering this definition, dynamic capacity is a multi-dimensional concept based on environmental analysis, timely decision-making, and fundamental changes in the enterprise's resources.

Dynamic competencies emphasize the continual pursuit of rearranging, renewing, and rebuilding firm capabilities in response to outside changes (Leonard-Barton, 1992), the basis for creating firm competitiveness and business efficiency. Dynamic capabilities are a source of sustainable competitive advantage (Collis, 1994). Therefore, dynamic capabilities can consolidate assets and focus on allocating assets (Eisenhart & Martin, 2000). The critical components of dynamic capabilities include the following:

Adaptive capability is a competency to configure and collaborate resources in reacting to uncertainty (Gibson & Birkinshaw, 2004). Oktemgil and Greenley (1997) found that with this capability, enterprises take advantage of external opportunities and changes to respond to the market quickly based on product innovation, but adaptive capabilities need not be limited to product innovation.

Absorptive capability emphasizes engaging internal and external knowledge to create a sustainable competitive advantage. Absorptive capability is the firm competency to realize the worth of factors from outside, combined with internal factors, to create unique products (Cohen & Levinthal, 1990; Fabrizio, 2009), processes, etc. Innovation

capability is an important resource in creating competitive advantages for enterprises. The ability to innovate is a core element that determines viability and success. A sustainable competitive advantage relies mainly on its capacity to develop knowledge, create processes, and exploit this knowledge effectively (Fabrizio, 2009).

Innovation is vital in redesigning the supply chain model toward rapid recovery and designing principles in the supply chain (Christopher & Peck, 2004).

When built to suit each firm, the dynamic capabilities of the supply chain will ground the resilience of firms' supply chains in the agri-food industry. Supply chain resilience builds on dynamic capabilities theory, which can quickly adapt to environmental changes. The agri-food supply chain is a complicated system, and using dynamic capabilities is crucial to getting through large changes (Beske, 2012). Dynamic capabilities help a firm develop the agility to adapt to market demands (Masteika & Cepinskis, 2015). Following changes in market volatility and supply chain disruptions, firms will trigger their capabilities to respond to environmental changes effectively. All the processes will create the firm's dynamic capabilities. The dynamic capabilities of firms will promote supply chain resilience by fostering collaboration, reconfiguring, creating agility, and maintaining the risk control culture.

Methodology

This study gathered qualitative primary data from firms in the Agri-food supply chain (AFSC) to examine the focal business phenomena. The qualitative research method is the primary method of systematically collecting and analyzing data in grounded theory (Myers, 2020; Strauss & Corbin, 1990). Additionally, qualitative research insights that

emerge from the AFSC interviews can be used to enhance firm supply chain resilience in the face of disruptions.

Study one's approach is based on grounded theory that is discovered from systematically collected and analyzed data in social studies (Glaser & Strauss, 1967). Grounded theory develops contextual, process-oriented, and explanatory descriptions of organizational phenomena (Myers, 2020). Grounded theory provides a comparatively well-documented method for analysis (Urquhart, 1997) that enables original discoveries closely related to the data, and grounded theory research develops new concepts and theories from related business phenomena (Myers, 2020). In addition, its implementation can support further studies and uncover new directions or methods of analysis that contribute to additional new findings (Strauss & Corbin, 1990). Additionally, the study used flexible pattern matching - the interaction of deductive and inductive methods at the literature review in coding relevant scholarly articles from main constructs to second-order codes. Flexible pattern matching enables iterative matching between theoretical and observational models, combining deductive and inductive methods with greater flexibility and more rigorous analytical processes (Bouncken et al., 2021).

Data Collection

Data collection consisted of conducting semi-structured interviews and a non-probability sampling method. The snowball sampling method developed by Goodman (1961) was used to recruit participants for the research based on their extensive experience and social networks. It used public databases from industry trade associations and event organizers to identify firms that meet the study's requirements. A recruitment

letter was emailed to the public company's email address, with the purpose of being forwarded to relevant persons; if the firm is willing to do so, then the participant can contact the researcher. The sampling strategies are purposive, allowing the selection of potential participants who must have extensive experience, skills, and knowledge in the field. Interviews were conducted until the study matured, meaning there were no further findings. Participants were required to meet the following requirements, shown in the recruitment letter/email: i) firms in the agri-food industry and those firms that contribute significantly to the agri-food value chain; ii) the size of the firm must be small, medium, and large sized, with intensive experience in managing their supply chain and understanding supply chain risks and resilience; iii) willing to identify potential participants; iv) permission of firm to access key information, and v) the participant agrees and is capable of being interviewed in English, as the interviews will cover geographic regions including North America, Europe, and Asia.

The recruitment letter/email was delivered to potential participants to introduce the research project and objectives, identify potential participants and firms, and encourage them to respond to the research. The participant is encouraged to introduce potential participants who are the best fit for the research. Based on a small population, this will expand to a significant population for conducting interviews. The recruitment letter also states how the interview will be conducted either online or in-person, with a duration of less than one hour, the date and time, and the location at the participant's convenience. Because the COVID-19 pandemic caused travel restrictions and different geographic regions operate under different time zones, it is better to provide adequate information to the participants for the efficiency of the interview. Once they agreed, they

were enrolled. Informed consent agreement that was acknowledged before each interview; the informed consent form reintroduces the researcher and their affiliated institution. The informed consent form acknowledgment restates the research objectives, the time required for the interview, voluntary participation, and expression of the benefits of the research findings, which may be helpful to relevant practitioners, including the participant's firm, in improving competitive advantage and efficiency. Moreover, the consent agreement assures each participant's right to withdraw during and after the interview to protect their privacy. The consent agreement also explains ways to maintain anonymity and confidentiality. It discloses the small risk of data hacking and how software and devices record, archive, process, and destroy the data. The consent agreement provides the interviewee's understanding of the research, their contribution to the field of study, and how the research will be conducted. The interview began once the interviewee agreed to the consent form by stating "yes" or "I agree" to participate. Both of these documents are provided in Appendix A.

All participants, executives, directors, and managers followed the same initial format with eight interview questions to open the door to topics, using open-ended questions to uncover new topics and themes. Based on the participants' industry knowledge and experience, the interview questions motivated the participants to share their insights about resilience and the impact of digital technologies in improving supply chain response to disruptions in the agri-food industry. Table 1 shows the interview questions, key themes, and descriptions to examine the study.

The semi-structured interviews were conducted until data saturation with the research themes was confirmed, and no further findings were uncovered compared to

previous interviews or without new insights (Myers, 2020; Miles et al., 2020). The interview structure, with a preformulated format and flexibility during the process, consists of open-ended questions that allow the interviewees to freely share their insights about the research topic and themes. Some new topics or themes may naturally be generated during the interview (Miles et al., 2020). These may uncover new insights from further analyses after the interview process.

Table 1 consists of eight interview questions divided into three categories: i) Introduction to collect data from personal and corporate information of the interview; ii) Main themes with the questions focused on supply chain disruptions, supply chain resilience, digital technologies, and firm performance; and iii) Further discussion section with open-ended questions that encourage interviewees to share their perspectives about supply chain resilience and digital technologies at their firms. Their insights may uncover new findings during this session. Lastly, the study discovers the firm's benefits from supply chain resilience in firm performance.

Table 1.

Key Themes, Description, and Semi-structured Interview Questions

Theme	Description	Semi-structured Interview Questions
Introductory section	Demographic information of the participant	Can you tell me briefly about yourself and your firm? *(Name, gender, age, career path, position, firm's name, locations, main businesses, employees, etc.)*
Agri-food supply chains	Defining characteristics and the factors specific to the agri-food supply chain that make it significantly different from other supply chains.	Can you tell me about the agri-food supply chain and what unique characteristics make it different, in terms of complexity, from other supply chains?
Supply chain disruptions	Significant disruptions by type, characteristics, consequences, and timeframe that have had a significant impact on the agri-food supply chain.	Can you tell me what disruptions your firm has had and the characteristics that are common among the disruptions? When did they occur? What was the impact on your business?
Supply chain resilience	Actions that lead to resilience following a supply chain disruption and why the action was effective in the context of the agri-food supply chain.	How does your firm identify a supply chain disruption in a timely manner, and what alternative activities may be employed to deal with the disruption? What activities or solutions do you think are resilient factors to the supply chain at your firm?
Digital technologies	Digital means of establishing/reestablishing supply chain resilience that significantly contributes in the context of the agri-food supply chain.	What digital technologies have been incorporated or do you plan to use in supply chain operations at your firm in order to prevent or respond to supply chain disruptions? How do digital technologies affect your firm's supply chain resilience?
Firm performance	The outcomes of supply chain resilience with the impact of digital technologies on the firm performance.	What are the benefits that your firm may get from supply chain resilience? *(In terms of business continuity, customer satisfaction, revenue, profit & loss, etc.)*
Open-ended questions	Further discussion with interview topics and uncovering new insights of participants about the study.	Did I miss anything about the mentioned topics, or do you want to tell me something more?

Data Analysis

Interviews were recorded in two ways: In-person interviews were recorded by the SONY recorder, while Zoom software (Zoom.us, 2022) and Microsoft Teams software (Microsoft.com, 2022) recorded face-to-face online interviews. After each interview, either with the SONY recorder or Teams/Zoom software, the digital recording was transcribed by Otter software, an advanced speech-to-text transcription and translation application (Otter.ai, 2022). Then, the transcription was rid of identifiable information by a study identification, which was also manually cleaned of transcription errors. After cleaning, the transcription was uploaded into NVivo 1.6.1 (2021).

NVivo 1.6.1 (2021) assists researchers in storing, organizing, analyzing, and finding insights into qualitative data such as interviews, surveys, and social media content. A software package like this is an efficient tool for storing, analyzing, and tracing qualitative data (Creswell & Creswell, 2018). All digital recordings were archived and stored on two password-protected, encrypted computers, with one as a backup. Identity is kept separate from interview data but can be linked if needed; the separated list of identity information is password protected. When transcription process finishes, all the links and digital recordings of the interviews are destroyed. There is a small risk of data hacking, which may happen whenever providing information online. No paper records were created; all notes and summaries were stored in digital and password-protected versions. Based on findings in study one at the strategic level, the research will go further with study two to discover the impact of digital technologies in improving supply chain resilience at the execution level.

Table 2 shows the themes used to analyze articles in NVivo, followed by the coding methods proposed by Miles et al. (2020), with the codes that must be created before conducting the fieldwork. The list of themes is formulated under the literature review, research question, and conceptual model. As mentioned in the methodology section, the study used the deductive method to formulate the main constructs of the study as key themes to second-order codes derived from literature reviews and the explanation of those codes. These theoretical models will make a stronger relationship with observed models that emerge from the interviews.

These themes (codes) are assigned to code the articles' data. Each second-level code has a definition tagged to data during the coding process. The agri-food supply chain (supply chain) theme is tagged with four themes at second-level codes, including ambiguity, complexity, uncertainty, and volatility. Second-level codes provide an additional layer of analysis of the key themes, providing a deeper understanding of first-level codes (Creswell & Creswell, 2018). The first-level code, such as disruptions, was identified during the coding process, and then the second-level code was also assigned; it was possible to have demand, supply, external, or internal disruptions as second-level codes. These second-level codes enable the researcher to assign the origin of disruption and gain a deeper understanding of the basics of disruption. It is the same as the coding approach for other first-level codes with resilience, digital technologies, and firm performance. The analysis method of the pilot project is the same as the method that applies to interviews, as mentioned above.

Table 2.

Key Themes to Codes Level One and Two

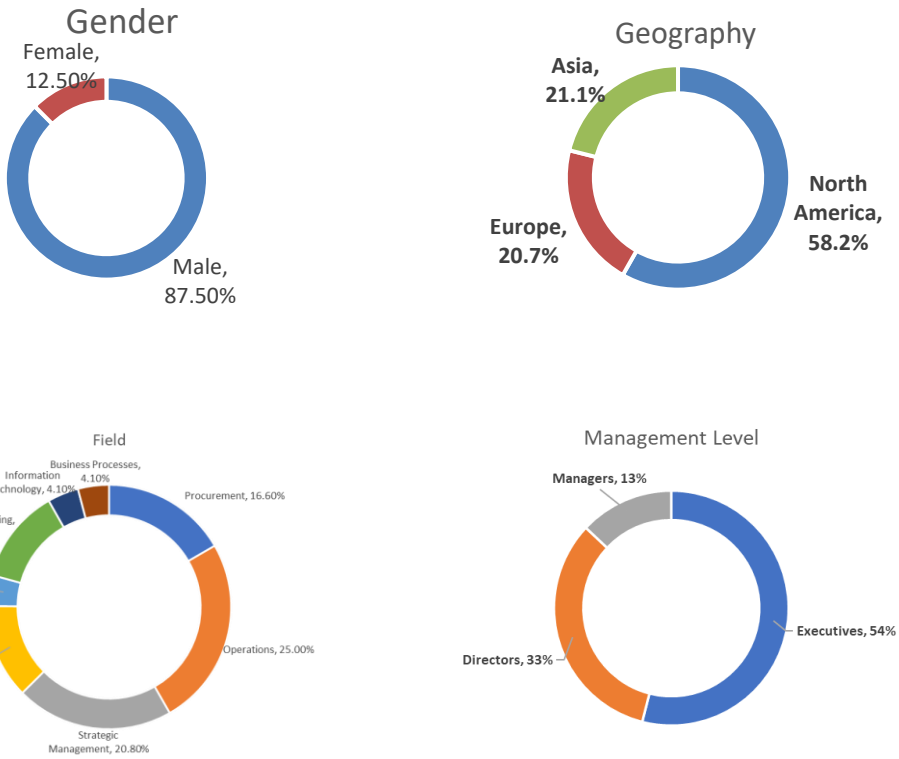
Level 1	Theme	Level 2	Theme	Description
1	Supply Chains	2	Ambiguity	Imprecision in decision-making, lack of clarity and consistency, ambiguous situation
1	Supply Chains	2	Complexity	Interdependency, variety, copiousness
1	Supply Chains	2	Uncertainty	Probability of occurrence
1	Supply Chains	2	Volatility	Variation of material flows
1	Disruptions	2	Demand disruptions	Higher demand, panic buying
1	Disruptions	2	External disruptions	Pandemics, natural disasters, social unrest
1	Disruptions	2	Internal disruptions	People, processes, internal issues
1	Disruptions	2	Supply disruptions	Suppliers
1	Resilience	2	Agility	Effectively and timely response to temporary changes
1	Resilience	2	Collaboration	Coordination of members in the network
1	Resilience	2	Flexibility	Ability to adjust production and workflows
1	Resilience	2	Reconfiguration	Redesign, changing business model.
1	Resilience	2	Redundancy	Contingent plan, Inventory
1	Resilience	2	Visibility	Ability to track and trace
1	Digital Technologies	2	Connectedness	Being connected
1	Digital Technologies	2	Responsiveness	Being responded
1	Firm Performance	2	Financial outcomes	Revenue, profit, and loss
1	Firm Performance	2	Nonfinancial outcomes	Business continuity, brand awareness

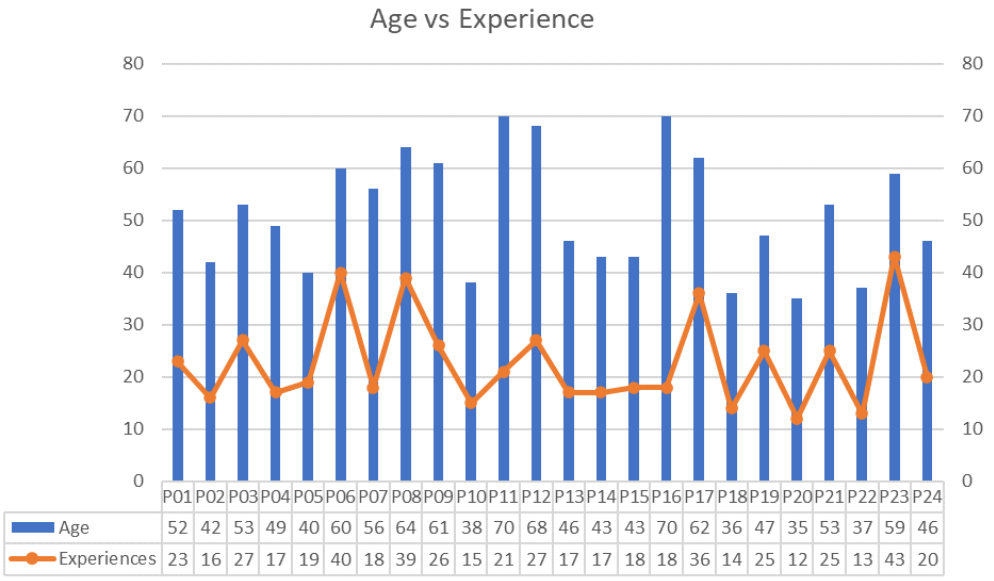
Results and Discussions

Descriptive Statistics

Data collection was conducted until data saturation, and additional interviews did not uncover new information. Every interview was given an identification number of P01 to P24. The interview data was saturated when the number of interviews reached twenty-one. To ensure data saturation was reached, the researcher conducted three more interviews from different demographic regions. A total of twenty-four interviews were conducted, with participants hailing from two North American countries, three European countries, and three Asian countries. Thirteen participants were from the United States, which is equivalent to 54 percent. Gender classification with 12.5 percent female and 87.5 percent male.

All combined participants possessed 546 years of working experience in the industry, with an average of more than 22 years of working experience, confirming that the participants have an extensive and comprehensive understanding of the industry. Most participants are from operations, strategic management, and procurement fields, accounting for more than 60 percent of total participation. The participants from small and medium-sized firms account for 42 percent, and the rest are from large firms with 58 percent. The smallest firm has 20 employees, and the largest has nearly 14,000 employees—participants at the executive level account for 54 percent, and the director-level participants account for 33 percent. A total of 87 percent of participants from the leadership level provided strategic views for the study, which meets the goal of this study, which is to provide a strategic view on the role of resilience in the agri-food supply chain. The details of the participants' descriptions are in Figure 2.





	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24
Age	52	42	53	49	40	60	56	64	61	38	70	68	46	43	43	70	62	36	47	35	53	37	59	46
Experiences	23	16	27	17	19	40	18	39	26	15	21	27	17	17	18	18	36	14	25	12	25	13	43	20

Figure 2. Descriptive Statistics of the Interview Respondents.

While concluding this section, we address the significantly different ratio of the gender of our participants, with three females and twenty-one males, which may mean that most of the people who are working in the agri-food industry are male. According to Schisler and Sbicca (2019), between 1978 and 2007, despite the rise in female principles from 5.2 % to 13.9 %, clear distinctions in work exist between males and females in the agricultural industry. As such, we find that our male-dominated interview participants match what is being seen in agriculture, with approximately 5-10 % of ag workers being female. These statistics are aligned with other scholars' findings.

Results and Discussions

All interview transcriptions were imported into NVivo for coding in a multiple-step process. All nodes were categorized into five overarching themes and one category for new findings that emerged from the interviews. The five main themes (code level one) are the agri-food supply chain (supply chain), supply chain disruptions (disruptions), supply chain resilience (resilience), digital technologies, and firm performance. Every code level one will have several codes in level two that are mentioned in the literature review and data analysis. Table 3 shows coding counts and levels one and two with references.

Key themes were synthesized during the interviews and qualitative data analysis, which explained the study's research question. The key themes are the agri-food supply chain, supply chain disruptions, supply chain resilience, digital technologies, and firm performance. Second-order codes were synthesized from scholarly articles in the literature review chapter, with eighteen codes to display key themes of the study.

Table 3.

Coding Counts

Codes	Source Count	Reference Count
Supply Chain	19	85
Ambiguity	6	8
Complexity	14	23
Uncertainty	18	29
Volatility	14	25
Disruptions	24	88
Demand disruptions	7	7
Supply disruptions	24	40
External disruptions	19	30
Internal disruptions	8	9
Resilience	24	223
Agility	14	24
Collaboration	21	52
Flexibility	20	38
Reconfiguration	18	37
Redundancy	13	19
Visibility	19	42
Digital Technologies	24	106
Connectedness	21	44
Responsiveness	19	42
Firm Performance	23	55
Financial outcomes	19	29
Nonfinancial outcomes	18	24

Mapping key themes of the study to second-order codes that were synthesized from literature review to interview coding as first-order codes, those codes were synthesized from twenty-four interviews in study one. Figure 3 shows the coding process from first-order to second-order, key themes, and the assertion synthesized from this study. Figure 3 provides an abridged version of semi-structured interview coding, key

themes, and assertion/theory of the study. The full version of the coding is available in Appendix B.

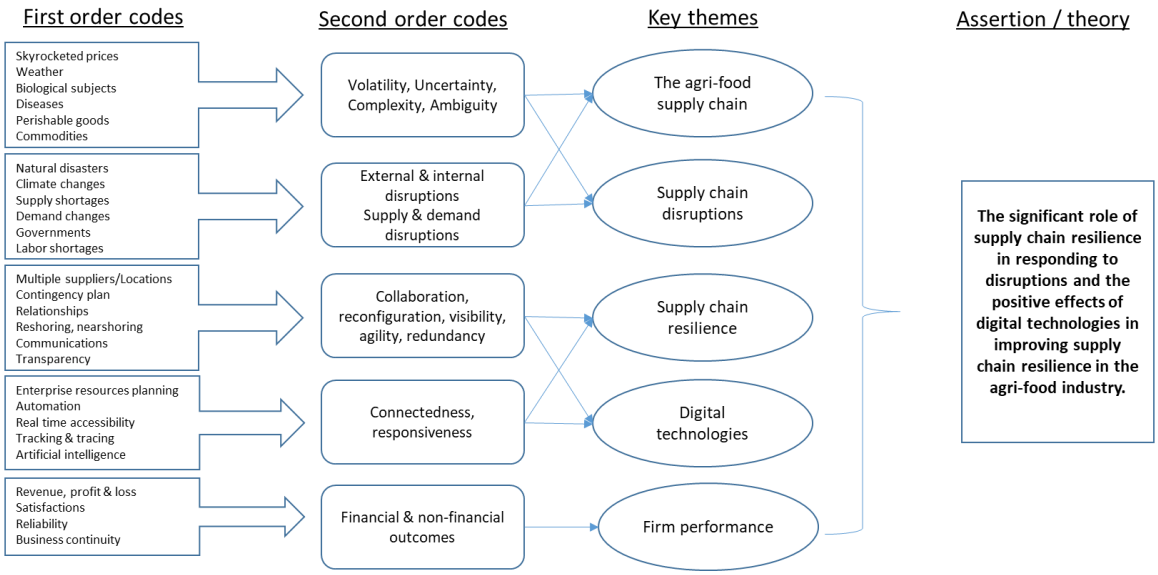


Figure 3. Semi-structured Interviews Coding and Themes

The following sections divide the details of first- and second-order codes by key themes.

The Agri-Food Supply Chain

Recall that VUCA, which stands for volatility, uncertainty, complexity, and ambiguity, can best describe supply chains' issues (Bennett & Lemoine, 2014). The agri-food supply chains have typical characteristics such as weather dependence, perishability, seasonal patterns, conditioned logistics, transportation, etc. Quotations follow that demonstrate situations faced by participants in the agri-food supply chain:

> I would say a little bit of maybe unpredictable nature; no one has a crystal ball that can predict when there will be a constraint in the ocean freight capacity, you can try and look at historical trends and match that to data

on growth in a market. But the unpredictable nature is difficult. But as they change or the market changes around them, do you have enough flexibility in your production capacity and capability? Do you have enough inventory to manage through maybe historical spikes in demand? And so, a lot of data regression is required to balance all of the elements of your supply chain to mitigate those unexpected pieces that often come from various disruptions you've described. (P01, Vice President Worldwide Procurement)

I always like to say that the animal will tell you how well it's doing in its environment. At the same time, the workers themselves, it's agribusiness as a whole, is an extremely hard job. You can't control the weather; you can't control the ability to have feed delivered on time; sometimes, you have live animals constantly producing, whether piglets, chicks, or eggs. (P07, Sr Vice President Worldwide, Quality Assurance)

COVID stops things and slows things down. But the war and the sanctions that are put in on that stop the air movement because pigs have a shelf life that is very short, right? Every day, they grow a kilo more, and they outgrow their ability to quickly be put in crates on an airplane. A few weeks ago, delay caused those specific animals to no longer be qualified, which means they are virtually worthless except for meat value; when you expected to clean a fair amount of money from and then what's below them, the younger ones would have to be retested. And there's just an enormous process there. For China, it's more than eight weeks of health testing certifications before the airplane. So if you get to the end, it's a problem. So, the sanctions on Russia really affected the global supply chain, particularly for all animals, because Russian company airbridge was carrying three-quarters of the animals around the world, not just pigs, everything. And when they were sanctioned not to be able to be used, only a few companies remained. Chinese companies can cross the Russian Airspace, but Western companies cannot. Can't stop for fuel. So now the limitation is on the airplane, which is significant. So the price difference is more than double now. The other real big concern in our industry is the lead time for this. I have a customer for Southeast Asia who knows that it's 18 months before they think their farm will be done. That we have to make genetic changes because we do cross matings or pure line baiting specifically for a country because genetics in Japan and genetics in Malaysia are very different. (P08, Director of Business Development, Asia)

Well, it's there's no firm's schedule. An example, this past Saturday night, we had a shipment of Holstein dairy bulls to go to Bangladesh. We have been canceled three weeks in a row, and in that fight, the flight was only offered on Saturday nights. So our flight was canceled on the 14th, the 21st of May the 28th of May. And we finally got everything confirmed. And the bulls were exported on the 4th of June. So because the flights kept

changing and connections, and they're short staff, and so those are part of the disruptions. It is because, with live animals, we're on a clock; we have a product that cannot sit on a dock or in a warehouse; they have to go and move. And there's an animal welfare issue because you want the animals to be comfortable and to get there in the best possible condition. So we deal with those types of things. (P09, President & CEO)

So, of course, as you know, in the entire world, so many challenges when we look at sort of the supply chain, and certainly with pork products, there's always that sense of the cold chain and keeping the integrity of the product. So it even makes it more challenging when you've got perishable goods. (P10, Vice President, Sales & Marketing)

To give you a bit of a feeling, we were able to ship from Europe to the U.S. with customs clearance and everything in a time. Minimum four weeks, max six weeks, that's now we're talking about 12, 15, 18 weeks. So in total, for sure, as you're saying, the total time of a project is getting longer. But also not that you have only longer lead items and you no longer project schedules, you have also done in increasing those, you know, logistics, for example, a container bringing one container from Europe to the U.S. has been tripled in the last one and a half years. Yeah, we are saying it was maybe two or 3000 in the past; it's now seven 8000 per 40-foot container. If we look at shipping from China, it's even four or five times what we paid in the past, so logistic costs are crazy. I mean literally three, four, or five times and an average longer ship shipping times than the unavailability of electrical components, but also raw material and some basic materials like wood, rubber, stainless steel, normal steel, etc. Their unavailability and the raw material price increase. I think those are the main issues at the moment we have. (P13, Vice President, Engineering)

We work with big integrators, but we also work with smallholder backyards. They don't know when they will waste, but it's very difficult to predict. So that's why we have these variations for the backyard market. But it's difficult to predict the exact accuracy. (P15, General Manager, Asia)

Agricultural products were also faced with a volatile situation when an industry executive mentioned agricultural commodities and trading. We have raw material supply chain disruption. Okay, we are affected by our Ukraine-Russia war. We normally get our feed wheat from the Black Sea from Ukraine. This is one of the key components of our feeds; because of the war, we have to shift to a different supplier, like Australia, which is a higher price than the black sea wheat. I think, number two, we are affected by animal diseases that restrict the movement of animals, as you know, African swine fever in pigs and bird flu for chickens. I think we also have bird flu right now in our country. So a lot of local government units close

> their border. So you know, it's not easy for us to transfer day- old chicks from one province to another. (P17, President)

Discussion. The agri-food supply chain is sensitive to any challenge from the outside; it is composed of commodities to serve the basic needs of people. Thus, when any unexpected events happen, it may lead to ripple effects on supply and demand, such as "skyrocketed prices." The agri-food supply chain faces volatility, uncertainty, complexity, and ambiguity.

Supply Chain Disruptions

The supply chain disruptions in the agri-food industry, abbreviated as "disruptions" in the NVivo, were categorized into four types: demand disruptions, supply disruptions, external disruptions, and internal disruptions. Participants shared their insights about disruptions in their firm operations:

> Disruptions in logistics and regional supply, where traditionally, companies may have been able to source materials and focus on core competency, and procurement from single regions or even more global supply chains had to pivot to regional supply due to disruptions. I think an interesting one has been an internal disruption that comes from the workforce. So I noticed how the most recent generation, I'll use millennials. I mean, we could be into Generation Z right now. But their approach to work-life balance and their portability within companies in terms of tenure and staying within have changed how we need to recruit, how we need to retain those employees, and how we need to communicate with those employees. (P01, Vice president, Worldwide Procurement)

The participant talked about the ripple effect of supply disruption due to the external disruption that impacted the supplier, and then it affected the focal firm:

> A big issue that we ran into last year was more weather-related. There was a deep freeze that went through North America. So propionic acid and

propylene glycol are two ingredients that were heavily affected. The freeze ended up basically destroying their facilities in Texas; that or they're not, they're not capable, not prepared to handle that kind of climate. For that extended time, it was three days until it essentially shut down one of our key suppliers, Dow, and put one of our suppliers at about half production on propionic acid and propylene glycol. We had business with a large company, Cargill, where they would buy a specific product from us. And they had we had an agreement in place with them that they would only buy it from us and that we could only sell it to them because it was a unique product for them. They ended up pulling that business for reasons unclear to us still today. And it left our firm with about $8 million of inventory on specific raw materials for that business. It didn't go into any other ingredients for us. We were left with that raw material on hand. So that was a big disruption to our business. We've had a lot of suppliers that have run into internal disruptions where they've had labor shortages. So I think our biggest impact is on the poultry side. But they're having difficulty keeping their lines filled with workers to process the parts we buy from them. So that's been a major disruption in the past two years, starting with COVID, but it's still ongoing. (P02, Procurement Manager, North America)

That was just labor availability. So not only do we not have the labor that we needed at the time of an outbreak, but also the labor market has drastically shrunk where, four years ago, I could hire for any opening relatively quickly. Now, I've actually had openings that have been open for over a year. So the availability of labor is not just an accusation; it's a chronic issue. One of our main raw materials is sunflower oil. Well, most of the sunflowers in the world are grown in Ukraine. So now everybody's shifting to other oil sources, which is constraining those because all of these markets were, I think, optimized and made extremely efficient. But there was no potential for any major swings within their efficiency models. (P03, Vice President, Operations).

From supply chain disruptions up until probably two to three years ago, supply chain issues were not much of a concern for us. I mean, once in a while, we had parts that normally have a four-week lead time that would jump out to six weeks. But for the most part, we were always able to maintain enough inventory, whether a short delay or delivery of parts or components. Now in the last couple of years, the supply chain issue has probably become the biggest struggle within our organization; I shouldn't say, probably without a doubt, it is our biggest struggle. It surpassed finding qualified workers, which used to be our biggest concern; now, it is finding the components and parts to complete the work we need to do. It's been a challenge. (P11, General Manager)

I would say the majority of our disruptions over the last couple of years, particularly, have mainly been from the manufacturers and to us that they

> are unable to provide us with the product for various reasons. We have had a lot of disruptions in minor items. Now. I mean, our largest concern is if we can't get a vaccine or a medication for pigs just because that's going to impact that animal's health. (P18, Purchasing Manager).

This participant talked about the volatility in price due to disruption in logistics and the price of the commodity:

> What happened is container freight prices just skyrocketed. So, instead of being $2,500, for a container, we were talking $15,000 per container. So what does that do to the price of the product? It's okay if you're buying a Nike shoe coming from China. An extra 50 cents for container freight shipment isn't that big of a deal on a Nike shoe, but when you're talking about a commodity or an agricultural ingredient when maybe the price is only $1 a pound coming over, you add another 50 cents on it, that doesn't make sense to ship it into the US. So what happened was, because we don't have enough supply in the US of a lot of those ingredients, it was panic mode. (P19, Director of Procurement)

> The major disruption for our business usually comes from governments and diseases for our business. (P20, General Manager)

> The main disruption we had we still have, I would say, the middle of last year, was starting for electronic components. For example, intelligent card smart cards, motors, and frequency converters were the main disruptions or restrictions on the supply chain on the incoming supply chain for Buhler, then on the outbound supply chain, we have mainly had disruption on the routes from Asia to Europe and Asia to the US. (P21, Global Head of Project Execution)

> Just recently, again, in Wuxi, China, where 600 employees of our organization stood overnight for two weeks in the factory in big holes to work for us to get the output done. But if you have situations like this, it's not only the issue of your production; it's also the issue of your suppliers, your supplier network, being disrupted. (P23, Global Head of Animal Nutrition)

Discussion. There are four types of disruptions. Industry practitioners usually refer to supply disruptions or upstream disruptions. Since the COVID-19 pandemic, practitioners have been strongly concerned about external and supply disruptions. The

ripple effect of a disrupted event inside the supply chain may severely affect others in the supply chain.

In summary, the two main constructs above are the agri-food supply chain and disruptions in the industry. Almost all participants mentioned the typical characteristics of the agri-food industry, such as “extremely hard job,” “live animals,” “short shelf life,” “worthless,” “weather dependence,” “long supply chain,” transportation complexity, “unpredictable,” “easily disrupted,” “government regulations” and so on. The participants highlighted the importance of alternative solutions, redundant plans, etc. Based on the participants’ insights, the study found that the supply chain is easily vulnerable to disturbance, leading to disruptions.

Supply Chain Resilience

The role of supply chain resilience in the agri-food industry is the main research question of this study. Scholars have proposed several elements that constitute resilience in the supply chain namely agility, collaboration, flexibility, reconfiguration, redundancy, and visibility. In this qualitative study, industry practitioners mentioned the following:

> So as not to borrow from something that was said before. But redundancy is a big piece in that; if you can imagine spaceflight, they would have redundant systems that are in place to correct for an out-of-service, unplanned incident. Do you have the redundancy in your system to cover those disruptions or unplanned outages? From our perspective, we would have globalization of our production on a certain product line. And so we would be able to serve our customers from multiple sites and regions. As I say, inventory carrying is always kind of the most expensive and last resort. But still, it's an element; it's an element to ensure that you have the elasticity in your supply to your customer to ensure those promises and commitments in terms of lead time and fulfillment. And again, from a procurement side, it's multiple approved suppliers. It's the harmonization of specification for your article of commerce so that when the unexpected

> happens with a force majeure or some adverse weather event, you don't have to go through the process of identifying how to fix that you've already made the contingency plan. And you're aware of the options you have, I'd say the levers you have, but the alternatives you have to continue to fulfill the commitment to the end users. (P01, Vice President, Worldwide Procurement)

Participants mentioned the relationship and the benefit of collaboration and visibility in the chain:

> First, I think building strong relationships with our suppliers and having that communication flow from them as quickly as possible when they see disruption is the most effective way. So last week was a great example. We had a fire down at one of our suppliers. And so I got an alert that day. And then how do we treat that we took that email and quickly put as many orders in with our alternative supplier as we could base on that email? And two days later, we got a notice of a force majeure from our supplier that had the fire because of the fire. So with that situation, we were able to be ahead of the other customers that we're gonna do the same thing and move orders to the new supplier. So having that visibility, that early warning sign, gave us a chance to stay ahead of it and avoid or minimize the impact on our firm. (P02, Procurement Manager, North America)

Participants also highlighted the resilience with redundancy, collaboration, agility, and flexibility of the chain, even though the cost of operations may be higher:

> We've buffered our inventories in more of a just-in-case scenario where we carry extra inventory in the areas that we feel are compromised or have supply chain challenges. So we carry extra inventory to help us through potential shortages or slowdowns at our suppliers. So the buffered inventory and the multiple supply sources are proactive ways. Especially in the past few years, we've had to be very agile with the ingredients we use, with our time to research and test out new ingredients and suppliers. So its agility has been critical in the past couple of years to keep up with supply. (P02, Procurement Manager, North America)

> We had been going through a supply assurance model where we got three or four vendors approved for every raw material. Other people have been going the other way, where the fewer vendors, the less cost, and there are fewer audits. So we were broader than most of our competitors. So we've

been able to keep our raw material interruptions minimal. (P03, Vice President, Operations)

Again, the resilience factor for us is those different relationships we build, right? Again, we want to have multiple sources for our raw materials. That way, if one source becomes incapacitated, somehow. We can get further into that in the technology section, too, but we can go another avenue and get things I know, we're also always looking at our formulas and finding out if there's other say we, we can use a different carrier, maybe, again, a real-world scenario, sunflower oil is, going through the roof or an unavailable because of the war in Ukraine. So, are there other carriers we can use to research that kind of thing, right? So I know we're always looking at the availability of materials. If there are substitutes or multiple vendors, we can get those from them. I think that brings a lot of resilience to our supply chain here, Kemin. (P05, Vice President, Information Technology)

One of the things I really appreciate is, especially on the logistics side, that we have a gentleman who does a lot of our logistics here, and he's been with us for almost 25 years. He's built solid relationships with many of our carriers, many of our freight companies export, and both domestic; he stays abreast and stays in tune with what's going on. And he keeps us up to date regarding those challenges that we may encounter, whether tomorrow or in months to come. So that collaborative effort is working together with the other functional areas, whether it be procurement, logistics, warehouse, or manufacturing, and that is to look not only at the present but the future. I think we've learned or we'll learn from the disruptions we've encountered, especially with COVID, as we build up a lot of inventory and raw material inventory. And looking back, was that the right decision? (P06, Business Processes Manager)

The following participants with longtime working experience in the industry provided a comprehensive view of resilience. They mentioned agility, collaboration, and reconfiguration of the business processes to deal with the disruption.

Now we can operate our equipment automatically hydraulic, lower, or electrically. And if we're short on hydraulic components, we can convert them to pneumatic or electric components. I think that gives us a lot more flexibility going down the road. The immediate answer would be multiple suppliers going out and coming up with multiple sources for what we need. The second one would be redesigning equipment. So we may use another similar, but a little bit different piece of equipment that would be more available. I really think we have the one really strong positive is that

we've become a lot more communicative with our customer base, we've developed a closer relationship because they know we're in it for the long haul, we understand the issues, they're going through that money is tight, we can't, you know, we're not just jacking the price up to make more money. And we've communicated that to them. And I think they understand it. They're seeing it with other input costs and ingredients. And so I think it's, it's been good that in that it's forced us to be. It's forced us to have a closer relationship with our customers. (P11, General Manager)

So, we see now that we have to stop way more than in the past we have to pre-order stuff; we have to assemble on stock, which we had never done before that normally we assembled to ship and not assembled to stock. We are adjusting our processes to that more agile market we have seen, so some of our processes were quite rigid because they were never at risk regarding things like this. (P13, Vice President, Engineering)

Many activities to we increased our stock of materials, and also we opened more supplies, and we also have to optimize the production process. (P14, General manager)

Supply chains and resilience of supply chains raise the issue of how to manage change generally and how quickly we manage chains, and that's about how adaptable and flexible we are as an organization. (P16, Chairman)

So I would say most often, it is dependent upon our relationship with the manufacturer, and that's why it's important to have regular meetings with them or regular communication with them so that you can learn of any supply chain disruptions because, in the industry, I don't think they are often going to come out and tell you, they have a shortage because if they tell you they have a shortage, everyone's going to try and buy up the remainder of the supply. (P18, Purchasing Manager)

One of the main factors is just knowing that we cannot put all our eggs in one basket. (P19, Director of Procurement)

We have learned over the past two years that flexibility is the key. Yeah, if you're if your system is very rigid. Yeah, you're stuck in your ways. You're not; it's especially elastic. It's especially when COVID first hit; you didn't know what would happen. (P20, General Manager)

Now, we immediately made contact with our suppliers; we invited the suppliers in order to find the solution; on the one hand, we specified our needs early. So they could plan better than before, and we also proposed alternatives we support or certain. For example, if electronic parts are unavailable, we look out for alternatives, even for alternative suppliers or alternative resellers; we try to avoid launching mass orders to the suppliers

> because that completely disturbs the supplier. So, instead of ordering parts through various channels, we directly contacted the suppliers to organize the parts, and the suppliers very well received that. So we had a good relationship, which helped a lot to organize the parts that were the main activity. (P21, Global Head of Project Execution)
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> The resilient factor about that was that we managed to follow up with all of these suppliers of all kinds, all over the world, with all of our different entities and keep the quantity up and all of our entities to follow them. Obviously, it is not an easy task, and currently, some materials are not available worldwide. (P22, Director of Project Management)

The study found that during the interview, participants recommended resilience, which means being well-prepared in advance to cope with disruption. Resilience means being strong, resisting difficulties, and being more adaptable to challenges. Due to the complexity of the agri-food supply chain and the frequency of uncertainties and disruptions, practitioners preferred to use redundancy as a resilient factor by increasing inventory, which they/their organizations rarely used before. The following is confirmation from the participants:

> The crisis, but you have to be prepared in advance; you have to make the investment, and it becomes part of your value proposition that you have those contingencies, that elasticity, and that additional capacity. So plan ahead, look at the market, look at the global situation and determine how we need to adjust or change to ensure that we have the availability to accommodate those upcoming events that may be occurring. (P01, Vice President, Worldwide Procurement).
>
> Being resilient means being strong and resisting the moves we must make until we're ready to move. So we've got to be resilient means we're strong enough, we're not going to be overcome by disruptions, we're going to accept them for what they are, take them on board, and look at ways of doing things better. (P16, Chairman).
>
> I think the biggest benefit of this resilience is that companies are better prepared to stay in business for the long term and be more adaptable to the challenges of the supply chain. (P24, Director of Business Development).

The study uncovered that resilience would increase firm robustness by overcoming future disturbance; robustness is defined as the ability to resist disrupted events without adaptation (Fabbe-Costes & Ziad, 2021).

Discussion. There were many changes in participants' perspectives during the pandemic and resulting disturbances. Before, practitioners preferred to promote resilience by enhancing supply chain flexibility, which helps the company quickly adjust its operation to deal with disruption. They managed an efficient chain using just-in-time processes. Today, participants focus on enhancing supply chain visibility, collaboration, agility, and redundancy – an element without cost optimization. Given increasing volatility, uncertainty, and complexity, the practitioner's perspective on supply chain management prepares for the just-in-case.

Supply chain resilience was the heart of the interviews, and we discussed how to promote resilience in the agri-food industry. After the discussions, the industry practitioners mentioned promoting resilience through enhancing supply chain visibility and supply chain collaboration. They tried to increase the visibility of their supply chain to respond quickly to unforeseen events. As a participant mentioned, "be the first to know," They can quickly design a suitable solution to deal with the situation before other competitors, then increase competitive advantage.

Digital Technologies

The influence of digital technologies is also the primary criterion for collecting data for this study. Digital technologies are uniquely powerful tools to promote resilient

elements like visibility, collaboration, and agility. Participants shared their views on the topic as follows.

The following Participants recommended using artificial intelligence, cloud computing, and enterprise resource planning systems (ERP) as digital tools to increase a firm's ability to deal effectively with unexpected events.

> As you know, it is much better clarity to your supply chain and the lead times. But that is not just the answer because when disruption occurs to your supply chain, you are more aware of them sooner, allowing you to respond sooner, but you still have to have a contingent plan to respond. The speed is the biggest piece and so can the digital technology tell you that you needed to invest in another manufacturing line two years ago, likely not. But when there is the potential for a problem, the digital and digitalization technology can help alert for the same manner that I say artificial intelligence is telling us about external influences.
>
> I think that in terms of having artificial intelligence and digitalization on data, you will start to be alerted to problems before the wheel is screech squeaking. We use artificial intelligence to mine the data out there to know if you have government influence, a labor strike, or a force majeure declared by some feedstock so that you can start your corrective action or risk mitigation sooner. And suppose you are not, as a company, leveraging the data that's out there and those resources. In that case, you then fall behind in relative nature to your competition, where technology really has to fill a gap in terms of clarification, harmonization, consolidation of the market demand, and then translating that back all the way through the value chain. (P01, Vice president, Worldwide Procurement).
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> It would be great if you talk about digital transformation as having those forecasts having our customers linked to us and we linked to our suppliers, but where they can send forecasts back to us and what their demand plan looks like. And we, in turn, send what our raw material requirements are to our suppliers and have that almost automated, so the whole supply chain is fed through. And there's, I mean, I can never say there are no surprises, but you can minimize the surprises and have that that free-flowing information up and down your supply chain of demand needs and how those are changing weekly or even daily through our relationships with suppliers, they hopefully let us know as soon as possible, but also through some online digital tools that we subscribe to. (P02, Procurement Manager, North America).

Besides our ERP system, I'd say we haven't put a lot of extra digital technology in place for the supply chain. We built some custom SharePoint solutions for them to help monitor and track things. We're using basic programs like Excel, our ERP system for our raw material needs, and our procurement lists for things like that. We're using run-of-the-mill technology. But we are looking to transform that right now; we have a big initiative right now to restructure our ERP system. So we're going to take a look at our processes across the board. Try to standardize and improve those, then move to a cloud-based ERP system. We don't really have an issue with downtime right now. But moving to the cloud gives us a little bit more resilience for that technical outage. You can do supply chain planning in that way; through your technology, you can even have it talk to your vendors and your customers so that you can try to get a complete vision of the supply chain So, our project right now is really setting the foundation so that in the future, we can plug tools like that in and have more resilience. So there's some tools like that, that you can build into get real time visibility into supply chain that can help you plan for those immediate issues, not necessarily for those long term supply chain disruptions.

I think it's called Nexus, but then you get that real real traceability for all of your shipments that are going on at a time so you can see what's going on. And you can also start to feed into different data feed sources for different socio socio economic situations that are going on again, pandemics, wars, you know, floods, you can, you can start to get feeds on all of that stuff. So you can pay attention to the global, the global supply chain and adjust how you need to write. Yeah, so I don't have specifics. But there's technologies out there that allow you to do that. (P05, Vice President, Information Technology)

So that is one of the digital technologies we feel are going to be beneficial, better management of our inventory and forecast utilization right now. We manage it more manually. And we feel that in the future, we'll have the tools necessary to provide more accurate information and to help our suppliers plan and give them more lead times to support our business. So if we have more automation in place, and use that technology, then we can provide our suppliers more advanced notice for materials we need, as well as provide our customers more information in regards to the planning of their orders. (P06, Business Processes Manager).

When there is a digital connection from one side of the Pacific Ocean to the other, it makes, it just makes the transaction better. And it allows us to ensure that those animals are working properly. Our resilience comes in from there also back into what we offer services from a genetic program and technical services. Those are now mostly remote. But they are all connected via the cloud. This is; it sounds crazy because ten years ago, it didn't happen. But now it does; we run one of the largest pig companies in

the world; we run their genetics program from France in the US by the cloud every night. (P08, Director of Business Development).

We use digital technology; I know our purchasing department reaches out to multiple suppliers; as I said, we used to reach out to one or two suppliers, two or three suppliers. Now we reach out, you know, when you're sending an email, you can send an email to 10 people as quickly as you can to one or two people. (P11, General Manager)

Our firm is always working, somebody sleeping, somebody's working, but around the time, you can make that you can take that as an advantage, with the technology you have in place. Digital tools and software, new software tools, etc., where we are tracking closely and following up more closely, we now have the visibility of where the goods are. (P13, Vice President, Engineering).

I would say the benefits of digital technology that we are implementing one is optimizations and efficiency; we will avoid human mistakes and increase customer satisfaction because we will be able to centralize the data; the flow will be smooths based on no breakdown in the process. (P15, General Manager).

The digital technology systems that we have allowed us to look very closely at our supply chains to see how effective they are. Whether we can improve them with too many steps in the process, add to change, or take from the different nodes in our supply chain, I worked in logistics for a long time. So I understand that a supply chain is exactly that. It's a chain, and it's made up of links. So and the chain is only as strong as its weakest link. So what our digital transformation system has done has given us the ability to focus on our weak links and then make them stronger to increase the resilience of our supply chain. So that's been the big thing about digital technology. It's given us an insight through a lens we didn't have before. So we can look at all of the steps in the process, identify the weaknesses, and address them. (P16, Chairman).

I think faster information flows so that we can adjust operations, track where we should put our resources in a certain province, and see a spike in demand or reduction in demand so we can adjust it faster. So, that's, I think, very important. (P17, President).

Having visibility if you have an ERP system and knowing when you haven't received a product, I can do it from home. So you know, I don't have to be in our warehouse to know whether or not a product has been received. Or if there's an issue with the order. Or if I need to order something, I'm not walking down the aisles of the warehouse saying, Oh, that pallet is a little low; maybe I need to order that item. (P18, Purchasing Manager).

> we've done it we've implemented because of all these disruptions is we have we working with a company called TIVE, and they make trackers, little trackers, and they're about the size of your of your cell phone. They're just a small little tracking system. And so all of our suppliers, whether international or domestic, we ask them if we have an order. So let's say we have an order of containers to come in from UP FENG company in China, we asked them to put a tracker on the container. So we can see where it's at at all times. So we can, you know, dial into our webs the type website and say, okay, Tracker number 100 is, you know, itting in the port here, or it's in California, and it's actually, you know, on on a truck and headed to, you know, Minnesota. And so we can tell, because what the most frustrating thing is, is, is, you know, they said it shipped on the state, but you don't know where it's at, they don't know where it's at, it could be somewhere between here and on a slow boat to China, but they really don't know, until it gets to the next destination. Well, now with these trackers, we can tell, oh, it's, it's, it's probably going to get there by this or no, it's, it's not even left the port. So it's, it's going to be a while. And so that has really helped us at least, become proactive instead of reactive. And So I think there's more accountability with digital tech. Now, people can watch what you're doing and where you're at. And that, yeah, more visibility, but it's caused more accountability, and some people don't like that. But yeah. (P19, Director of Procurement).

> It needs to be the connected day-to-day operations of supply chain planners and commodity traders. The feedback the staff receives is passed on to the company's leadership, and then decisions are made accordingly. (P24, Director of Business Development).

Discussion. Not only during the pandemic era, many academia and practitioners have also proven the benefits of digital technologies in managing supply chains. Digital technologies seem to be the most effective way to promote supply chain resilience. Characteristics of digital technologies are connectedness and responsiveness, which improve the agri-food supply chain to deal with disruptions. Participants in this study mostly agreed on the positive impact of digital technologies in improving resilience by improving visibility, collaboration, and agility. Participants mentioned that the list of digital technologies includes enterprise resources planning (ERP), artificial intelligence (AI), cyber security, cloud, the internet of things, automation, and tracking technologies.

Those technologies enhance their firm's resilience capability by increasing collaboration between a focal firm and its suppliers and customers, enhancing their supply chain visibility.

Undoubtedly, digital technologies are crucial in improving resilience in the agri-food supply chain. A second study of this research will be proposed in Chapter 4 to examine how digital technologies improve supply chain resilience. Industry practitioners' perspectives about digital technologies such as ERP, AI, cloud, and tracking technologies are crucial influences in building resilience capability in the agri-food supply chain.

In summary, the connection between the previous main constructs includes the agri-food supply chain, supply chain disruptions, supply chain resilience, and digital technologies. Participants mentioned the benefits of using technologies to promote visibility, collaboration, and better anticipate unexpected events in their chain. They confirmed that deploying digital technologies promotes resilience and accountability in their operations.

Firm Performance

During the interviews, most participants mentioned resilience would help the firm maintain business continuity, increase customer satisfaction, and increase trust from suppliers and customers. A resilient supply chain will improve firm performance in terms of nonfinancial outcomes. By retaining customers, the firm may get more revenue, improving profit and loss from resilience. Participants also confirmed resilience would improve firm competitive advantage.

I would sleep better at night if we had more supply chain resilience; the firm's benefit to the resilience is business continuing. Having that for our suppliers or customers makes our firm a more reliable partner. It allows us to put more trust and maybe get more customer satisfaction, which goes hand in hand with that. I think it's a huge thing for the firm that retains many customers; many suppliers are failing on the promise they make to their customers of delivering on time. And our firm has not; I think we are staying very high at 95 - 98% on-time delivery in North America, which is phenomenal in today's supply environment and helps contribute to our customer retention. (P02, Procurement Manager, North America).

Yeah, well, definitely response. And again, reducing risk, reducing overall risk. I mean, if you're more resilient, you're able to handle unexpected things that come up, and you're able to navigate through those better, instead of, instead of what we have been doing with, you know, a customer needs it, it doesn't matter what the cost is, go ahead and get it done. You know, if you had the digital systems in place, you might not have had to make that decision, you know, it might have been the customer needs it. Here's three options. Here's our already loaded cost impact of those three options, which one do we want to do? Or here's three options, and they don't cost any more. So here, here's, here's how we handle that. So I think, you know, the digital would help on the decision making process, it would speed the decisions, and it should lead to a lower cost overall. And more customer satisfaction, which is what drives us. The number one thing for me is customer satisfaction; specifically, the customer knows that they can count on us because the customer is usually in the same position. If something happens in the supply chain, it usually simultaneously impacts our customers, us, and vendors. If we can tell the customer, hey, we've got this, we're resilient, we can handle whatever has come up, you don't worry about it, allowing the customer to look for new business, rather than looking internal, and slows their growth down. Obviously, business continuity is better. The more time we give, the more customers focus on expanding their market and their sales rather than worrying about their supply chain, which is us; that drives our revenue because the more they sell, the more resell, so our revenue goes up. (P03, Vice President, Operations).

A couple of things that come to mind were improved relationships with our customers and suppliers to provide certainty of reliability for supporting their business needs. So just engage more of their customers, providing more information, supporting them with manageable inventory levels, and keeping inventory levels to support our needs and those we impact without major disruptions. (P06, Business Processes Manager).

Two big areas; one would be customer retention. We were able to provide products in a timely manner, and then we were able to keep our competition away from specific customers and retain a high degree of

customer value, which also kept both our sales force that's motivated to continue the process and drive sales as their number one activity, but then also utilize other members of the team to create more of a multi-contact model. (P07, Senior Vice President, Worldwide Quality Assurance).

With resilience, we have customer satisfaction; we have business growth. And if we have business growth, of course, we will also improve our bottom line because we have much more business. (P15, General Manager).

I think a major benefit is business continuity, I mean, being able to guarantee to customers that we can supply our goods when we say we can, in other words, live up to the promises we're making. And that's very important in business. I mean, if you promise to deliver at a particular time, and they do it, that's a good thing. And it's a loyalty generator. So business continuity in the supply chain is very good. It also provides you with customer loyalty and customer satisfaction. But there are other things, too; I mean, if people within the company know that your supply chain is strong and resilient, then the people in the company will have the confidence to work within the system and know it's going to operate. So there's a double benefit. (P16, Chairman).

I think we really want customer satisfaction; customers are happy they will keep coming back and buying our products. That's number one. (P17, President).

I think resilience; the multiplier effect is basically you ensure your supply on everything is a lot more fixed. So that will increase your resilience as a company because you'll be able to budget a lot better. You will be able to predict your cash flow and your profit and loss accurately. And also, customer satisfaction will be a lot better because if the customer orders something in October, you can supply it in October. (P20, General Manager).

Yeah. I mean, the main benefit, obviously, is that we are in a competitive situation. And the more resilient we can supply our goods, deliver our products, and install our plans, the faster our customers can start to produce and make money. (P21, Global Head of Project Execution).

Supply chain resilience and sustain resilience helped the company definitely helped connect the company continuity company's operations, and it is probably due to resilience that our company has done very well during the COVID pandemic; we haven't lost any people. Nobody got let go. Nobody left the company, and we're still as same as we worked for three years ago. Also, regarding customer satisfaction, I know that we are a respected company overseas, and people know us by name and respect us.

> Things have done well in terms of revenue and profit this year. (P24, Director of Business Development).

Discussion. Supply chain resilience undoubtedly benefits the agri-food industry; all participants confirmed the crucial role of resilience in helping the agri-food supply chain deal with disruptions. Resilience contributes to a firm's nonfinancial outcomes, such as business continuity, customer satisfaction, customer retention, and strong partnerships. A firm can improve its financial performance by increasing revenue, profit, and sales cycles and reducing the loss if a disruption occurs.

Findings

How do digital technologies assist the agri-food supply chain in responding to disruptions by affecting supply chain resilience? How does supply chain resilience affect firm performance under the impact of digital technologies in the agri-food supply chain? Study one conducted a qualitative approach with a mix of deductive and inductive methods by utilizing flexible pattern matching following Bouncken et al. (2021). The deductive approach leveraged pre-formulated key themes that were synthesized and coded from extant literature reviews, with the inductive approach incorporated in coding data from interviews that fit the pre-formulated key themes.

The study presented participants' insights about the main constructs in the previous results and discussions section. From the results and discussions, the study found that i) the agri-food supply chain is differentiated from others by its characteristics. The supply chain is easily vulnerable to external changes that lead to disruption. ii) disruption is sometimes unavoidable, so resilience is "to be the first to know" (i.e., to possess supply chain visibility), and collaboration is a crucial element in the resilience

capability of the agri-food supply chain. iii) with the progress of Industrial Revolution 4.0, the incorporated digital technologies are feasible and available at a reasonable cost. Digital technologies promote responsiveness and connectedness, which are vital elements of supply chain visibility and collaboration. iv) The outcomes of firm performance under the effect of supply chain resilience are mentioned as nonfinancial outcomes in the short term, such as business continuity, customer retention, satisfaction, etc.

New findings came up in the interviews, as did observations that did not fit into the pre-existing themes.

Information Asymmetry

Information asymmetry is a real problem in the agri-food industry, the agri-food supply chain presents a structural inequity in market access and information. The agri-food supply chain is a vertical integration from agriculture to food industries, integrating a huge number of participants from farm input providers, growers, processors, distributors, retailers, and consumers. A big firm with strong human, capital, and management resources will take advance to a small farm in market and information accesses. It is a commodity production with mass producers and mass consumers. Even some matured agri-food supply chains in the United States, such as the poultry, hog, and egg supply chains, are well-managed by several giant enterprises. We still see thousands of participants who are integrated into these supply chains as contractors, growers, and service providers. The maturity of participants is unequal; thus, the interpretation and response to information are different. In information asymmetry, only a few participants can access and use relevant information to maintain and gain a competitive advantage

(Miller, 2021). In addition, information asymmetry may be stronger when their interpretation of information relies on their own interests. For example, consumers respond quantitatively to retail prices, and then processors interpret these responses and send modified responses to growers via grades and standards (Hennessy, 1996).

Third-party Influence

Supply chain resilience may come from a third party. The resilience of the agri-food supply chain can strongly rely on public policy. Agri-food products are perishable and need refrigerated or frozen storage and transportation. An important function of the government is managing a national food system to ensure equitable food and market access and improve system resilience (Miller, 2021). Supply chain disruption will never go away and is often difficult to predict, and no one knows when the next disruption will happen (Blessley & Mudambi, 2022). A typical example of the public policy implemented by the government is that the United States Department of Agriculture (USDA) purchases agri-food products to reduce the impact of the trade war with China and provides food banks to avoid supply chain disruption. Thus, food banks are beneficiaries of the government policy to protect farmers (Blessley & Mudambi, 2022). The government can create a sustainable agri-food supply chain through public-private partnerships.

Propositions

Based on the study findings and the assertion of the significant role of supply chain resilience in responding to disruptions and the positive effects of digital

technologies in improving supply chain resilience in the agri-food industry, several propositions are formed to articulate the quantitative findings of study two.

> P1**:** Supply chain resilience is particularly important in the agri-food supply chain because as it is sensitive to vulnerabilities and easily disrupted by disturbances, its commodities possess the characteristics of being alive (e.g., pigs), perishable (e.g., fruits and vegetables), and weather and time-dependent.

The foundation of study one is an exploratory study on the role of supply chain resilience in the agri-food industry. The attributes that are unique to the agri-food supply chain emerged inductively through 24 semi-structured interviews.

> P2: Digital technologies with connectedness and responsiveness will promote supply chain resilience via visibility and collaboration to better deal with disruptions in the agri-food supply chain.

During the interviews, participants confirmed the positive impact of digital technologies in improving resilience. Two attributes of digital technologies are connectedness, which enhances supply chain visibility, and responsiveness, which enhances the ability to respond quickly to disruption. Participants also confirmed that several digital technologies, such as cloud-based enterprise resources planning, could enhance real-time connectedness, that tracking and tracing technologies would provide real-time data, and that artificial intelligence would provide real-time responsiveness. Proposition two confirms that digital technologies will improve supply chain resilience to deal with disruptions.

P3: Supply chain disruption effects are dampened when the firm incorporates digital technologies, which leads to increased firm performance.

Study one confirmed that digital technologies are associated with resilient factors in dealing with supply chain disruptions. When supply chain disruptions decrease, or a firm can quickly bounce back from the disruption, the firm will see better outcomes, as participants confirm to maintain flows of goods and services, consequently increasing customer satisfaction.

Concept Model

The concept of the improvement of resilience capability in the agri-food supply chain with the involvement of digital technologies remains undefined in the literature. Agri-food supply chain resilience, according to Kumar and Singh (2021) and Zhao et al. (2022), as firmly established in the extant literature that focuses on defining components of resilience, but defining the factor to improve resilience is not well established. This research defines how to improve supply chain resilience through tools or solutions for digitalizing business processes and operations.

Figure 4 illustrates the proposed research model illustrating the impact of digital technologies on improving supply chain resilience in addressing supply chain disruptions in the agri-food industry. Note that this concept model is not meant to suggest causal flows or mathematical relationships of the study's main constructs.

Figure 4 illustrates a concept model where digital technologies are moderators between supply chain disruptions to supply chain resilience and the resilience to firm

performance in the agri-food supply chain. To fully understand the impact of improving supply chain resilience, study one divided the impact into two stages. Stage one is the impact of digital technologies on supply chain resilience in dealing with disruptions. Stage two is the impact of supply chain resilience on firm performance with the involvement of digital technologies.

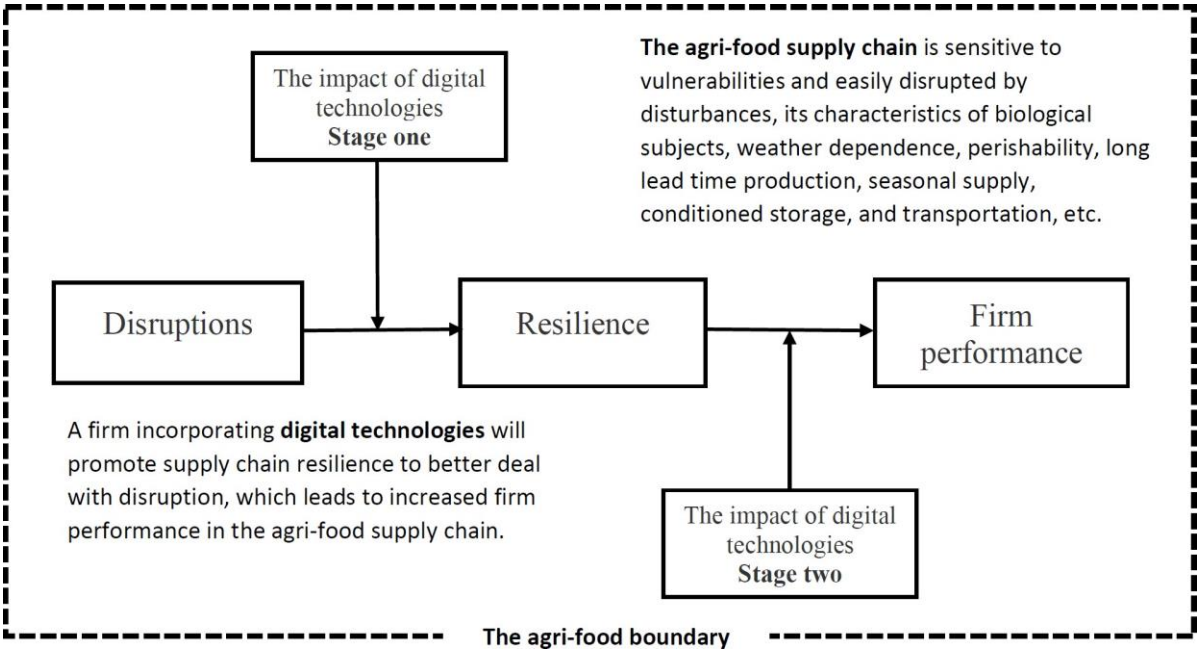

Figure 4. Concept Model

In stage one, the study examined the role of digital technologies in early warning, detecting the possibility of risks to the agri-food supply chain. Increasing visibility is one of the concerns proposed by most of the participants in the interviews. They recognized the crucial role of supply chain visibility in preventing a negative event from disrupting the supply chain. Supply chain resilience refers to preparation for disruptive events, quickly responding to the disruption, recovery, and improving the firm's growth or competitive advantage after the disruption (Sheffi & Rice, 2005; Tukamuhabwa et al.,

2015). Digital technologies, such as enterprise resource planning systems, integrated business planning systems, and artificial intelligence, can increase visibility and collaboration in the supply chain. Stage two of the study examined the impact of digital technologies in improving firm performance. Participants confirmed in their interviews the positive impact of digital technologies in improving resilience by increasing flexibility, agility, visibility, and collaboration in the supply chain. Several technologies, such as enterprise resource planning, tracking and tracing technologies, and artificial intelligence, were mentioned during the interviews, many of which were presumed to be tied to firm performance.

Conclusion

Study one aims to examine the role of supply chain resilience and the effect of digital technologies in the context of the agri-food industry; the study also investigated the distinction between an agri-food supply chain and another supply chain. The study's findings conclude with three propositions above and beyond that; the study uncovered another finding that information asymmetry and supply chain resilience may come from a third party in the agri-food industry.

CHAPTER 4

DIGITAL TECHNOLOGIES MATTERS: A QUANTITATIVE ANALYSIS OF THE IMPACT OF DIGITAL TECHNOLOGIES IN ENHANCING RESILIENCE CAPABILITY AND FIRM PERFORMANCE IN THE AGRI-FOOD INDUSTRY

Background

A qualitative study (study one) provided participants' experiences and perceptions that reinforced the crucial role of supply chain resilience in the agri-food industry. Findings uncovered that industry practitioners highly recommended building the resilience capability of firms in the agri-food industry that corresponds to its many unique characteristics, such as weather dependence, conditioned storage and transportation, and long lead time production. In addition, the agri-food supply chain encompasses agricultural production and food processing phases, comprising agriculture and food supply chains, rendering it easily disrupted. Building resilience capability along the agri-food supply chain will help firms recover from disruptions.

Digital technologies can improve efficiency, equity, and environmental sustainability in the agricultural and food systems. They can significantly reduce the transaction costs of sellers and buyers. Digital technologies also reduce inequality in access to information, technologies, markets, and knowledge. They provide more data analysis capabilities that help users in the agri-food industry decide faster and more precisely. Various digital technologies are deployed in the agri-food industry, leading to better engagement and informed consumers, farmers, and producers and significantly

contributing to public awareness of food consumption. These technologies range from simple to complex systems, and the adoption of digital technologies can vary significantly across geographical locations and players in the agri-food industry. Digital technologies have been widely proven to benefit across industries and institutions. Table 4 provides the application of digital technologies in the agri-food industry. Sixteen digital technologies, DTS1 to DTS16, were adapted from the World Bank Group (2019). These technologies are currently deployed in the agri-food industry.

Table 4.

The Application of Digital Technologies in the Agri-food Industry

DTS	Digital Technologies	Application
DTS1	Distributed ledger technologies and smart contracts	Distributed ledger technologies and smart contracts help the agri-food supply chain improve product traceability, contract certainty, proof/verification, and compliance with sanitary and phytosanitary requirements.
DTS2	Mobile technologies	Mobile technology allows workers and farmers to control their machinery and equipment on-site and off-site. This remote management capability and autonomous machinery increase efficiency and reduce manual operations.
DTS3	Cloud computing	Cloud computing often gathers, analyzes, and stores agriculture and food production data. Cloud-connected wireless sensors collect data from the field, which is then analyzed by machine learning in real-time to give farmers and producers information about their farm and plant situations.
DTS4	Big data analytics	Big data in agriculture has been instrumental in managing resources, such as managing and optimizing inputs and employees and proposing solutions in several specific situations.
DTS5	Internet of Things	IoT smart agriculture products are designed to do such things as monitor crop fields using sensors and to automate irrigation systems.

Table 4.
(continued)

DTS6	Agricultural sensing and Aerial imaging technologies	Several sensing and imaging technologies are used in precision agriculture, providing data that helps farmers monitor and optimize crops and adapt to changing environmental factors.
DTS7	Robotics and automation	Robotics and automation can be paired with other digital technologies to autonomously navigate fields, farms, and plants, to identify and collect relevant information, harvest work, and further processing.
DTS8	Artificial intelligence and machine learning	Artificial intelligence and machine learning can provide projections, solutions, and insights to increase yield, reduce inputs, monitor operations, and detect problems.
DTS9	Data collection technologies	Data collection includes but is not limited to activity monitors. One application, for example, is to help hog farmers collect data about their hogs' health.
DTS10	Precision agriculture	Precision agriculture improves the productivity and quality of agricultural and food products while optimizing input usage.
DTS11	Institutions for data sharing	These institutions manage data services for the benefit of users in the agri-food industry.
DTS12	Encryption, data protection, and data sharing technologies	The use of encryption techniques and secure storage methods for protecting agricultural and food data.
DTS13	Food-sensing technologies	Cost-effective and noninvasive approaches, such as spectroscopy and imaging analysis, are used to identify food quality, such as protein, fat content, moisture, and food safety, such as pollutants and pathogens.
DTS14	Digitized marketplaces for agri-food products	Provide access to the new markets, reducing transaction costs, price transparency, and potentially shortening the agri-food supply chain.
DTS15	E-extension services	Provide farmers with access to information to resolve their operating problems in a timely and efficient manner by facilitating knowledge flow.
DTS16	Digitized transactions and payments	Improve farmers' access to pay and get paid via digital channels. Financial institutions and agricultural enterprises use of digital transaction records to facilitate credit and financial services.

Digital data, technologies, and automation are the main parts of the digitalization process that promise to improve service quality and transparency and create additional value for businesses (Verhoef et al., 2021). The two main features of connectedness and responsiveness of digital technologies will help the firm increase supply chain visibility, collaboration, and timely, effective response to the disruption. Digital technologies positively impact supply chain management by reducing the ripple effect and correlation with supply chain risk management (Ivanov et al., 2019). The objective of study two was to gain additional insights into the research questions, verify the mechanism of digital technologies to affect supply chain resilience, and then assist the agri-food supply chain in responding to supply chain disruption and firm performance improvement under the impact of digital technologies. Study two also expands the impact of the dissertation and further contributes to findings and assertions of supply chain resilience in the agri-food industry. In addition, study two will provide insights into the alignment of digital technologies and supply chain resilience in dealing with agri-food disruption caused by major shocks, e.g., the COVID-19 pandemic, wars, and natural disasters.

This quantitative study (study two) examines agri-food industry leaders' perceptions of the impact of digital technologies in improving supply chain resilience—specifically, their perception of adopting digital technologies in their supply chains. Because of the investment budget, technology adoption may limit the incorporation of digital technologies into their operations, but through respondent perceptions, which may drive their firm to incorporate suitable digital technologies in the future.

Conceptual Model and Hypothesis

To briefly summarize, study one investigated the perceptions of supply chain decision-makers employed at firms on the impact of supply chain resilience and digital technologies in the agri-food industry. This research refined the main constructs, including supply chain disruptions and firm performance. Figure 5 illustrates the conceptual model of supply chain disruptions as drivers that affect supply chain resilience and consequently affect firm performance. The conceptual model also shows the influence of digital technology as a variable to moderate resilience to deal with disruptions and firm performance. In this follow-up study, a conceptual model was proposed to further test the impact of supply chain resilience and digital technology in the agri-food industry.

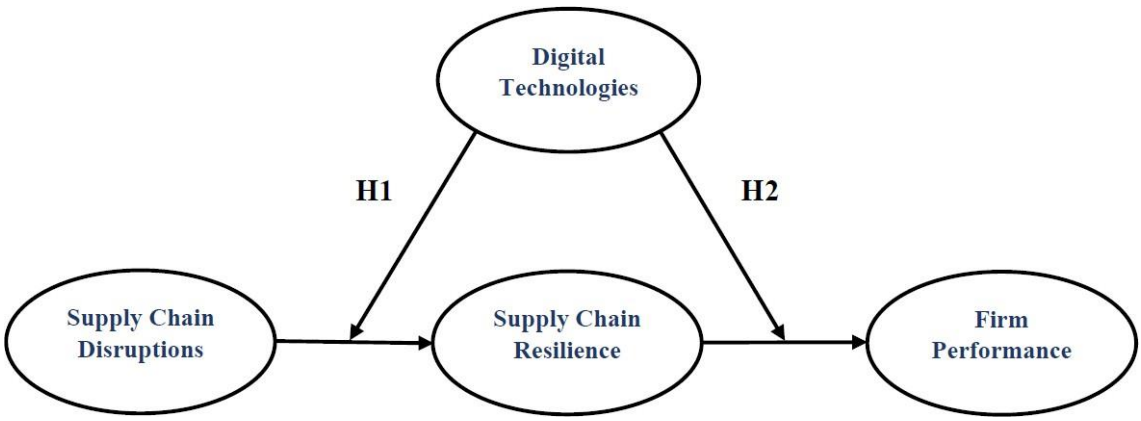

Figure 5. Conceptual Model - The Impact of Digital Technologies as Moderators

The notion of the impact of digital technologies on supply chain resilience is generally well-established in the literature. The resilience of the agri-food supply chain is relatively unexplored, and literature focuses separately on agriculture or the food supply chain. The notion of the influence of digital technologies on resilience capability in the

agri-food supply chain is absent in the literature. Digital technologies increase supply chain visibility and collaboration, positively affecting supply chain resilience (Ivanov et al., 2019). Study two aims to test and quantify the effects of digital technologies in improving resilience capability to deal with supply chain disruptions and firm performance in the agri-food supply chain. Thus, the outcomes of study one lead to the hypotheses for study two, as stated below.

Digital technologies moderate the relationship between supply chain disruptions and resilience. Supply chain resilience is considered a primary driver of supply chain risk management to navigate disruptions (Ponomarov & Holcomb, 2009). Supply chain disruptions and associated risks are the most concerning and challenging to firms in global markets (Craighead et al., 2007). Given the complexity of the agri-food supply chain, the supply chains inevitably experience unanticipated disruptions. Hence, the agri-food supply chain's resilience comprises the partners' collaborative capability to detect disruptions with appropriate actions to respond, recover, and incorporate post-disruption learning (Stone & Rahimifard, 2018). Resilience is the capability to recover to a normal or better situation than before disruption (Christopher & Peck, 2004). A supply chain with the ability to quickly detect and effectively respond to a disruptive event is less likely to be severe than a supply chain without the capability to detect and quickly respond (Craighead et al., 2007). The relationship between disruptions and resilience in the supply chain networks has been proven, and empirical studies have also proved the positive effects of resilience capability on disruptions. In this sub-conceptual model, the study examines a factor of digital technologies as a moderating variable to affect the

relationship between supply chain disruptions as an independent variable and supply chain resilience as a dependent variable.

Digital technologies create many opportunities by changing and improving business processes; the primary drivers of applying digital technologies into operations are enhancing service quality and cost-effective performance. Digital technologies positively impact supply chain management and reduce ripple effects (Ivanov et al., 2019). The typical digital technologies such as tracking and tracing technologies, the internet of things, integrated automation, machine learning, and big data can improve manufacturing flexibility and supply chain visibility, enhance collaboration, mitigate supply chain risks, and reduce transaction costs (Ivanov et al., 2019; Min, 2019). In addition, several digital technologies are applied in the agri-food industry, such as smart farming, aerial imaging technology, the fifth generation, and global positioning system technology, which will enhance collaboration, flexibility, and visibility. Those are core competencies of resilience capability.

Supply chain disruptions are unavoidable, resulting from several incidents; risks are inherent to all supply chains (Craighead et al., 2007). A supply chain disruption occurrence may affect more than one supply chain or firm, but why and how one firm or supply chain would be more severe than another would be explained by its supply chain risk management, risk mitigation, and resilience capabilities. Digital technologies enhance disruption risk control analytics in the supply chain; technologies such as the internet of things, cyber-physical systems, and smart, connected appliances will facilitate the evolution of digital supply chain operations (Ivanov et al., 2019). In study one, the findings of two unique features of digital technologies are connectedness and

responsiveness, and these features will enhance resilience capability by collaborating partners to jointly manage disruptions and sharing information and competencies between partners (Ju & Hu, 2021). Digital technologies assist users in accessing and accumulating information from targeted sources in real-time, converging business processes, promoting supply chain risk detection, and consequently improving supply chain resilience (Arrais-Castro et al., 2018). Big data analytics, sensing, tracking, and tracing technologies promote the supply chain's preparedness to deal with the disruption (Ivanov et al., 2019). These findings motivated the hypotheses below.

H1: The higher the employment of digital technologies, the greater is the perceived resilience to firm disruption in the agri-food industry.

Digital technologies moderate the relationship between resilience and firm performance. The definition applied in research is that resilience is the ability to detect and respond to disruption quickly and then to effectively adapt and recover in a timely manner, the restoration to the normal or better situation before disturbance, the ability to bounce back and maintain business continuity (Christopher & Peck, 2004; Ponomarov & Holcomb, 2009). Resilience is considered an ability to minimize the negative effects of disruptions (Gunasekaran et al., 2015). Resilience capability can positively affect firm performance by avoiding disruptive events or preventing disruption at a minimum level of loss, and then resilience capability to improve the restoration process, which will lead to recovery of firm performance to pre-disruption or better situation (Tukamuhabwa et al., 2015). Therefore, supply chain resilience is considered to proactively manage pre-, in, and post-disruption. Many empirical studies have proved the positive effects of supply

chain resilience on firm performance. This conceptual model lays out a study to examine digital technologies as a moderating variable on the relationship between resilience and firm performance in the agri-food industry.

Digital technology deployment can help reduce a firm's cost and time (Jagtap & Duong, 2019). However, digital technologies such as the cloud require efficient sharing of relevant data in the supply chain network, and then other technologies like big data analytics can assist in optimizing the supply chain operations in resource exploitation, time, and costs. Consequently, deploying digital technology is expected to positively affect the relationship between resilience and firm performance, leading to the hypothesis stated below.

H2: The higher the employment of digital technologies, the greater is the perceived firm performance to resilience in the agri-food industry.

Methodology

This second study used quantitative analysis to examine the impact of digital technologies as a moderating variable in improving supply chain resilience and firm performance in the agri-food industry. A moderating variable influences the strength and the direction of the relationship between independent and dependent variables (Baron & Kenny, 1986). This study uses qualitative methods in study one and quantitative methods in study two to examine one business phenomenon – the impact of digital technologies in improving supply chain resilience, which will improve accuracy and deeper understanding (Hussein, 2009). The non-probability sampling research focuses on the resilience capability in the agri-food supply chain, the impact of digital technologies as a

moderating variable in improving supply chain resilience as a dependent variable in the first sub-conceptual with supply chain disruptions as an independent variable, and in the second sub-conceptual model where firm performance was dependent variable and resilience was an independent variable. The study employed purposive and snowball sampling techniques to connect and recruit participants who are working in the agri-food industry. Quantitative analysis used descriptive statistics, frequencies, Cronbach's alpha, correlations, factor analysis, regression analyses, one sample T-test, and one-way ANOVA.

Data Collection

In this quantitative study, the data was collected as primary data; this primary data collection method is the method by which respondents fulfill the survey themselves (Hair et al., 2019). The initial surveys were sent to three industry-targeted people for feedback. Then, the research team refined content and processes regarding wording and meaning, which would aid the participants in proper understanding and being comfortable with the survey; e.g., the research team added model variable definitions after the screening question that helped respondents better understand jargon words. The surveys determined the sample size to be 200 respondents to reach a good representative sample level (Hair et al., 2019). The respondents were recruited through public databases from industry trade associations and event organizers to identify firms in the agri-food industry. A recruitment letter was emailed to the company's public emails, with the purpose of forwarding it to relevant persons if the firm was willing to do so; at the end of the email is the investigator's contact information and the survey link. If the relevant persons were

willing to participate, they clicked on the link to the Qualtrics website, an online survey platform (Qualtrics, 2023). Demographic information was also at the end of the survey without restrictions on demographic category. The survey launched on March 2, 2023, and closed on March 31, 2023. The research team did not contact the potential respondents directly; they freely decided to participate, and the participation was voluntary.

Data Screening

In order to have industry perspectives, the survey limited respondents must be working at firms in the industry by the question, "Is your firm doing business in the agri-food industry?" with the answer "Yes = 1" and "No = 0," only for respondents who chose "Yes," the survey leads to participant consent, model variable definitions, and then the survey content. The industry respondents were provided with industry perspectives that helped investigators understand the industry insights. In addition, data screening processes were also to eliminate uncompleted responses; only completed responses were used for data analyses.

Questionnaire

The questionnaire included a series of predefined questions, and each respondent answered the same series of questions in the same format. The application of a structured questionnaire helped the survey collect a huge amount of data that was easily quantifiable by suitable statistical software. The questionnaire was divided into three sections: demographic, closed-ended questions, and open-ended questions. The demographic

section comprised general information about respondents, including gender and geographical location scaled by nominal category, age, education, and the firm size scaled by ordinal category. The open-ended section was called the digital technology section, where these questions asked respondents' perspectives about which technology they were using and important rankings in the predefined list of digital technologies in the agri-food industry. The closed-ended question section was hypothetical, which included closed-ended questions regarding the model variables, including supply chain disruptions, supply chain resilience, digital technologies, and firm performance. Each model variable included several questions that were adapted and validated from previous studies. These selected questions were used to verify the relationships of the research model. The respondents were required to answer questions according to a seven-point Likert scale ranging from 1 = "Strongly" disagree" to 7 = "Strongly agree" and a nominal scale in demographic questions. An ordinal scale, a seven-point Likert scale, tends to balance response discrimination well (Nunnally, 1978). The model variables are adapted with sub-questions, as shown below.

Supply Chain Disruptions (SCD). Six items were adapted from Parker and Ameen (2018) to measure disruptions in the agri-food supply chain to measure the degree of vulnerability, uncertainty, and the source of disruption. These items are 1) The agri-food supply chain is easily vulnerable to supply chain disruptions; 2) Supply chain disruption easily happens from a disturbance in the agri-food industry; and 3) The agri-food industry will be strongly affected by internal disruptions; 4) external disruptions; 5) supply disruptions; and 6) demand disruptions.

Supply Chain Resilience (SCR). Five items were adapted from Parker and Ameen (2018) and Um and Han (2020) to measure the ability to response quickly to disruptions and the adaptive capability to bounce back from the disruption in the agri-food industry. These items are 1) Your firm can respond quickly to supply chain disruptions; 2) Your firm can adapt to the supply chain disruptions through information sharing; 3) Your firm can deploy the adaptability to deal with supply chain disruptions; 4) Your firm can deploy alternative plans to deal with supply chain disruptions; and 5) Resilience is emerging to be a crucial capability at our firm.

Digital Technologies (DTS). Digital technologies were tested as a moderating variable between supply chain resilience and supply chain disruptions and between supply chain resilience and firm performance in the agri-food industry. Five items have been adapted from Tortorella et al. (2019) to measure the moderating impact of digital technologies: 1) Your firm incorporates digital technologies into operations and supply chain management; 2) Your firm uses monitoring and controlling systems in operations such as enterprise resource planning systems, manufacturing execution, business planning, and consolidation, etc.; 3) Your firm incorporates digital technologies, digital services, and automation to optimize business processes and operations; 4) Digital technologies significantly improve responsiveness and connectedness at your firm; and 5) Digital technologies significantly improve resilience capability in your firm's supply chain.

Firm Performance (FIR). This model construct is a dependent variable of the relationship to supply chain resilience moderated by digital technologies. Six items were adapted from Liu et al. (2018) to measure the model of firm performance include: 1)

Your firm is able to restore pre-disruption customer service levels quickly; 2) Your firm maintains the smooth running of operations during the disruption; 3) Your firm is able to limit the loss caused by supply chain disruptions; 4) Supply chain resilience significantly improves trust from customers and partners at your firm; 5) Supply chain resilience significantly improves customer satisfaction at your firm; 6) Supply chain resilience significantly contributes to maintaining business continuity at your firm. Table 5 summarizes the models, indicators, survey questions, and cited author(s).

Table 5.

List of Model Variables and Sub-questions

Variables	Survey Questions	References
Supply Chain Disruptions (SCD)	The agri-food supply chain is easily vulnerable to supply chain disruptions. Supply chain disruption easily happens from a disturbance in the agri-food industry. The agri-food supply chain is strongly affected by external disruptions. The agri-food supply chain is strongly affected by internal disruptions. The agri-food supply chain is strongly affected by supply disruptions. The agri-food supply chain is strongly affected by demand disruptions.	Adapted from Parker and Ameen (2018)
Supply Chain Resilience (SCR)	Your firm has the ability to respond quickly to supply chain disruptions. Your firm has the ability to adapt to supply chain disruptions through information sharing. Your firm has the ability to deploy the adaptability to deal with supply chain disruptions. Your firm has the ability to deploy alternative plans to deal with supply chain disruptions. Resilience is emerging to be a crucial capability at your firm.	Adapted from Parker and Ameen (2018); Um and Han (2020)

Table 5.
(continued)

Digital Technologies (DTS)	Your firm incorporates digital technologies into operations and supply chain management. Your firm uses monitoring and controlling systems in operations such as enterprise resource planning systems, manufacturing execution, business planning, consolidation, etc. Your firm incorporates digital technologies, digital services, and automation to optimize business processes and operations. Digital technologies significantly improve responsiveness and connectedness at your firm. Digital technologies significantly improve resilience capability in your firm's supply chain.	Adapted from Tortorella et al. (2019)
Firm Performance (FIR)	Your firm is able to restore pre-disruption customer service levels quickly. Your firm maintains the smooth running of operations during the disruption. Your firm is able to limit the loss caused by supply chain disruptions. Supply chain resilience significantly improves trust from customers and partners at your firm. Supply chain resilience significantly improves customer satisfaction at your firm. Supply chain resilience significantly contributes to maintaining business continuity at your firm.	Adapted from Liu et al. (2018)

Table 5 shows the finalized model variables and sub-questions or indicators used for conducted surveys and data analyses if any indicator was unsatisfied with the test of validity or reliability and then eliminated in the next analysis. The complete questionnaire with all items is in Appendix C.

Data Analysis

The analyses in this study include descriptive statistics, frequencies, Cronbach's alpha, correlation, factor analysis, regression analyses, one-sample T-tests, and one-way ANOVA. First, descriptive and frequency statistics were collected to summarize participant demographics and descriptions of the survey data. Second, inferential statistics were used to predict a targeted population from a surveyed sample. Inferential statistics, such as factor analysis, correlation, regression, etc., were used to point out the potential relationships, patterns, and trends between variables. All statistical methods were implemented using IBM SPSS statistics software version 28.

Factor Analysis

Factor analysis was conducted to merge the subset data into one dataset to simplify indicators. The most prevalent factor analysis approach is principal component analysis (PCA). PCA combines indicators with fewer indicators of principal components that were expected to represent the features of all prior indicators (Hair et al., 2019). In this study, these indicators were presented through questions in the survey and categorized into model constructs, including "Supply Chain Disruption," "Supply Chain Resilience," "Digital Technologies," and "Firm Performance."

Common Method Bias

Common method bias (CMB) occurs in one survey when both independent and dependent variables are captured in the same response method (Kock et al., 2021). Both independent and dependent variables were responded to by individual cognition.

Harman's single-factor method was used to analyze common method bias by using all 22 factors of all model variables.

Validity and Reliability Analysis

Factor validity was tested for all indicators using a statistical analysis model called factor analysis. Factor analysis is a method to reduce a large number of variables into a smaller number of variables by grouping all variables with common variance into a common variable called a factor. According to Hair et al. (2019), factor loadings used for further analysis should have a value equal to or higher than 0.6. The explanation is that the individual indicator would explain at least 60 percent of the total variance. If the factor loading was lower than 0.6, it needs to be justified before considering whether to keep it.

In addition, the Kaiser-Meyer-Oklin (KMO) test was conducted to verify the observed indicators were proper and suitable for test factor analysis. The KMO test values above 0.5 are acceptable, suggesting that the indicators are suitable for testing a factor-loading analysis; the value under is unacceptable (Spicer, 2005). According to Hair et al. (2016), the significant value (P value) of Bartlett’s test of sphericity must be below 0.05, which implies there is sufficiently different between the correlation matrix and identity matrix, a dataset was normally distributed and appropriated to further analysis

The study also measured the reliability of the model by examining the internal consistency in measurement in a group of indicators by testing Cronbach's alpha. According to Hair et al. (2019), Cronbach's alpha value ranges between 0.8<0.9, which indicates high reliability; the value ranges from 0.7<0.8 is considered good reliability,

values from 0.6<0.7 is considered an acceptable level, and the value below 0.6 is considered unacceptable, indicators below 0.6 were eliminated, these indicators were not accurately measured in the model.

Regression Analysis

Regression analysis was conducted to examine the linear relationship between two or more variables; correlation analysis was used to examine relationships that exist between variables, directions, and the degree of relationship (Hair et al., 2019). Hypotheses must be developed to state that relationships between variables exist in the research context and model. The null hypothesis and alternative hypothesis were determined by the result of a p-value below 0.05; then, we could state reject the null hypothesis; if the p-value was equal to above 0.05, we accepted the null hypothesis (Hair et al., 2019). This conceptual model presented one dependent variable and two independent variables in each sub-model; the analysis used was multiple linear regression. This study examines two relationship models by multiple linear regression analysis. The first sub-model has two independent variables, including digital technologies and supply chain disruptions; one dependent variable is supply chain resilience. The second sub-model has two independent variables, including digital technologies and supply chain resilience; one dependent variable is the firm performance. In this research context, the moderating effect of digital technologies was investigated. The results of linear regression coefficients interpreted positive or negative relationships. The two models were examined separately to test hypothesis H1 and hypothesis H2.

The study also assessed the model fit of the hypothesized model, and multiple regression analyses need different model fits to consider different model characteristics (Xia & Yang, 2018). This study chose the squared multiple correlation (R2), F-test, standard error, and beta coefficient. The R-squared measures determine the portion of variance or the data fit in the dependent variable that is explained by the independent variable. The R-squared value ranges between 0 and 1, in which R2 equals 1, indicating the best fit for the data, while the R2 value equal to above 0.8 indicates a strong correlation between variables. F-test is used to test the null hypothesis by using the portion of variance described by the alternative hypothesis, and a significant F-test indicates that R2 is reliable. The standard error implies the average distance of sample means from the regression line. The beta coefficient implies the change of the dependent variable when the independent variable changes a unit; the value of the beta coefficient ranges between - 1 and 1 (Hair et al., 2019).

In addition, study two examined the participants' perspectives on deploying digital technologies in the agri-food industry. The analyses used in this section are descriptive statistics. One sample T-test was used to verify the participants' perspectives at a high level of digital technology deployment. The study also used One-way ANOVA to analyze the homogeneity of groups and compare the differences between the means of the groups.

Results

Screening Questions

The questions aim to screen respondents who are not working in the agri-food industry as the respondents were asked, "Is your firm working in the agri-food industry?" If the respondent says "Yes" the survey will continue, and if they say "No" the survey will stop. The surveys also counted the number of uncompleted responses. During the survey period, there were 316 responses in the Qualtrics platform, in which saying "No" totaled 57 responses, accounting for 18 percent; uncompleted responses were 34 responses, accounting for 10.8 percent. There were 225 completed responses, accounting for 71.2 percent of total responses, which will be used for further descriptive statistics and analyses. This number of completed responses is higher than the target of 200 responses, as presented in Figure 6.

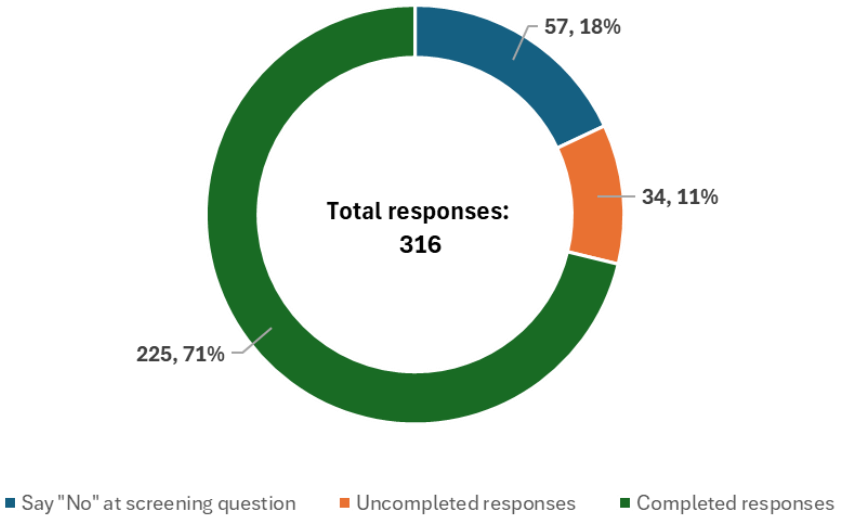

Figure 6. Descriptive Screening Questions

Demographic Summary

This study received 225 completed responses. Most of the responses came from Asia and North America. Study two consolidates the findings from study one, which showed that most people working in the agri-food industry are males.

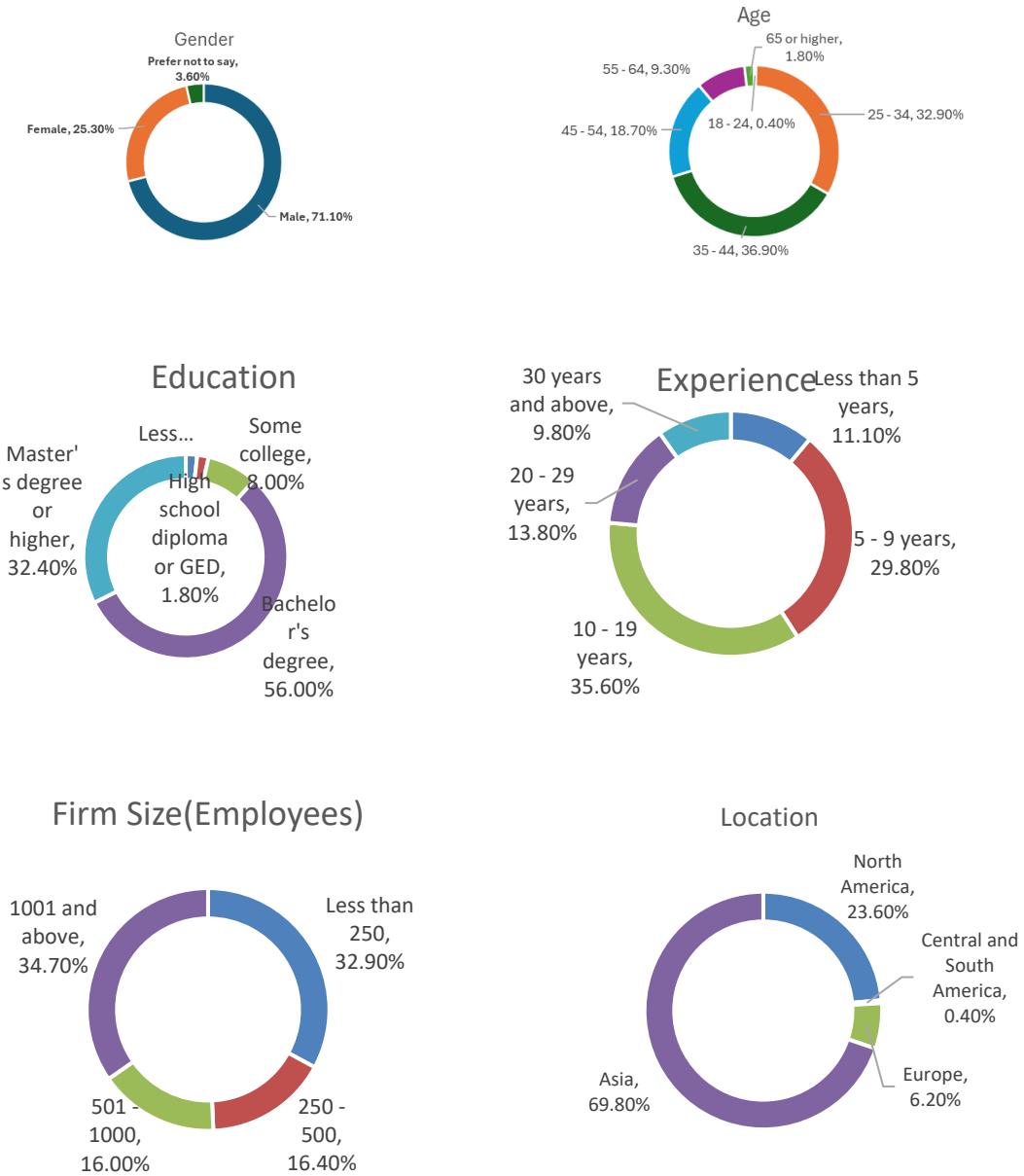

Figure 7. Descriptive Statistics – Demographic Summary

Figure 7 provides a demographic summary indicating that most respondents working in the agri-food industry are aged 25 – 44. Most of them hold bachelor's degrees and have middle careers with 5 to 19 years of experience. They work at firms with less than 250 and above 1000 employees.

Descriptive Statistics

A summary of all factors related to their model variables, including the mean of each model variable and its standard deviation, is as follows. Supply chain disruption (SCD) is represented by factors SCD1 to SCD5; Supply chain resilience (SCR) is represented by factors SCR1 to SCR5; Digital technologies (DTS) is represented by factors DTS1 to DTS5; and Firm performance is represented by factors FIR1 to FIR6. The mean value of model variables five on the seven-point Likert scale indicates that respondents agree and above about the influence of supply chain disruptions with a mean value of 5.6489, the role of supply chain resilience with a mean value of 5.5556, the effects of digital technologies with a mean value of 5.6578 and firm performance with a mean value of 5.6674.

Table 6.

Descriptive Statistics of Model Variables

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
SCD	225	2.40	7.00	5.6489	0.79232
SCR	225	2.40	7.00	5.5556	0.85616
DTS	225	2.80	7.00	5.6578	0.89405
FIR	225	3.00	7.00	5.6674	0.71139

Common Method Bias

Harman's single-factor method was used to measure common method bias that may appear from the same respondents for independent and dependent variables in one survey. The analysis used IBM SPSS to perform all 21 factors of this study with the result of 25.885 percent of the total variance, and the result confirmed that there was no common method bias in this study.

Validity and Reliability

Correlation Matrix of Model Variables. Table 6 shows the correlation matrix between model variables; several relationships are statistically significant (0.01 level). The strongest positive relationships have been seen between supply chain resilience (SCR) and firm performance (FIR) at a 0.490 correlation. In addition, moderating variable digital technologies and supply chain disruption (DTSxSCD) has a positive relationship with model variable supply chain resilience (SCR) at a 0.288 correlation. Moderating variable digital technologies and supply chain resilience (DTSxSCR) has a positive relationship with model variable supply chain disruption at a strong 0.319 correlation and a positive relationship with firm performance (FIR) at a strong 0.418 correlation. Notably, FIR is considered the ultimate consequence of the study; the correlation of this research model showed that FIR has strong correlations with SCR and DTS. DTS played a strong role in moderating the effects of the relationship between SCR and FIR. The correlation matrix is presented in detail in Table 7.

Table 7.

Correlation Matrix of Model Variables

Correlations (n=225)							
		SCD	SCR	DTS	FIR	DTSxSCD	DTSxSCR
SCD	Pearson Correlation	1					
	Sig. (2-tailed)						
SCR	Pearson Correlation	0.104	1				
	Sig. (2-tailed)	0.122					
DTS	Pearson Correlation	0.081	-0.001	1			
	Sig. (2-tailed)	0.224	0.99				
FIR	Pearson Correlation	.260**	.490**	.473**	1		
	Sig. (2-tailed)	<.001	<.001	<.001			
DTSxSCD	Pearson Correlation	-0.118	.288**	-0.091	0.069	1	
	Sig. (2-tailed)	0.077	<.001	0.172	0.304		
DTSxSCR	Pearson Correlation	.319**	0.02	-0.01	.428**	0.043	1
	Sig. (2-tailed)	<.001	0.766	0.886	<.001	0.52	

** Correlation is significant at the 0.01 level (2-tailed).

Cronbach's alpha. A measurement of Cronbach's alpha was used to examine the internal consistency and reliability of a group of factors. Crobach's alpha value of the model variable must be above 0.6, and if the corrected item-total correlation is above 0.3, then the reliability of the variable is acceptable. The results of each variable in this study are as follows: Cronbach's Alpha of supply chain disruptions (SCD) = 0.773 > 0.6 AND corrected item-total correlation > 0.3, so SCD reliability is acceptable. Cronbach's Alpha of supply chain resilience (SCR) = 0.831 > 0.6 AND corrected item-total correlation > 0.3, then SCR reliability is acceptable. Cronbach's Alpha of digital technologies (DTS) = 0.8571 > 0.6 AND corrected item-total correlation > 0.3, so DTS reliability is acceptable. Cronbach's Alpha of firm performance (FIR) = 0.805 > 0.6 AND corrected item-total correlation > 0.3, so FIR reliability is acceptable. All the details of Cronbach’s Alpha are presented in Appendix D.

Kaiser-Meyer-Olkin (KMO), Bartlett's test of sphericity (Bartlett's), and Factor Loadings. Sampling adequacy is determined by KMO value; all factors have a KMO value higher than 0.5 and a significant level of 0.05 for Bartlett's, and all factor loadings must be higher than 0.6. One factor with extraction sums of squared loading must be above 50.00%, and Eigenvalues must be above 1, then the factor analysis is acceptable.

This study used exploratory factor analysis (EFA), a technique within factor analysis to uncover the underlying relationships between measured variables. According to Hair et al. (2019), when using exploratory factor analysis with independent and dependent categories, the technique can be used for factor analysis, and either independent or dependent variables can be considered separately. The following analyses are presented to test the validity of each model variable.

Supply chain disruption. Supply chain disruption with six factors: Although other analysis values are in the range and significance, Extraction Sums of Squared Loadings for one component are at 47.353 percent of the variance, which is unacceptable. The factor with the lowest loading at the component matrix – SCD6 with 0.584 was eliminated, and exploratory factor analysis was performed with the updated component matrix at five factors. Updated component matrix at supply chain disruptions with five factors, the new component matrix shows that KMO = 0.783 > 0.5, and Bartlett's test = <0.001 (sig. <0.05) suggests that the data is satisfied for factor analysis and a substantial correlation. One factor with extraction sums of squared loadings at 51.830% and Eigenvalues = 2.591 > 1. The updated factor analysis is acceptable.

Supply chain resilience. The component matrix of supply chain resilience with KMO = 0.836 > 0.5 and Bartlett's test = <0.001 (sig. <0.05) suggests that the data is satisfied for factor analysis and a substantial correlation. One factor with extraction sums of squared loading at 60.292% and Eigenvalues = 3.015 > 1. The factor analysis of supply chain resilience is acceptable.

Digital technologies. The component matrix of digital technologies with KMO = 0.780 > 0.5 and Bartlett's test = <0.001 (sig. <0.05), indicating that the data is satisfied for factor analysis and a substantial correlation. One factor with extraction sums of squared loading at 63.691% and Eigenvalues = 3.185 > 1. The factor analysis of digital technologies is acceptable.

Firm performance. The validity of model variables where FIR is the dependent variable, KMO determines the sampling adequacy, and the rotated component matrix presents components and factor loadings. The component matrix of firm performance shows that KMO = 0.778 > 0.5, and Bartlett's test = < 0.001 (sig. < 0.05) suggests that the data is satisfied for factor analysis and a substantial correlation. Two components were extracted from the analysis with extraction Sums of Squared Loadings at 75.848 %, Eigenvalues of component one = 3.116, and Eigenvalue of component two = 1.435 > 1. The rotated component matrix shows the factor loadings of every component in which component one represents FIR4, FIR5, and FIR6, and component two represents FIR1, FIR2, and FIR3. The study will further analyze these outcomes in the following discussion section. All the details of KMO, Bartlett's test, and factor loadings are presented in Appendix 4. A summary of Validity and Reliability analyses is presented in Table 8.

Table 8.

Summary of Validity and Reliability

Model variables	Questions	Cronbach's alpha	KMO	Bartlett's	Loadings
Supply chain disruptions (SCD)	Respondent's approval relating to disruptions in the agri-food supply chain.	0.773	0.783	<0.001	
SCD1	The agri-food supply chain is easily vulnerable to supply chain disruptions.				0.749
SCD2	Supply chain disruption easily happens from a disturbance in the agri-food industry.				0.780
SCD3	The agri-food supply chain is strongly affected by external disruptions.				0.701
SCD4	The agri-food supply chain is strongly affected by internal disruptions.				0.644
SCD5	The agri-food supply chain is strongly affected by supply disruptions.				0.718
Supply chain resilience (SCR)	Respondent's approval relating to resilience capability in the agri-food supply chain.	0.831	0.836	<0.001	
SCR1	Your firm has the ability to respond quickly to supply chain disruptions.				0.795
SCR2	Your firm can adapt to supply chain disruptions through information sharing.				0.787
SCR3	Your firm has the ability to deploy the adaptive capability to deal with supply chain disruptions.				0.879
SCR4	Your firm has the ability to deploy alternative plans to deal with supply chain disruptions.				0.815
SCR5	Resilience is emerging to be a crucial capability at your firm.				0.570
Digital technologies (DTS)	Respondent’s approval relating to the deployment of digital technologies in the firm operations.	0.857	0.780	<0.001	
DTS1	Your firm incorporates digital technologies into operations and supply chain management.				0.796
DTS2	Your firm uses monitoring and controlling systems in operations such as enterprise resource planning systems, manufacturing execution, business planning, consolidation, etc.				0.750

Table 8.
(continued)

DTS3	Your firm incorporates digital technologies, digital services, and automation to optimize business processes and operations.				0.841
DTS4	Digital technologies significantly improve responsiveness and connectedness at your firm.				0.813
DTS5	Digital technologies significantly improve resilience capability in your firm's supply chain.				0.788
Firm performance (FIR)	Respondent's approval relating to firm performance in the agri-food industry.	0.805	0.778	<0.001	
FIR1	Your firm is able to restore pre-disruption customer service levels quickly.				0.812
FIR2	Your firm maintains the smooth running of operations during the disruption.				0.844
FIR3	Your firm is able to limit the loss caused by supply chain disruptions.				0.855
FIR4	Supply chain resilience significantly improves trust from customers and partners at your firm.				0.822
FIR5	Supply chain resilience significantly improves customer satisfaction at your firm.				0.892
FIR6	Supply chain resilience significantly contributes to maintaining business continuity at your firm.				0.893

Multiple Linear Regression Analysis

The IBM SPSS software was used to test the hypotheses in the conceptual model using multiple linear regression analyses. The conceptual model was divided into two sub-models with two dependent variables. In sub-model one, digital technologies (DTS) and supply chain disruptions (SCD) were predictor variables; supply chain resilience (SCR) was the target variable. In sub-model two, digital technologies and supply chain resilience were predictor variables; firm performance was the target variable.

Supply chain resilience as a dependent variable. In this scenario, SCR is a dependent (target) variable, and the independent variables (predictors) are SCD, DTS,

and a moderating variable named DTSxSCD. This analysis tests the moderation effect of digital technologies on the relationship between SCD and SCR, as mentioned in H1, "*The higher the employment of digital technologies, the greater is the perceived resilience to the firm disruption."* These hypotheses are supported if there is a statistical significance with a p-value below 0.05 (Hair et al., 2019).

This analysis found a significant effect ($\beta = 0.138$, $p < 0.033$) of SCD on SCR, and DTS did not have a significant effect on SCR ($\beta = 0.016$, $p < 0.806$), as indicated in Figure 18. This research aims to investigate the impact of digital technologies as a moderating variable. The analysis found a significantly positive impact ($\beta = 0{,}305$, $p < 0.001$) of digital technologies on the relationship between SCD and SCR. The results state that the higher the employment of digital technologies, the greater is the perceived resilience to firm disruptions.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.320[a]	0.102	0.090	0.81676	2.074

a. Predictors: (Constant), DTSxSCD, DTS, SCD

b. Dependent Variable: SCR

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16.768	3	5.589	8.379	.000[b]
	Residual	147.428	221	0.667		
	Total	164.196	224			

a. Dependent Variable: SCR

b. Predictors: (Constant), DTSxSCD, DTS, SCD

oefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	4.603	0.509		9.039	0.000		
	SCD	0.149	0.070	0.138	2.149	0.033	0.981	1.019
	DTS	0.015	0.061	0.016	0.246	0.806	0.987	1.014
	DTSxSCD	0.281	0.059	0.305	4.741	0.000	0.979	1.021

a. Dependent Variable: SCR

Figure 8. Multiple Linear Regression: Supply Chain Resilience as Dependent Variable

This study also examined the model fit in this regression analysis by accessing the R-squared index. The analysis found that the independent variable explained significant variance in the dependent variable (R-squared = 0.102). The F-test value for SCR as a target variable is higher than 0 (F = 8.379), implying the portion of the variance in the target variable that was explained by the predictor variables. The statistical significance of the F-test ($p < 0.001$) describes that the R2 value for the target variable was reliable. The standard error value of all predictor variables for SCR ranged from 0.64 to 0.69. These values imply that the sample mean was less varied from the standard deviation of the sampling distribution. Furthermore, the variance inflation factors (VIF) results ranged

from 1.014 to 1.021, well below the cutoff of 4 (Obrien, 2007), that multicollinearity was not a concern.

The histogram of standardized residuals described that the data contained approximately normally distributed errors. The normal P-P Plot of the standardized residual was close to the line. The standardized Scatterplot suggested that the assumptions of homogeneity of variance and linearity met with the data. The histogram, P-P Plot, and Scatterplot are presented in Figure 9.

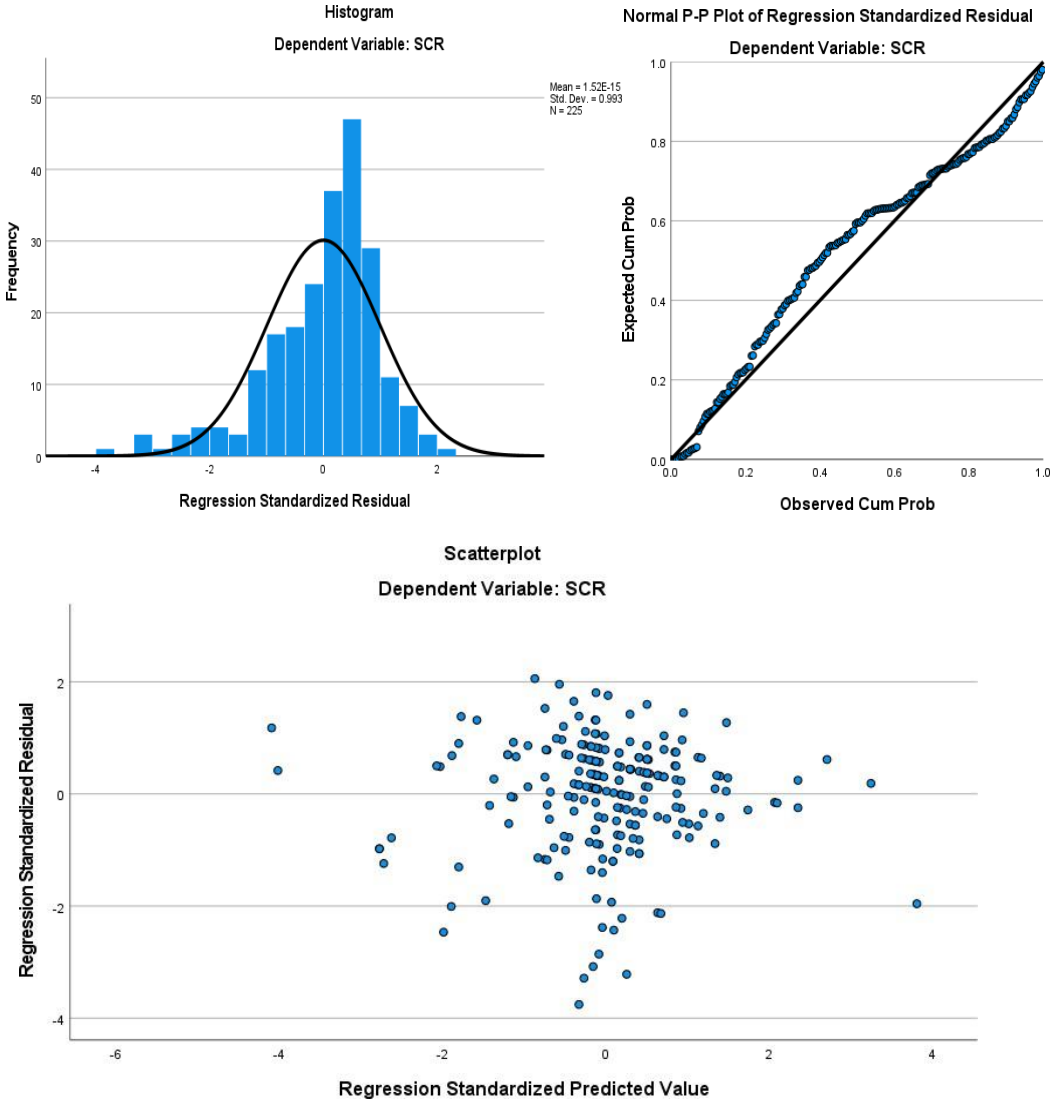

Figure 9. Histogram, P-P Plot, and Scatterplot

Firm performance as a dependent variable. The hypothesis tested firm performance as a target variable. The moderating effect of digital technologies (DTSxSCR) on the relationship between supply chain resilience (SCR) and firm performance (FIR) was hypothesized by *H2: "The higher the employment of digital technologies, the greater is the perceived firm performance to resilience in the agri-food industry."*

As presented in Figure 18, the study found that as predictors in this model, there was a significant effect of SCR on FIR ($\beta = 0.482$, $p < 0.001$) and a significant effect of digital technologies on the firm performance ($\beta = 0.478$, $p < 0.001$. The hypothesis H2 needed to be tested in this model was the moderating effects of digital technologies on the relationship between SCR and FIR, and the result shows that DTSxSCR significantly and positively ($\beta = 0.423$, $p < 0.001$) moderate the effect of supply chain resilience on the firm performance. The result also implies that the higher the employment of digital technologies, the greater the resilience to improve firm performance.

In terms of the model fit in this regression analysis for firm performance as the target variable, Figure 10 shows that predictor variables explained significant variance in the dependent variable firm performance (R-squared = 0.643). The F-test value for firm performance higher than zero (F = 132.937) explained that the alternative hypothesis explains a huge proportion of the variance. The hypothesis explains a significant percentage of 64.3 of the variance, and a relationship exists between supply chain resilience and firm performance. There was a significant ($p < 0.001$) in the F-test value, and then the R-squared value for firm performance as a target variable is reliable. The standard error ranged from 0.040 to 0.048, indicating a very low standard error that

implies a good model fit. In addition, the variance inflation factors (VIF) resulted at 1.00 for all independent variables, well below the cutoff of 4 (Obrien, 2007), so multicollinearity was not a concern.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin- Watson
1	.802[a]	0.643	0.639	0.42766	1.914

a. Predictors: (Constant), DTSxSCR, DTS, SCR
b. Dependent Variable: FIR

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	72.941	3	24.314	132.937	.000[b]
	Residual	40.420	221	0.183		
	Total	113.361	224			

a. Dependent Variable: FIR
b. Predictors: (Constant), DTSxSCR, DTS, SCR

Coefficients[a]

Model		Unstandardized Coefficients		Standar dized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	1.292	0.261		4.955	0.000		
	SCR	0.400	0.033	0.482	11.995	0.000	1.000	1.000
	DTS	0.380	0.032	0.478	11.899	0.000	1.000	1.000
	DTSxSCR	0.358	0.034	0.423	10.528	0.000	1.000	1.000

a. Dependent Variable: FIR

Figure 10. Multiple Linear Regression: Firm Performance as Dependent Variable

The histogram of standardized residual indicated that the data contained approximately normally distributed errors. The normal P-P Plot of standardized residual points was not close to the line, but in general, it was. The standardized Scatterplot

suggests that the assumptions of homogeneity of variance and linearity are met with the data. The histogram, P-P Plot, and Scatterplot are presented in Figure 19.

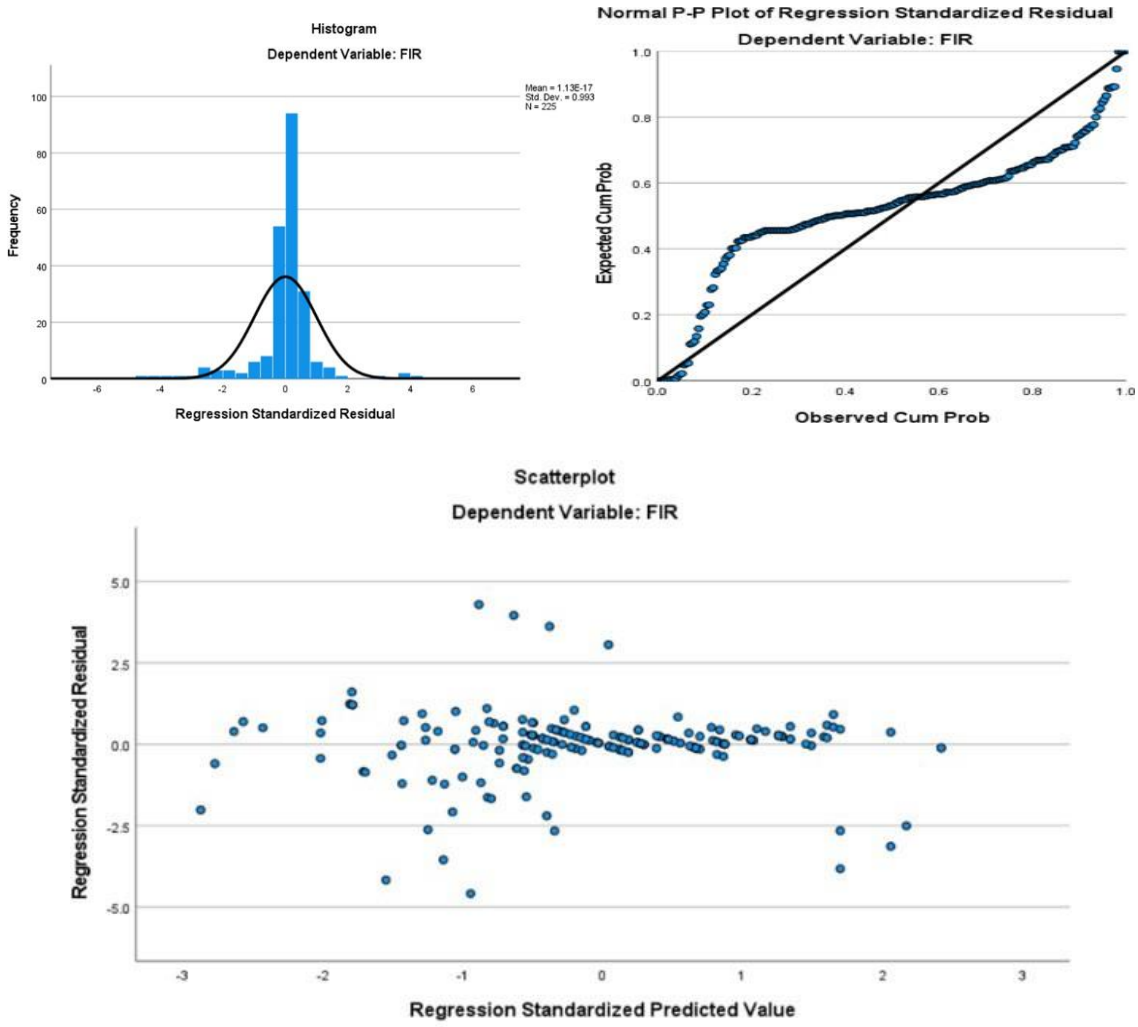

Figure 11. Histogram, P-P Plot, and Scatterplot

In summary, this study investigated the role of digital technologies as a moderator in relationships between supply chain disruptions as an independent variable and supply chain resilience as a dependent variable. The relationship between the two variables was significantly moderated ($p < 0.001$). Therefore, hypothesis H1 is supported. The second

test was the moderating effects of digital technologies on the relationship between supply chain resilience as an independent variable and firm performance as a dependent variable. The finding was that digital technologies significantly moderate the relationship between the two variables ($p < 0.001$), and hypothesis H2 is supported. The moderating effects in the two relationships are presented in Table 8.

Table 9.

Summary of Multiple Linear Regression

Hypotheses	Independent Variable	Moderator	Dependent Variable	Beta Coefficient	p-value	Hypothesis supported/ rejected
H1	Supply chain disruptions	Digital technologies	Supply chain resilience	0.305	<0.001	supported
H2	Supply chain resilience	Digital technologies	Firm performance	0.423	<0.001	supported

Digital Technologies Preferences

Descriptive Statistics

The survey also asked respondents who are working in the agri-food industry about their preferences in the importance of each digital technology in their operations—the ranking with the lowest at one and highest at ten. The list of digital technologies used in this study was adapted from the World Bank Group (2019). They suggested that several digital technologies will significantly transform agriculture and food production. They proposed that digital technologies can transform agriculture practices and food production. The deployment of digital technologies improves the accessibility of farmers' market information, productivity, and cost management. Respondents from the agri-food industry highly rated digital technologies such as mobile technologies (DTS2), big data analytics (DTS4), the internet of things (DTS5), Cloud computing (DTS3), Data collection technologies (DTS9), etc.; a full list of preferred technologies is in Table 9. Participants were also asked about their preferences regarding the importance of every digital technology that may benefit firms in the agri-food industry, with ratings from least benefit (1) and (10) at the most benefit. Table 9 presents the survey results with mobile technologies (DTS2) as the most beneficial, with a mean of 7.44, and E-extension services (DTS15) at the least beneficial, with a mean of 5.77.

Table 10.

Descriptive Statistics of Digital Technologies Preferences

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Mobile technologies (DTS2).	225	1	10	7.44	2.104
Big data analytics (DTS4).	225	1	10	7.2	2.13
Internet of Things (DTS5).	225	1	10	7.04	2.138
Cloud computing (DTS3).	225	1	10	6.79	2.293
Data collection technologies (DTS9).	225	1	10	6.77	2.351
Encryption, data protection, and data sharing technologies (DTS12).	225	1	10	6.73	2.243
Precision agriculture (DTS10).	225	1	10	6.64	2.473
Digitized transactions and payments (DTS16).	225	1	10	6.53	2.542
Digitized marketplaces for agri-food products (DTS14).	225	1	10	6.47	2.39
Institutions for data sharing (DTS11).	225	1	10	6.46	2.324
Robotics and automation (DTS7).	225	1	10	6.46	2.161
Distributed ledger technologies and smart contracts (DTS1).	225	1	10	6.43	2.348
Agricultural sensing and aera imaging technologies (DTS6).	225	1	10	6.19	2.47
Artificial intelligence and machine learning (DTS8).	225	1	10	6.06	2.423
Food-sensing technologies (DTS13).	225	1	10	5.79	2.454
E-extension services (DTS15).	225	1	10	5.77	2.409

Preferred Digital Technologies at a High Level of Deployment

Based on regression analysis with DTS as a moderating variable in SPSS by Hayes PROCESS (2023). It was also discussed in more detail in the following discussion part. The analysis result showed that the level of digital technology deployment was at three levels: the lowest level at the mean of 4.76, medium at the mean of 5.66, and the highest level of digital technology deployment at the mean of 6.55. The previous analysis confirmed the hypothesis: *" The higher the employment of digital technologies, the greater is the perceived resilience to the firm disruption in the agri-food industry "* This analysis used one sample T-test to test participants' perceptions of the deployment of every single digital technology at the high level of deployment at 6.55. This analysis with H0: "*digital technology deployment equal 6.55*" if $p>0.05$ and H1: "*digital technology deployment differ 6.55*" if $P<0.05$. Table 13 presents the results of the analysis, in which digital technologies DTS1, DTS3, DTS7, DTS9, DTS10, DTS11, DTS12, DTS14, and DTS16 were supported by H0, and digital technologies DTS2, DTS4, DTS5, DTS6, DTS8, DTS13, and DTS15 were not supported (supported by H1). The mean difference of H1-supported technologies was also examined with technology means higher than 6.55; Table 12 presents DTS2, DTS4, and DTS5 as higher than 6.55; those technologies are still beneficial to the firm operation if deployed. Therefore, based on participants' perceptions, all digital technologies except DTS6, DTS8, DTS13, and DTS15 were highly beneficial to the supply chain in the agri-food industry.

Table 11.

One Sample T-test of Digital Technologies

One-Sample Test							
	Test Value = 6.55						
			Significance			95% Confidence Interval of the Difference	
	t	df	One-Sided p	Two-Sided p	Mean Difference	Lower	Upper
Distributed ledger technologies and smart contracts (DTS1).	-0.788	224	0.216	0.432	-0.123	-0.43	0.19
Mobile technologies (DTS2).	6.314	224	0.000	0.000	0.886	0.61	1.16
Cloud computing (DTS3).	1.548	224	0.061	0.123	0.237	-0.06	0.54
Big data analytics (DTS4).	4.578	224	0.000	0.000	0.650	0.37	0.93
Internet of Things (DTS5).	3.470	224	0.000	0.001	0.494	0.21	0.78
Agricultural sensing and aera imaging technologies (DTS6).	-2.179	224	0.015	0.030	-0.359	-0.68	-0.03
Robotics and automation (DTS7).	-0.640	224	0.261	0.523	-0.092	-0.38	0.19
Artificial intelligence and machine learning (DTS8).	-3.020	224	0.001	0.003	-0.488	-0.81	-0.17
Data collection technologies (DTS9).	1.397	224	0.082	0.164	0.219	-0.09	0.53
Precision agriculture (DTS10).	0.546	224	0.293	0.586	0.090	-0.23	0.41
Institutions for data sharing (DTS11).	-0.567	224	0.286	0.572	-0.088	-0.39	0.22
Encryption, data protection, and data sharing technologies (DTS12).	1.197	224	0.116	0.233	0.179	-0.12	0.47
Food-sensing technologies (DTS13).	-4.638	224	0.000	0.000	-0.759	-1.08	-0.44
Digitized marketplaces for agri-food products (DTS14).	-0.523	224	0.301	0.602	-0.083	-0.40	0.23
E-extension services (DTS15).	-4.837	224	0.000	0.000	-0.777	-1.09	-0.46
Digitized transactions and payments (DTS16).	-0.098	224	0.461	0.922	-0.017	-0.35	0.32

Preferred Digital Technologies by Firm Size

Because digital technology deployment is a huge capital investment, the return on investment and firm interests may differ between the firms. Therefore, the study used One-Way ANOVA to test the perspective of participants in different firm sizes. The firm sizes are based on the number of employees at the firm, with scales of less than 250 employees as small-size firms, from 250 to 500 employees, from 501 to 1000 employees as medium and medium-large firms, and the large size is more than 1000 employees. This analysis aimed to examine whether there were differences between people's perspectives from different firm sizes. The result of the Levene test with $p = 0.547 > 0.05$ explained that the variances were not significantly different from each other or the homogeneity of variances was met. ANOVA $p = 0.418 > 0.05$ explained that there were no different means between groups or no different perspectives of digital technology deployment between people working in different firm sizes, as presented in Figure 12.

The use of digital technologies by industry practitioners is studied in aggregate, regardless of firm sizes and geographical location. Usage of specific technologies may vary if investigated at a more granular level.

Descriptives								
DTS								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Less than 250	74	6.4738	1.61410	0.18763	6.0999	6.8478	1.81	9.00
250 –500	37	6.7314	1.45333	0.23893	6.2469	7.2160	3.50	9.31
501 – 1000	36	6.1823	1.56370	0.26062	5.6532	6.7114	1.63	8.88
1001 and above	78	6.6779	1.80795	0.20471	6.2703	7.0855	1.69	10.00
Total	225	6.5403	1.65193	0.11013	6.3233	6.7573	1.63	10.00

Tests of Homogeneity of Variances					
		Levene Statistic	df1	df2	Sig.
DTS	Based on Mean	0.709	3	221	0.547
	Based on Median	0.752	3	221	0.522
	Based on Median and with adjusted df	0.752	3	215.392	0.522
	Based on trimmed mean	0.707	3	221	0.549

ANOVA					
DTS					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7.769	3	2.590	0.948	0.418
Within Groups	603.495	221	2.731		
Total	611.264	224			

Figure 12. Preferred Digital Technologies by Firm Sizes

Preferred Digital Technologies by Geographical Locations

Similar to the previous analysis, the study examined the perspective of participants in different locations around the world. The results showed that the Levene test with $p = 0.242 > 0.05$ and ANOVA with $p = 0.176 > 0.05$ explained that the homogeneity of groups was met, and there were no differences between participants in

different locations. Digital technologies benefit the firm's performance in different geographical locations, as presented in Figure 13.

Descriptives								
DTS								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
North America	53	6.1097	1.42178	0.19530	5.7178	6.5016	2.00	8.88
Central and South America	1	6.0625					6.06	6.06
Europe	14	6.5446	1.57398	0.42066	5.6359	7.4534	2.19	8.75
Asia	157	6.6883	1.71801	0.13711	6.4175	6.9591	1.63	10.00
Total	225	6.5403	1.65193	0.11013	6.3233	6.7573	1.63	10.00

Tests of Homogeneity of Variances					
		Levene Statistic	df1	df2	Sig.
DTS	Based on Mean	1.430	2	221	0.242
	Based on Median	1.483	2	221	0.229
	Based on Median and with adjusted df	1.483	2	218.804	0.229
	Based on trimmed mean	1.435	2	221	0.240

ANOVA					
DTS					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	13.496	3	4.499	1.663	0.176
Within Groups	597.768	221	2.705		
Total	611.264	224			

Figure 13. Preferred Digital Technologies by Geographical Locations

Discussion

This study found that supply chain disruptions easily propagate throughout the network because the agri-food supply chain is sensitive to vulnerabilities and easily disrupted by disturbance. The findings of this study have consolidated the results of study one, a qualitative study on the matter. The study findings are based on hypotheses that were addressed at the beginning of this study.

A key finding of the study about the participants' perceptions is that digital technologies positively impact supply chain resilience in improving resilience capability to deal with disruptions and firm performance in the agri-food industry.

Hypothesis 1: The higher the employment of digital technologies, the greater is the perceived resilience to firm disruption in the agri-food industry.

Supply chain disruptions significantly and positively affected resilience capability, but the strength of the effect was not strong (β=0.138). It implies more disruption in the chain, but it is not a big contribution to the resilience of the agri-food supply chain. The other explanation of the effect of disruption is the resilience capability needed by the firm to build rather than learn from past disruptions or "self-educated through disruptions." A firm in the agri-food industry needs to proactively design, build, and operate its resilient supply chain to deal with disruptions. In the relationship between supply chain disruptions and supply chain resilience, if digital technologies act as a moderator on the relationship, the outcome makes the difference (β=0.305). This implies that when disrupted events occur in the chain, with the moderating effect of digital technologies, a firm's resilience capability will significantly contribute to dealing with the disruption. The deployment of digital technologies to the supply chain operation will

maintain connectedness and responsiveness, supporting the chain to proactively cope with disturbance by increasing visibility, flexibility, and agility (Ivanov et al., 2019).

Figure 14 enhances this argument that visualizes the conditional effect of independent variable supply chain disruption (SCD) and dependent variable supply chain resilience (SCR) under the impact of digital technologies (DTS) as moderators in three scenarios: low, medium, and high. Low or without the influence of digital technologies at 4.76 presents "the more SCD, the lower SCR in the supply chain," influenced by DTS at medium (5.66) and high (6.55) levels implied "the more SCD, the more resilience capability to improve." The visualization displayed the conditional effect of SCD, SCR, and DTS by Hayes (2023) PROCESS in IBM SPSS (2023), visualizing the hypothesis one by numbers.

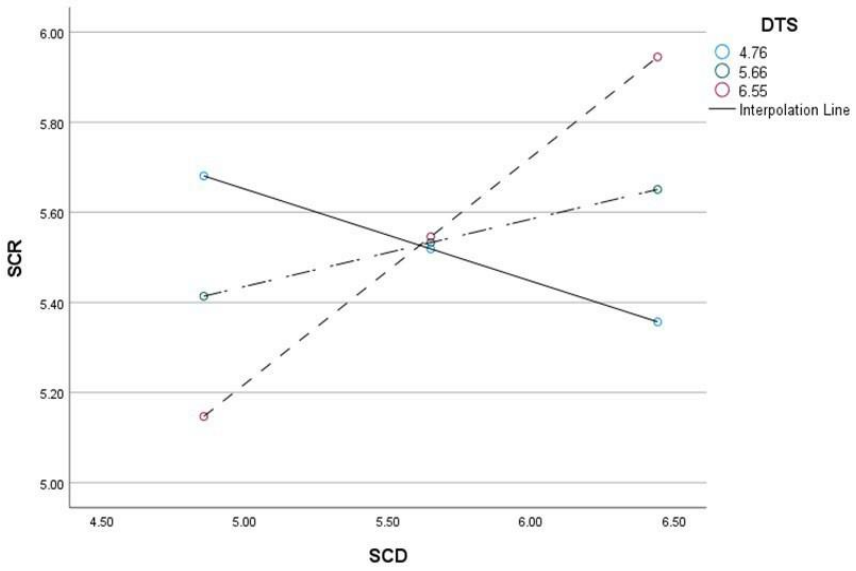

Figure 14. Visualization Hypothesis One

Hypothesis 2: The higher the employment of digital technologies, the greater is the perceived firm performance to resilience in the agri-food industry.

The effects of supply chain resilience on the firm performance under the moderation of digital technologies, with significant impact (β=0.423). Figure 15 demonstrates the conditional effect of independent variable supply chain resilience (SCR)and dependent variable firm performance (FIR) under the influence of digital technologies (DTS) as moderators in three scenarios: low, medium, and high. There is not much difference at a low level or without the influence of digital technologies. Then, with the influence of DTS at medium (5.66) and high (6.55) levels, the firm's performance dramatically changes. The slope of the line indicates the benefit of level deployment of digital technology. This visual chart consolidates hypothesis two. Figure 15 visualizes the conditional effect of SCR, FIR, and DTS by Hayes (2023) PROCESS in IBM SPSS (2023).

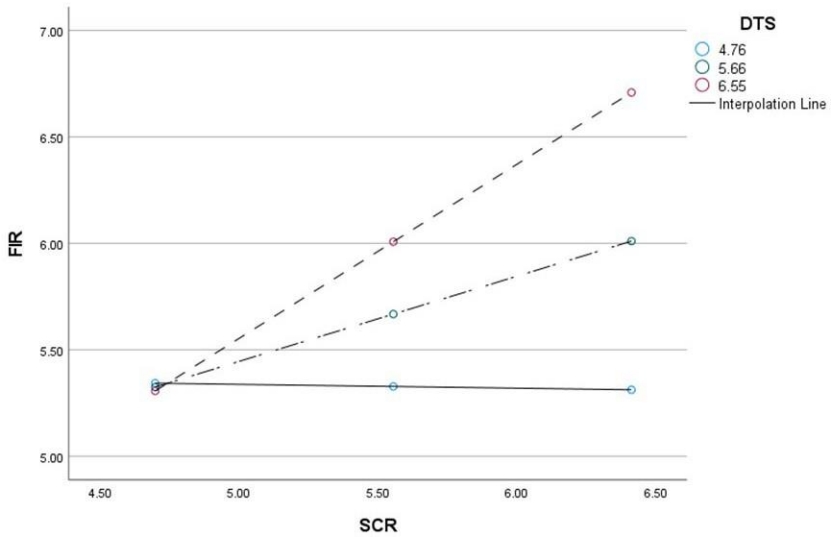

Figure 15. Visualization Hypothesis Two

The second key finding is that the ultimate outcomes of firm performance (FIR) were divided into two groups, financial and nonfinancial outcomes, thus leading to the response of participants being divided into two components during the exploratory factor analysis. Where FIR1, FIR2, and FIR3 represent financial outcomes and FIR4, FIR5, and FIR6 represent nonfinancial outcomes. That implies those outcomes are distinguished from each other. Future research may go further to study a tradeoff mechanism between financial and nonfinancial outcomes when building the resilience capability of a supply chain.

The third key finding is that digital technologies are strongly preferred among participants in the industry. Their perspectives imply that digital technologies improve supply chain resilience in dealing with disruptions and firm performance. After consolidating for different firm sizes and geographical locations, no difference was found among respondents. In addition, respondents perceive that twelve of sixteen digital technologies were highly beneficial to the firm operations in the agri-food industry. Notably, several digital technologies have high preferences from industry practitioners, such as mobile technologies, data collection technologies, big data analytics, cloud computing, and precision agriculture. For example, mobile technologies emerge to be the most beneficial to the industry because of their decentralized operations and the nature of business, like rural areas, biosecurity, and mass operations. These issues are an obstacle to physical connection. The fifth generation of mobile technologies will resolve the problems with wireless and high data transmission. Data collection technologies help farms and firms collect desired data from the field through technologies such as area imaging, sensing, radio frequency identification, quick response codes, etc. Data generated from data

collection technologies will be transferred to big data analytic technologies for analysis. As a result, firms and farmers can utilize precision agriculture technology to optimize their farming. Digital technologies will help farms and firms produce higher-yield crops, less waste, optimized inputs, and higher productivity.

CHAPTER 5

CONCLUSIONS AND CONTRIBUTIONS

This research aimed to develop a new theory in research gaps in the extant literature on the agri-food supply chain. Through an exploratory study, the research examines resilience in the agri-food supply chain and how digital technologies assist the supply chain in addressing disruptions and improving firm performance. The agri-food supply chain presents all typical features of volatility, uncertainty, complexity, and ambiguity. The agri-food supply chain comprises one or two production cycles: agricultural production and food processing. In addition, weather dependence and the long lead times in production place pressure on firms along the supply chain, rendering the supply chain susceptible to vulnerabilities and disruptions. It is a prominent issue and getting the concerns of practitioners and academia when firms face disruptions with higher frequencies and catastrophes. The COVID-19 pandemic has been “a perfect shock” to test the resilience capability of a firm in the agri-food supply chain. Notably, the research observes that firms apply many solutions to address these conditions, most prominently by incorporating digital technologies. The pandemic has been a catalyst for the digitalization of the agri-food supply chain.

Conclusions

Study one examines practitioners' perceptions in the industry and supply chain management about resilience and digital technologies in assisting the supply chain in dealing with disruptions and operational outcomes at a strategic level. The study

collected data through interviews with industry practitioners, and a qualitative analysis provided insights from executives, directors, and managers about the role of supply chain resilience and the impact of digital technologies in the agri-food industry. The study confirmed a crucial relationship between building resilience capability and increasing competitive advantage, which synergizes effectively around the introduction of digital technologies. The COVID-19 pandemic puts the agri-food supply chain in the most challenging time when leading a resilient supply chain is needed more than ever. The study results showed that participants perceived resilience as crucial in helping the agri-food supply chain bounce back quickly and maintain business continuity. The results of the study can be briefly summarized as: i) Supply chain resilience is extremely important in the agri-food supply chain because of its sensitively vulnerable from disturbances; ii) Digital technologies can promote supply chain resilience in collaboration between partners and visibility of the entire chain to better deal with disruption in the agri-food supply chain; iii) Firm performance increases when the firm incorporates digital technologies that can minimize negative effects of supply chain disruptions. The study also suggested that firms should proactively build their resilience capability rather than learn from past disruptions.

Study two is a quantitative study aimed at verifying respondents' perceptions to evaluate whether digital technology offers an effective solution to improve supply chain resilience. Practitioners working in the agri-food industry at the execution level provided their perceptions about the impact of digital technologies on the agri-food supply chain to improve resilience capability to deal with disruptions and improve firm operational outcomes. The study finds that practitioners see effective solutions to prevent supply

chain disruptions and maintain business continuity in enhancing the resilient elements, such as adaptive capability by increasing the ability to adapt to the changes, promoting the last-mile strategy, and working on contingency plans. Practitioners confirmed the need to promote the visibility of their supply chain by connecting members to follow the end-to-end supply chain model. Collaboration is a crucial element in supply chain resilience.

Digital technology applications have been widely proven over the past decade, and the study provides further evidence that digital technologies significantly contribute to firm operations and performance with connectedness and responsiveness. Digital technologies help supply chains deal with disruptions by affecting core resilience capabilities such as visibility, collaboration, and agility in the supply chain. The study also proposes a list of digital technologies beneficial to the agri-food industry, which is a helpful reference for practitioners in their operations. Several digital technologies, such as mobile technology, have been widely deployed in the agri-food industry, which allows farmers to monitor and control farm equipment from anywhere. Big data in managing farm resources and cloud computing is used to collect, analyze, and store data. Farmers use robots for harvesting; precision agriculture helps to feed the correct amount at the right time, which increases productivity and yield. Food sensing technologies to identify pollutants, pathogens in food products, and many more. The key things to accelerate the deployment of digital technologies are affordability and the return on investment.

Contributions

Theoretical Contribution

Uncovering the insights into supply chain resilience that were limited in extant research in the agri-food supply chain, an incremental contribution to the body of knowledge is to acknowledge the significant improvement of supply chain resilience under the impact of digital technologies in the agri-food industry. In the light of the dynamic capabilities theory by Teece et al. (1997), this study confirms that resilience capability is the dynamic capability of a firm to respond to turbulence through its flexibility, innovative adaptability, and collaboration. Resilience capability also enhances a firm's absorptive, adaptive, and restorative capabilities in the agri-food industry to better deal with disruptions in the future.

Managerial Implications

The study implies that the resilience capability of firms will help them better absorb disruption, quickly adapt their business processes, and be robust in restoring to the new norm. The study results encourage industry practitioners to proactively respond and make appropriate decisions to limit losses and gain a better position in the agri-food industry. The study results imply that practitioners should promote collaborative approaches to the entire supply chain and increase supply chain visibility and integration to promote supply chain robustness to overcome disturbances and disruptions. Moreover, industry practitioners must take advantage of Industrial Revolution 4.0 and digital technologies to gain competitive advantages; digital technologies will gradually become involved in human life. The research also suggests that several technologies significantly

benefit the agri-food supply chain, such as mobile technologies, big data analytics, the Internet of Things, data collection technologies, etc. Digital technologies are powerful tools to support transactions in decentralized networks like the agri-food supply chain.

Limitations and Future Research

Firstly, the scope of this study only focused on the “from farm to table” supply chain in the agri-food industry; the generalizability of the findings may not be across all industries. The study recommended further study of supply chain resilience in different industries and contexts with the involvement of digital technologies.

Secondly, the COVID-19 pandemic was a "perfect" shock to the agri-food supply chain. Its disruption and ripple effects may be reached at an exceptional magnitude, and its consequences may have amplified respondents' perceptions. The consequences of the COVID-19 pandemic have not yet been fully measurable in short-term and long-term impacts on the agri-food industry.

Thirdly, the limitation is that supply chain disruptions may also come from digital disruptions, such as cyberattacks, natural disasters, service provider outages, physical security breaches, data corruption, and software and hardware failures. In other words, digital technologies also increase the possibility of the vulnerability of the agri-food supply chain. For example, the world's largest meat processor, JBS USA, paid a ransom equivalent to $11 million in Bitcoin following a cyberattack that disrupted its domestic and international operations and threatened to disrupt food supply chains (Reuters, 2021). The question of "to pay or not to pay" to a cyberattack would be interesting.

Finally, supply chain resilience may come from a third party. The agricultural and food sector is a social matter related to the people's living standards that may cause political issues. Thus, government interference may sometimes occur, which does not reflect the free-market mechanism (Blessley & Mudambi, 2022).

Future research should examine the relationship between supply chain resilience and supply chain robustness in the agri-food industry and the role of digital technologies on supply chain visibility, supply chain integration, and supply chain robustness. Additionally, the role of governmental interference in improving supply chain resilience and the digital disruptions in the agri-food industry would be potential areas of future research.

REFERENCES

Ahumada, O., & Villalobos, J. R. (2009). Application of planning models in the agri-food supply chain: A review. *European Journal of Operational Research*, *196*(1), 1–20. https://doi.org/10.1016/j.ejor.2008.02.014

AG and food sectors and the economy. USDA ERS - Ag and Food Sectors and the Economy. (2021). https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy/

Anbumozhi, V., Thangavelu, S., & Kimura, F. (2016, May 13). *Supply Chain Resilience: Reducing Vulnerability to Economic Shocks, Financial Crises, and Natural Disasters*. ERIA. https://www.eria.org/research/supply-chain-resilience-reducing-vulnerability-to-economic-shocks-financial-crises-and-natural-disasters/.

Aramyan, L. H., Oude Lansink, A. G. J. M., van der Vorst, J. G. A. J., & van Kooten, O. (2007). Performance measurement in agri-food Supply Chains: A case study. *Supply Chain Management: An International Journal*, *12*(4), 304–315. https://doi.org/10.1108/13598540710759826

Barney, J. B. (2001a). Resource-based theories of competitive advantage: A ten-year retrospective on the resource-based view. *Journal of Management*, *27*(6), 643–650. https://doi.org/10.1177/014920630102700602

Barney, J. B. (2001b). Is the Resource-Based "View" a Useful Perspective for Strategic Management Research? Yes. *The Academy of Management Review*, *26*(1), 41. https://doi.org/10.2307/259393

Barreto, I. (2009). Dynamic Capabilities: A Review of Past Research and an Agenda for the Future. *Journal of Management*, *36*(1), 256–280. https://doi.org/10.1177/0149206309350776

Bennett, N., & Lemoine, J. (2014). What VUCA really means for you. *Harvard Business Review*, *92*(1/2).

Beske, P. (2012). Dynamic capabilities and sustainable supply chain management. *International Journal of Physical Distribution & Logistics Management*, *42*(4), 372–387. https://doi.org/10.1108/09600031211231344

Blackhurst, J., Dunn, K. S., & Craighead, C. W. (2011). An Empirically Derived Framework of Global Supply Resiliency. *Journal of Business Logistics*, *32*(4), 374–391. https://doi.org/10.1111/j.0000-0000.2011.01032.x

Blessley, M., & Mudambi, S. M. (2022). A trade war and a pandemic: Disruption and resilience in the Food Bank Supply Chain. *Industrial Marketing Management*, *102*, 58–73. https://doi.org/10.1016/j.indmarman.2022.01.002

Bouncken, R. B., Qiu, Y., Sinkovics, N., & Kürsten, W. (2021). Qualitative research: Extending the range with flexible pattern matching. *Review of Managerial Science, 15*(2), 251–273. https://doi.org/10.1007/s11846-021-00451-2

Christopher, M., & Peck, H. (2004). Building the Supply Chain Resilience, Vol. 15, No. 2, pp1-13, 2004. *International Journal of Logistics Management,* 15(2), 1–13.

Chopra, S., & Sodhi, M. S. (2004). Supply-chain breakdown. *MIT Sloan Management Review*, *46*(1), 53-61.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly*, *35*(1), 128. https://doi.org/10.2307/2393553

Collis, D. J. (1994). Research Note: How Valuable are Organizational Capabilities? *Strategic Management Journal*, *15*(S1), 143–152. https://doi.org/10.1002/smj.4250150910

Copeland, L. (2022). Resilience of agri-food systems. *Agriculture*, *12*(4), 543. https://doi.org/10.3390/agriculture12040543

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Los Angeles, CA: SAGE.

Eisenhardt, K. M., & Martin, J. A. (2000). Dynamic capabilities: what are they? *Strategic Management Journal*, *21*(10-11), 1105–1121. https://doi.org/10.1002/1097-0266(200010/11)21:10/11<1105::aid-smj133>3.0.co;2-e

Fabrizio, K. R. (2009). Absorptive capacity and the search for innovation. *Research Policy*, *38*(2), 255–267. https://doi.org/10.1016/j.respol.2008.10.023

Ghalayini, A. M., & Noble, J. S. (1996). The changing basis of performance measurement. *International Journal of Operations & Production Management*, *16*(8), 63–80. https://doi.org/10.1108/01443579610125787

Gibson, C. B., & Birkinshaw, J. (2004). The Antecedents, Consequences, and Mediating Role of Organizational Ambidexterity. *Academy of Management Journal*, *47*(2), 209–226. https://doi.org/10.5465/20159573

Gimbert, X., Bisbe, J., & Mendoza, X. (2010). The role of performance measurement systems in strategy formulation processes. *Long Range Planning*, *43*(4), 477–497. https://doi.org/10.1016/j.lrp.2010.01.001

Glaser B. & Strauss A.L. (1967) The Discovery of Grounded Theory: Strategies for Qualitative Research. Aldine Publishing Company, New York

Goodman, L. A. (1961). Snowball sampling. *The Annals of Mathematical Statistics*, *32*(1), 148–170. https://doi.org/10.1214/aoms/1177705148

Harrison, J. S., & Freeman, R. E. (1999). Stakeholders, social responsibility, and performance: Empirical evidence and theoretical perspectives. *Academy of Management Journal*, *42*(5), 479–485. https://doi.org/10.5465/256971

Hennessy, D. A. (1996). Information asymmetry as a reason for food industry vertical integration. *American Journal of Agricultural Economics*, *78*(4), 1034–1043. https://doi.org/10.2307/1243859

Ho, W., Zheng, T., Yildiz, H., & Talluri, S. (2015). Supply chain risk management: A literature review. *International Journal of Production Research*, *53*(16), 5031–5069. https://doi.org/10.1080/00207543.2015.1030467

Hobbs, J. E. (2021). Food Supply Chain Resilience and the COVID-19 pandemic: What have we learned? *Canadian Journal of Agricultural Economics/Revue Canadienne D'agroeconomie*, *69*(2), 189–196. https://doi.org/10.1111/cjag.12279

Houlihan, J. B. (1988). International Supply Chains: A New Approach. Management Decision, 26(3), 13–19. https://doi.org/10.1108/eb001493

Hussein, A. (2009). The use of triangulation in Social Sciences Research. *Journal of Comparative Social Work*, *4*(1), 106–117. https://doi.org/10.31265/jcsw.v4i1.48

Ivanov, D. (2021a). Supply chain viability and the COVID-19 pandemic: A conceptual and formal generalization of four major adaptation strategies. *International Journal of Production Research*, *59*(12), 3535–3552. https://doi.org/10.1080/00207543.2021.1890852

Ivanov, D. (2021b). Digital Supply Chain Management and technology to enhance resilience by building and using end-to-end visibility during the COVID-19 pandemic. *IEEE Transactions on Engineering Management*, 1–11. https://doi.org/10.1109/tem.2021.3095193

Ivanov, D. (2022). Digital Supply Chain Management and technology to enhance resilience by building and using end-to-end visibility during the COVID-19 pandemic. *IEEE Transactions on Engineering Management*, 1–11. https://doi.org/10.1109/tem.2021.3095193

Ivanov, D., Dolgui, A., & Sokolov, B. (2019). The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. *International Journal of Production Research*, *57*(3), 829–846. https://doi.org/10.1080/00207543.2018.1488086

Jüttner, U., & Maklan, S. (2011). Supply Chain Resilience in the global financial crisis: An empirical study. *Supply Chain Management: An International Journal*, *16*(4), 246–259. https://doi.org/10.1108/13598541111139062

Kumar, P., & Singh, R. K. (2021). Strategic framework for developing resilience in agri-food supply chains during COVID 19 pandemic. *International Journal of*

Logistics Research and Applications, 1–24. https://doi.org/10.1080/13675567.2021.1908524

Lebas, M., & Euske, K. (2007). A conceptual and operational delineation of performance. *Business Performance Measurement*, 125–140. https://doi.org/10.1017/cbo9780511488481.008

Leonard-Barton, D. (1992). Core capabilities and core rigidities: A paradox in managing new product development. *Strategic Management Journal*, *13*(S1), 111–125. https://doi.org/10.1002/smj.4250131009

Lezoche, M., Hernandez, J. E., Alemany Díaz, M. del, Panetto, H., & Kacprzyk, J. (2020). Agri-Food 4.0: A survey of the supply chains and technologies for the Future Agriculture. *Computers in Industry*, *117*, 103187. https://doi.org/10.1016/j.compind.2020.103187

Li, F., Nucciarelli, A., Roden, S., & Graham, G. (2016). How smart cities transform operations models: A new research agenda for operations management in the Digital Economy. *Production Planning & Control*, *27*(6), 514–528. https://doi.org/10.1080/09537287.2016.1147096

Liu, C.-L., Shang, K.-C., Lirn, T.-C., Lai, K.-H., & Lun, Y. H. V. (2018). Supply Chain Resilience, firm performance, and management policies in the liner shippingindustry. *Transportation Research Part A: Policy and Practice*, *110*, 202–219. https://doi.org/10.1016/j.tra.2017.02.004

Macfadyen, S., Tylianakis, J. M., Letourneau, D. K., Benton, T. G., Tittonell, P., Perring, M. P., ... & Smith, H. G. (2015). The role of food retailers in improving resilience in global food supply. *Global Food Security*, *7*, 1-8.

Masteika, I., & Čepinskis, J. (2015). Dynamic Capabilities in Supply Chain Management. *Procedia - Social and Behavioral Sciences*, *213*, 830–835. https://doi.org/10.1016/j.sbspro.2015.11.485

Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining Supply Chain Management. Journal of Business Logistics, 22(2), 1–25. https://doi.org/10.1002/j.2158-1592.2001.tb00001.x

Michel-Villarreal, R., Vilalta-Perdomo, E. L., Canavari, M., & Hingley, M. (2021). Resilience and digitalization in short food supply chains: A case study approach. *Sustainability*, *13*(11), 5913. https://doi.org/10.3390/su13115913

Miles, M. B., Huberman, A. M., & Saldaña Johnny. (2020). *Qualitative Data Analysis: A methods sourcebook*. SAGE Publications, Inc.

Miller, C. C., Washburn, N. T., & Glick, W. H. (2013). Perspective—the myth of firm performance. *Organization Science*, *24*(3), 948–964. https://doi.org/10.1287/orsc.1120.0762

Miller, M. (2021). Big Data, information asymmetry, and Food Supply Chain Management for Resilience. *Journal of Agriculture, Food Systems, and Community Development*, 1–12. https://doi.org/10.5304/jafscd.2021.111.017

Min, H. (2019). Blockchain technology for Enhancing Supply Chain Resilience. *Business Horizons*, *62*(1), 35–45. https://doi.org/10.1016/j.bushor.2018.08.012

Myers, M. D. (2020). *Qualitative research in business & management*. SAGE Publications Ltd.

Nations, U. (2022, October). A world of 8 Billion. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/undesa_pd_2022_pb_140.pdf

Nations. U., F. A. O. (2021). *World Food and Agriculture - Statistical Yearbook 2021*. FOOD & AGRICULTURE ORG.

Oktemgil, M., & Greenley, G. (1997). Consequences of high and low adaptive capability in UK companies. *European Journal of Marketing*, *31*(7), 445–466. https://doi.org/10.1108/03090569710176619

Parker, H., & Ameen, K. (2018). The role of resilience capabilities in shaping how firms respond to disruptions. *Journal of Business Research*, *88*, 535–541. https://doi.org/10.1016/j.jbusres.2017.12.022

Peck, H. (2005). Drivers of Supply Chain Vulnerability: An integrated framework. *International Journal of Physical Distribution & Logistics Management*, *35*(4), 210–232. https://doi.org/10.1108/09600030510599904

Peterson, W., Gijsbers, G. and Wilks, M. (2003). An Organizational Performance Assessment System for Agricultural Research Organizations: Concepts, Methods, and Procedures. ISNAR Research Management Guidelines No. 7, *International Service for National Agricultural Research*, The Hague.

Pettit, T. J., Croxton, K. L., & Fiksel, J. (2013). Ensuring Supply Chain Resilience: Development and implementation of an assessment tool. *Journal of Business Logistics*, *34*(1), 46–76. https://doi.org/10.1111/jbl.12009

Ponomarov, S. Y., & Holcomb, M. C. (2009). Understanding the concept of Supply Chain Resilience. *The International Journal of Logistics Management*, *20*(1), 124–143. https://doi.org/10.1108/09574090910954873

PricewaterhouseCoopers. (2021). *Global Crisis Survey 2021: Building resilience for the future*. PwC. https://www.pwc.com/gx/en/issues/crisis-solutions/global-crisis-survey.html.

Remember, search, and share your voice conversations. Otter Voice Meeting Notes. (n.d.). Retrieved May 2, 2022, from https://otter.ai/home

Remko, van H. (2020). Research opportunities for a more resilient post-covid-19 supply chain – closing the gap between research findings and Industry Practice. *International Journal of Operations & Production Management*, *40*(4), 341–355. https://doi.org/10.1108/ijopm-03-2020-0165

Saldana, J. (2021). *The coding manual for qualitative researchers*. SAGE Publications Ltd.

Shisler, R. C., & Sbicca, J. (2019). Agriculture as carework: The contradictions of performing femininity in a male-dominated occupation. *Society & Natural Resources*, *32*(8), 875-892.

Seashore, S. E., & Yuchtman, E. (1967). Factorial analysis of Organizational Performance. *Administrative Science Quarterly*, *12*(3), 377. https://doi.org/10.2307/2391311

Sheffi, Y., & Rice Jr, J. B. (2005). A supply chain view of the resilient enterprise. *MIT Sloan management review*, *47*(1), 41.

Stone, J., & Rahimifard, S. (2018). Resilience in agri-food supply chains: a critical analysis of the literature and synthesis of a novel framework. Supply Chain Management, 23(3), 207–238. https://doi.org/10.1108/SCM-06-2017-0201

Strauss, A., & Corbin, J. (1990). *Basics of qualitative research*. Sage.

Taouab, O., & Issor, Z. (2019). Firm performance: Definition and measurement models. *European Scientific Journal ESJ*, *15*(1). https://doi.org/10.19044/esj.2019.v15n1p93

Tendall, D. M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q. B., ... & Six, J. (2015). Food system resilience: defining the concept. *Global Food Security*, *6*, 17-23.

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, *18*(7), 509–533. https://doi.org/10.1002/(sici)1097-0266(199708)18:7<509::aid-smj882>3.0.co;2-z

Tortorella, G. L., Giglio, R., & van Dun, D. H. (2019). Industry 4.0 adoption as a moderator of the impact of Lean production practices on Operational Performance

Improvement. *International Journal of Operations & Production Management*, *39*(6/7/8), 860–886. https://doi.org/10.1108/ijopm-01-2019-0005

Tsolakis, N. K., Keramydas, C. A., Toka, A. K., Aidonis, D. A., & Iakovou, E. T. (2014).

Agrifood supply chain management: A comprehensive hierarchical decision-making framework and a critical taxonomy. *Biosystems Engineering*, *120*, 47–64. https://doi.org/10.1016/j.biosystemseng.2013.10.014

Tukamuhabwa, B. R., Stevenson, M., Busby, J., & Zorzini, M. (2015). Supply Chain Resilience: Definition, review and Theoretical Foundations for further study. *International Journal of Production Research, 53*(18), 5592–5623. https://doi.org/10.1080/00207543.2015.1037934

Um, J., & Han, N. (2020). Understanding the relationships between global supply chain risk and supply chain resilience: The role of Mitigating Strategies. *Supply Chain Management: An International Journal*, *26*(2), 240–255. https://doi.org/10.1108/scm-06-2020-0248

USDA ERS. (n.d.). *AG and food statistics: Charting the essentials*. USDA ERS - Ag and Food Statistics: Charting the Essentials. https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/

Nations, U. (2021). *World Food and Agriculture - Statistical Yearbook 2021*. FOOD & AGRICULTURE ORG.

Nations, U. (2022). *World population to reach 8 billion on 15 November 2022*. United Nations. https://www.un.org/en/desa/world-population-reach-8-billion-15-november-2022

NVivo. (n.d.). Retrieved May 2, 2022, from https://www.qsrinternational.com/nvivo-qualitative-data- analysis-software/home

Urquhart, C. (1997). Exploring Analyst-Client Communication: Using Grounded Theory Techniques to Investigate Interaction in Informal Requirements Gathering. *Information Systems and Qualitative Research*, 149–181. https://doi.org/10.1007/978-0-387-35309-8_10

Van der Vorst, J.G.A.J., (2000). *Effective food supply chains: generating, modelling and evaluating supply chain scenarios*. Proefschrift Wageningen [http://www.library.wur.nl/wda/dissertations/dis2841.pdf]

Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J., Fabian, N., & Haenlein, M. (2021). Digital Transformation: A multidisciplinary reflection and research agenda. *Journal of Business Research*, *122*, 889–901. https://doi.org/10.1016/j.jbusres.2019.09.022

Video conferencing, cloud phone, webinars, chat, virtual events: Zoom. Zoom Video Communications. (n.d.). Retrieved May 2, 2022, from https://zoom.us/

Wang, C. L., & Ahmed, P. K. (2007). Dynamic capabilities: A review and research agenda. *International Journal of Management Reviews*, *9*(1), 31–51. https://doi.org/10.1111/j.1468-2370.2007.00201.x

Wernerfelt, B. (1984). A resource-based view of the firm. *Strategic Management Journal*, *5*(2), 171–180. https://doi.org/10.1002/smj.4250050207

World Health Organization. (n.d.). *Who coronavirus (COVID-19) dashboard*. World Health Organization. Retrieved May 2, 2022, from https://covid19.who.int/

World Bank Group, (2019). *Future of Food: Harnessing Digital Technologies to Improve Food System Outcomes*. Open Knowledge Repository. https://openknowledge.worldbank.org/entities/publication/52f37cc3-66c3-5fd0-aa51-85a5823c64f7

Zhao, G., Liu, S., Wang, Y., Lopez, C., Zubairu, N., Chen, X., Xie, X., & Zhang, J. (2022). Modelling enablers for building agri-food supply chain resilience: Insights from a comparative analysis of Argentina and France. *Production Planning & Control*, 1–25. https://doi.org/10.1080/09537287.2022.2078246

APPENDIX A

RECRUITMENT MATERIALS

Subject: **Doctoral Research**

Dear Sir/ Madam,

I am a doctoral student at Temple University, Fox School of Business in Philadelphia, Pennsylvania, USA. Our team is doing research on supply chain resilience in the agri-food industry. The research is designed to help enterprises be more resilient to deal with supply chain disruptions. Particularly, the exploratory study focuses on the role of supply chain resilience and how digital technologies impact the supply chain resilience in the agri-food industry. The face-to-face interview will take less than one hour and use online or in-person meetings, with scheduled times and locations at your convenience. Your name and company will be kept confidential, and a summary of significant findings will be shared with you, if required.

To participate in the research, you must meet the following requirements:

1) ***You are*** from enterprises in the agri-food industry that contribute significantly to the agri-food value chain. Your firm may be genetics developers, agri-chemical producers, grain producers, agri-commodities traders, mechanical solutions and/or information technologies providers, farming activities, animal health services providers, meatpackers, food manufacturers, logistic services providers, wholesalers, and retailers.
2) ***Your firm*** must be in small-medium-sized enterprises with from 10 to 249 employees or large-sized enterprises with more than 249 employees.
3) ***You are*** working as an executive, a manager, or a team leader in supply chain management, procurement, logistics, operations, or information technologies. You must possess at least five years of work experience in the field.
4) ***All*** interviews and information exchanges are English.

Your participation in this research is important. It may help enterprises be more resilient, thus improving competitive advantages and efficiency. I appreciate your consideration of participation.

If you meet the research's conditions and are willing to participate, please respond to this email or feel free to call me on my cellphone to schedule a suitable time for interviewing.

Luong Dao

Email: ldao@temple.edu

Cellphone: +1 267 228 9099

Recruitment Letter/Email

Informed Consent Form

I am Luong Dao, a doctoral student at Temple University, Fox School of Business, Philadelphia, Pennsylvania, United States of America. I am conducting an exploratory study on the role of supply chain resilience and the impact of digital technologies in improving supply chain resilience in the agri-food industry for my doctoral dissertation.

Today, you are invited to participate in this interview, which will take less than one hour. Your participation is voluntary. If you do not wish to participate, you may stop at any time without any consequences. Your name and company will be kept confidential and not appear anywhere in the final papers.

The interview will be recorded, and a digital copy will be archived. Keeping your confidentiality, we will assign a study identification of your identity. We will store all data on two password-protected, encrypted computers; one of them is a backup solution. Your identity will be kept separate from your interview data, but it can be linked if we need to; the separated list of identities will be password protected. We will use Nvivo software to transcribe(coding) the interview. Once the transcription process is finished, the link and the digital copy of the interview that we are producing today will be destroyed. There is a small risk of data being hacked. This is a risk that may happen whenever you provide information online. We are using a secure system to collect and archive this data.

There will be no direct benefit to you right now, but I hope that the significant findings may be helpful to you and related practitioners in doing business in the future. The findings may improve the company's competitive advantage and efficiency and benefit a broad array of stakeholders.

This interview is being overseen by Temple University Institutional Board (IRB). An IRB is a group of people who perform an independent review of research implementation. You may talk to them at +1 215 707 3390 or irb@temple.edu with reference: *Protocol title:* ***The impact of digital technologies in improving supply chain resilience: An exploratory study in the agri-food industry****; Protocol number:* ***29374****; Approved date:* ***April 11, 2022***. You can contact the IRB about research participants' rights, questions, complaints about the study, any problems, or talking to someone else about the research.

Your participation is voluntary, and you can withdraw at any time during and after the interview without any consequences by sending an email to ldao@temple.edu or calling +1 267 228 9099. All data from this interview will be removed from the research.

Informed Consent Form

APPENDIX B

FULL LIST OF CODES AND THEMES

Table 12.

Full List of Codes and Themes

First-order codes	Second-order codes	Key themes	Assertion/Theory
Skyrocketed prices	Volatility	The Agri-food supply chains	The significant role of supply chain resilience in responding to disruptions and the positive effects of digital technologies in improving supply chain resilience in the agri-food industry.
Commodities			
Weather dependence	Uncertainty		
Animal diseases			
Social & political unrests.			
Perishable goods	Complexity		
Conditioned logistics			
Biological subjects			
Ripple effects	Ambiguity		
Unexpected events			
Climate changes	External disruptions	Supply chain disruptions	
Natural disasters			
Governmental regulations			
Labor shortages	Internal disruptions		
Facility safety			
Material shortages	Supply disruptions		
Workforce limitations			
Demand changes	Demand disruptions		
Multiple suppliers	Agility	Supply chain resilience	
Contingency plan			
Multiple locations			
Customer/supplier relationship	Collaboration		
Communications			
Harmonized specifications	Flexibility		
Alternative sources and products			
Redesignation	Reconfiguration		
Reshoring			
Increase inventory	Redundancy		
Additional capacity			

Table 12.
(Continued)

Transparency	Visibility	Digital technologies
Accessibility		
Enterprise resources planning system	Connectedness	
Tracking and tracing		
Global positioning system		
Real-time	Responsiveness	
Artificial Intelligence		
Radiofrequency identification		
Automation systems		
Revenue	Financial outcomes	Firm performance
Profit and loss		
Customer satisfaction	Non-financial outcomes	
Reliable partners.		
Customer retention		
Business continuity		

APPENDIX C

SURVEY QUESTIONS

Description:

The population will be a convenience sample sent out to practitioners working in the agri-food industry. The goal is to reach 200 people, with at least 100 respondents.

Introductory section and Consent agreement:

This survey is a part of research on the impact of digital technologies in improving supply chain resilience in the agri-food industry. The research investigates how resilience allows a firm to overcome supply chain disruptions and improve firm performance with the help of digital technologies. The questionnaire has been thoroughly constructed, and answering the following questions should not take more than 15 minutes. All information that you provide will be kept strictly confidential.

Screening questions:

1. Is your firm doing business in the agri-food industry?
    a. Yes
    b. No

The survey continues after a positive response above

Demographic questions:

1. What is your gender?
    a. Male

b. Female

c. Prefer not to say

2. What is your age?

    a. 18-24

    b. 25-34

    c. 35-44

    d. 45-54

    e. 55-64

    f. 65 or higher

3. Where is your geographical location?

    b. North America

    c. Central and South America

    d. Europe

    e. Asia

    f. Africa

    g. Oceania

4. What is your highest level of education? Select one.

    a. Less than a high school diploma

    b. High school diploma or GED

    c. Some college

    d. Bachelor's degree

    e. Master's degree or higher

5. What best describes your firm size in terms of (full-time equivalents)

employees?

a. Less than 250

b. 250 –500

c. 501 – 1000

d. 1001 and above

6. How many years are you working in the industry?

a. Less than 5 years

b. 5-9 years

c. 10-19 years

d. 20-29 years

e. 30 years and above

Addresses hypotheses

1=Strongly disagree 2=Disagree 3=Somewhat disagree 4=Neutral 5=Somewhat agree 6=Agree 7=Strongly agree

A. Please assess to which degree you approve the following statements regarding disruptions in the agri-food supply chain.

1. The agri-food supply chain is easily vulnerable to supply chain disruptions.
2. Supply chain disruption easily happens from a disturbance in the agri-food industry.
3. The agri-food supply chain is strongly affected by external disruptions.
4. The agri-food supply chain is strongly affected by internal disruptions.
5. The agri-food supply chain is strongly affected by supply disruptions.

6. The agri-food supply chain is strongly affected by demand disruptions.

B. Please assess to which degree you approve the following statements regarding resilience capability in your supply chain.

1. Your firm has the ability to respond quickly to supply chain disruptions.
2. Your firm has the ability to adapt to supply chain disruptions through information sharing.
3. Your firm has the ability to deploy the adaptive capability to deal with supply chain disruptions.
4. Your firm has the ability to deploy alternative plans to deal with supply chain disruptions.
5. Resilience is emerging to be a crucial capability at your firm.

C. Please assess to which degree you approve the following statements regarding the relevance of using digital technologies in your supply chain operations.

1. Your firm incorporates digital technologies into operations and supply chain management.
2. Your firm uses monitoring and controlling systems in operations such as enterprise resource planning systems, manufacturing execution, business planning, consolidation, etc.
3. Your firm incorporates digital technologies, digital services,

and automation to optimize business processes and operations.

4. Digital technologies significantly improve responsiveness and connectedness at your firm.
5. Digital technologies significantly improve resilience capability in your firm's supply chain.

D. Please assess to which degree you approve of the following statements regarding your firm performance.

1. Your firm is able to restore pre-disruption customer service levels quickly.
2. Your firm maintains the smooth running of operations during the disruption.
3. Your firm is able to limit the loss caused by supply chain disruptions.
4. Supply chain resilience significantly improves trust from customers and partners at your firm.
5. Supply chain resilience significantly improves customer satisfaction at your firm.
6. Supply chain resilience significantly contributes to maintaining business continuity at your firm.

E. Please choose which digital technologies are most beneficial to your supply chain resilience when following a disruption. *(First, choose the technologies that you use, then rank the used technologies from highest to lowest).*

1. Distributed ledger technologies and smart contracts

(e.g., Blockchain technologies).

2. Mobile technologies (e.g., 5G, GPS).
3. Cloud computing
4. Big data analytics
5. Internet of Things
6. Sensing and Aera imaging technologies
7. Robotics and automation
8. Artificial intelligence and machine learning
9. Data collection technologies
10. Precision agriculture
11. Institutions for data sharing
12. Encryption and data protection
13. Food-sensing technologies
14. Digitized marketplaces for agri-food products
15. E-extension services
16. Digitized transactions and payments.

Thank you very much for your participation; we appreciate your contribution to the survey.

SURVEY END

APPENDIX D

RESULTS AND ANALYSIS (STUDY TWO)

Table 13.

Harman's Single-factor Test Total Variance Explained

Component	Initial EigeN values			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.436	25.885	25.885	5.436	25.885	25.885
2	3.203	15.252	41.136			
3	2.501	11.912	53.048			
4	1.529	7.280	60.328			
5	0.994	4.733	65.060			
6	0.914	4.352	69.412			
7	0.807	3.841	73.253			
8	0.687	3.273	76.525			
9	0.626	2.981	79.506			
10	0.602	2.867	82.374			
11	0.532	2.533	84.906			
12	0.452	2.153	87.059			
13	0.428	2.037	89.096			
14	0.414	1.970	91.067			
15	0.357	1.701	92.767			
16	0.320	1.522	94.289			
17	0.288	1.371	95.660			
18	0.252	1.201	96.862			
19	0.236	1.126	97.987			
20	0.231	1.100	99.087			
21	0.192	0.913	100.000			

Extraction Method: Principal Component Analysis.

Cronbach's Alpha:

Reliability Statistics

Cronbach's Alpha	N of Items
.773	6

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
SCD1	28.10	14.892	.549	.732
SCD2	28.33	13.829	.588	.720
SCD3	28.13	15.309	.518	.740
SCD4	28.52	15.286	.467	.753
SCD5	27.96	15.204	.587	.725
SCD6	28.24	15.694	.416	.765

Figure 16. Reliability Test of Supply Chain Disruptions

Reliability Statistics

Cronbach's Alpha	N of Items
.831	5

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
SCR1	22.39	11.685	.651	.791
SCR2	22.27	11.804	.642	.794
SCR3	22.27	11.475	.771	.757
SCR4	22.19	12.010	.678	.784
SCR5	22.00	14.143	.419	.850

Figure 17. Reliability Test of Supply Chain Resilience

Reliability Statistics

Cronbach's Alpha	N of Items
.857	5

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
DTS1	22.68	13.067	.674	.826
DTS2	22.63	13.503	.620	.840
DTS3	22.76	12.469	.734	.810
DTS4	22.50	13.162	.680	.825
DTS5	22.59	14.038	.654	.832

Figure 18. Reliability Test of Digital Technologies

Reliability Statistics

Cronbach's Alpha	N of Items
.805	6

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
FIR1	28.60	12.509	.604	.765
FIR2	28.74	12.264	.605	.765
FIR3	28.77	12.080	.547	.784
FIR4	28.03	13.597	.589	.770
FIR5	27.96	14.061	.538	.781
FIR6	27.93	14.361	.546	.782

Figure 19. Reliability Test of Firm Performance

Kaiser-Meyer-Olkin test (KMO), Bartlett's Test and Factor Loadings:

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.805
Bartlett's Test of Sphericity	Approx. Chi-Square	312.354
	df	15
	Sig.	<.001

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.841	47.353	47.353	2.841	47.353	47.353
2	.869	14.478	61.831			
3	.724	12.068	73.899			
4	.619	10.315	84.214			
5	.537	8.954	93.168			
6	.410	6.832	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component 1
SCD2	.750
SCD5	.741
SCD1	.718
SCD3	.687
SCD4	.634
SCD6	.584

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

Figure 20. KMO, Bartlett's, and Factor Loadings of Six Factors of Supply Chain Disruptions

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.783
Bartlett's Test of Sphericity	Approx. Chi-Square	258.702
	df	10
	Sig.	<.001

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.591	51.830	51.830	2.591	51.830	51.830
2	.745	14.904	66.734			
3	.663	13.266	80.000			
4	.585	11.698	91.698			
5	.415	8.302	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component 1
SCD2	.780
SCD1	.749
SCD5	.718
SCD3	.701
SCD4	.644

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

Figure 21. Updated KMO, Bartlett's, and Factor Loadings of Five Factors of Supply Chain Disruptions

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.836
Bartlett's Test of Sphericity	Approx. Chi-Square	430.985
	df	10
	Sig.	<.001

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.015	60.292	60.292	3.015	60.292	60.292
2	.766	15.311	75.603			
3	.491	9.815	85.418			
4	.447	8.934	94.351			
5	.282	5.649	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component 1
SCR3	.879
SCR4	.815
SCR1	.795
SCR2	.787
SCR5	.570

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

Figure 22. KMO, Bartlett's, and factor loadings of Supply Chain Resilience

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.780
Bartlett's Test of Sphericity	Approx. Chi-Square	552.497
	df	10
	Sig.	<.001

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.185	63.691	63.691	3.185	63.691	63.691
2	.848	16.969	80.660			
3	.426	8.523	89.184			
4	.308	6.165	95.348			
5	.233	4.652	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component 1
DTS3	.841
DTS4	.813
DTS1	.796
DTS5	.788
DTS2	.750

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

Figure 23. KMO, Bartlett's, and Factor Loadings of Digital Technologies

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.778
Bartlett's Test of Sphericity	Approx. Chi-Square	581.738
	df	15
	Sig.	<.001

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.116	51.932	51.932	3.116	51.932	51.932	2.353	39.219	39.219
2	1.435	23.916	75.848	1.435	23.916	75.848	2.198	36.629	75.848
3	.437	7.279	83.127						
4	.389	6.488	89.614						
5	.359	5.988	95.602						
6	.264	4.398	100.000						

Extraction Method: Principal Component Analysis.

Rotated Component Matrix[a]

	Component	
	1	2
FIR6	.893	
FIR5	.892	
FIR4	.822	
FIR3		.855
FIR2		.844
FIR1		.812

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]

a. Rotation converged in 3 iterations.

Figure 24. KMO, Bartlett's, and Factor Loadings of Firm Performance