# The role of dairy farmers in driving supply chain 4.0 adoption: A case study from the New Zealand dairy supply chain

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Diyalagoda Pathirathnahalage Manju Prasanna

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Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of Master of Commerce and Management

# Abstract

## The Role of Dairy Farmers in Driving Supply Chain 4.0 Adoption: A Case Study from the New Zealand Dairy Supply Chain

By

Diyalagoda Pathirathnahalage Manju Prasanna

This study explores the crucial role of dairy farmers in driving the adoption of digital technologies within New Zealand's dairy industry. As a cornerstone of the national economy, the dairy sector significantly contributes to GDP and global exports. With industries worldwide undergoing rapid digital transformation, integrating tools such as the Internet of Things (IoT), Artificial Intelligence (AI), big data analytics, and blockchain has become essential for enhancing efficiency, improving product quality, and ensuring supply chain transparency. However, while large corporations and processing companies have embraced these innovations, the role of dairy farmers—who form the backbone of the industry—remains underexamined.

This research employs a qualitative case study approach, drawing on semi-structured interviews with dairy farmers and processing company representatives. Additionally, it also integrates secondary sources such as industry reports, government publications, and academic journals to provide a broader analysis of the drivers, challenges, and benefits associated with Supply Chain 4.0 adoption. Findings reveal that dairy farmers, as primary producers, are central to the digital transformation process. Their proactive engagement with IoT devices and AI-powered farm management systems has enabled real-time monitoring of livestock health, milk yield, and environmental conditions. Big data analytics have empowered these stakeholders to predict production trends, optimize resource allocation, and

manage supply chain fluctuations effectively. Although blockchain technology remains in its early stages of deployment within the industry. It has the potential to ensure transparency and secure traceability as a significant future asset for enhancing consumer trust in the quality and origin of dairy products.

However, the study also highlights several barriers to adopting these digital technologies. High initial investment costs and the steep learning curves associated with complex digital tools limit the widespread implementation of digital technologies particularly for small to medium-sized farms. In addition, concerns regarding data privacy and the integration of new systems with existing farm operations further complicate the adoption process. Multi-stakeholder collaboration is identified as a critical success factor for the digital transformation of the dairy supply chain. Dairy cooperatives and processing companies play an instrumental role by facilitating access to technical expertise and financial resources. Furthermore, technology providers are urged to design user-friendly, customizable solutions tailored to the specific operational needs of dairy farmers. Government agencies are also recommended to strengthen these initiatives by implementing appropriate solutions to digital transformation in agriculture.

The study concludes that while Supply Chain 4.0 technologies are already transforming New Zealand's dairy industry, there is still significant room for improvement. This research adds to the growing discussion on digital transformation in agriculture by offering valuable insights and practical recommendations to guide future policies and industry practices.

**Keywords:** Supply Chain 4.0, Dairy Farming, New Zealand Dairy Supply Chain, Digital Transformation, Role of Dairy Farmers, Emerging Technologies, Stakeholder Collaboration

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# Chapter 1

# Introduction

## 1.1 Background of the Study

The dairy industry plays a vital role in New Zealand's economy, making a substantial contribution to both GDP and export earnings. In an increasingly competitive global market, the adoption of Supply Chain 4.0 technologies has become essential for sustaining and strengthening the sector. These digital innovations are transforming traditional supply chain operations by enhancing efficiency, transparency, and responsiveness (MacCarthy et al., 2016). This shift is largely driven by the integration of cutting-edge technologies, including the Internet of Things (IoT), big data analytics, blockchain, and artificial intelligence (AI). By incorporating these advancements, dairy supply chains can optimize resource management, improve traceability, and enhance decision-making processes, ensuring that the industry remains adaptable and resilient in a rapidly evolving marketplace (Ivanov, Dolgui, et al., 2019 a)

Dairy farmers play a pivotal role in the adoption and implementation of these advanced supply chain technologies. As primary producers, they are at the forefront of the supply chain, where the quality and efficiency of their operations significantly impact the downstream processes (Christopher, 2016). Therefore, their willingness to adopt and integrate Supply Chain 4.0 technologies is crucial for the overall success of the digital transformation in the dairy sector (Derakhti et al., 2023).

The integration of Supply Chain 4.0 technologies presents numerous advantages for dairy farmers, including increased productivity, improved product quality, and enhanced traceability (Monostori et al., 2016). For example, IoT devices enable real-time monitoring of livestock health and milk production, allowing farmers to make informed, data-driven decisions that optimize operational efficiency (Kamble et al., 2018). Additionally, blockchain technology enhances product traceability, giving consumers greater confidence in the authenticity and quality of dairy products (Antón et al., 2017).

However, the transition to Supply Chain 4.0 also presents challenges, particularly for dairy farmers who may lack the technical expertise and financial resources required to implement these advanced technologies (Büyüközkan & Göçer, 2018) Additionally, the success of such initiatives depends on the collaborative efforts of various stakeholders, including technology providers, industry associations, and government agencies (Oesterreich & Teuteberg, 2016).

This case study explores the role of dairy farmers in driving the adoption of Supply Chain 4.0 within the New Zealand dairy supply chain. This study initially aims to examine the experiences, challenges, and successes of these primary producers. And, then provide insights into how the dairy sector can effectively leverage digital technologies to enhance supply chain efficiency and competitiveness.

The dairy industry stands as one of the cornerstones of New Zealand's economy, playing a pivotal role in driving the nation's financial growth. Renowned worldwide for its premium-quality products, the industry has earned a strong reputation in international markets. Its efficient supply chain management practices are key to its global recognition. To stay ahead in an increasingly competitive global market, the sector is consistently pursuing cutting-edge innovations. One such transformative development is the integration of Supply Chain 4.0 technologies, which leverage advanced digitalization, automation, and data analytics. These technologies serve to enhance and streamline supply chain operations, positioning the industry for continued success.

In 2020, McKinsey & Company stated that emerging technologies like the Internet of Things (IoT), artificial intelligence (AI), blockchain, and big data analytics have transformed Supply Chain Management into what is known as Supply Chain 4.0. This shift has led to improved visibility, efficiency, and responsiveness across the entire supply chain. In the dairy industry, these technologies present opportunities to simplify processes, enhance product quality, and better meet changing consumer demands.

New Zealand's dairy sector is renowned for its efficiency and innovation, with dairy farmers playing a central role in the production and supply chain processes. The leading dairy processing company in New Zealand manages a complex network of

farmers, processing plants, and distribution channels to deliver dairy products globally. As Supply Chain 4.0 technologies gain prominence, it becomes imperative to analyse the role of dairy farmers in driving their adoption and integration within the industry.

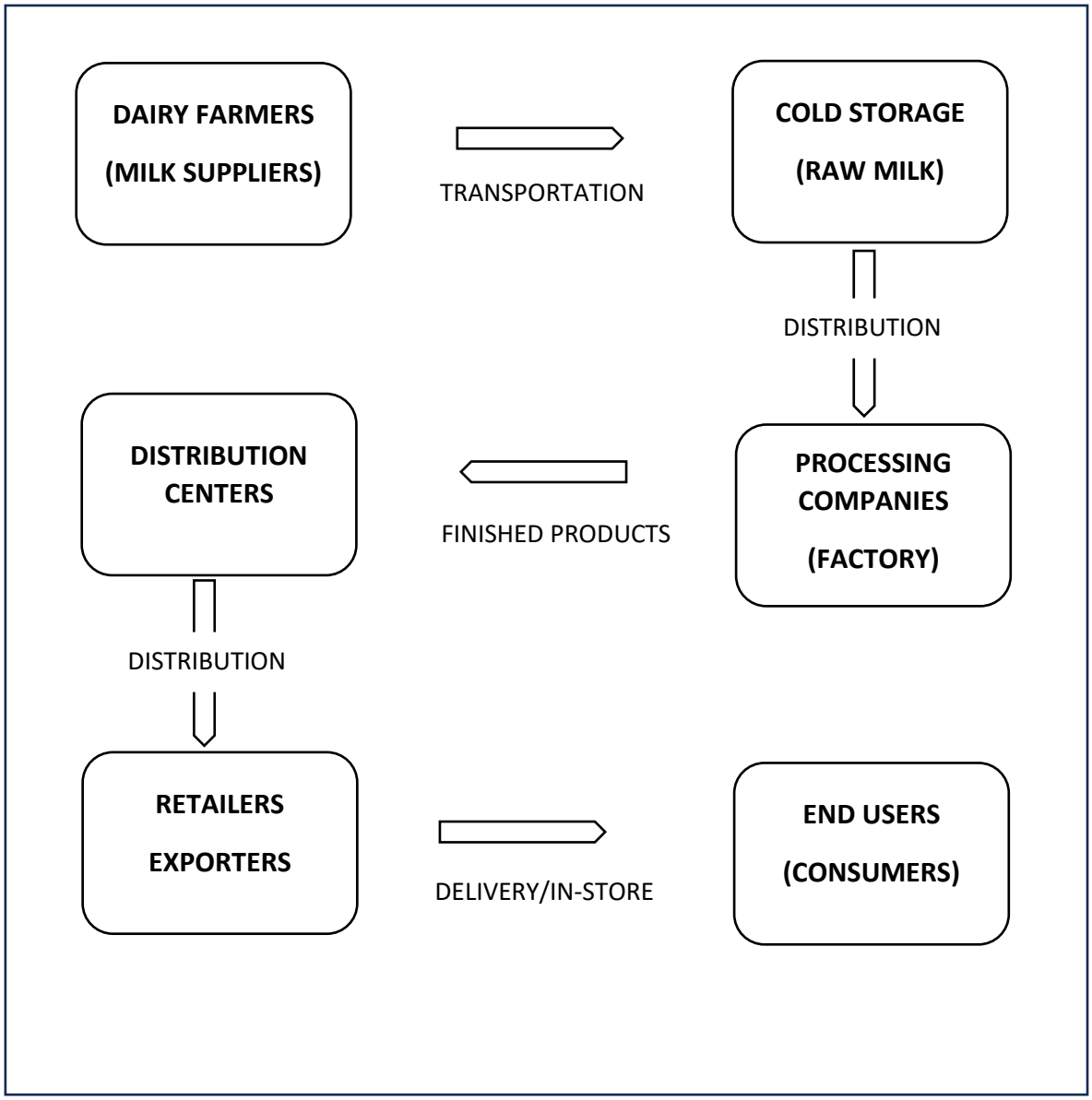


**Figure 1.1 The flow of the Dairy Supply Chain Process**

Source: Developed by the Author

In the context of Supply Chain 4.0 adoption in the New Zealand dairy sector, a diverse range of stakeholders play a critical role. These include dairy farmers, dairy cooperatives, processing companies, technology providers, government agencies, and consumers (McKinsey & Company, 2020).

**Dairy Farmers:** As the foundational producers in the dairy supply chain, dairy farmers are responsible for the production of milk and the management of their herds. The implementation of technology within their operations influences key processes such as data collection, farm automation, and the overall decision-making framework. The level of investment and openness these farmers have towards adopting Supply Chain 4.0 technologies is pivotal in driving industry-wide innovation and enhancing operational efficiency throughout the supply chain. Their proactive engagement with these advancements will ultimately determine the sector's ability to remain competitive and sustainable on a global scale.

**Dairy Cooperatives and Processing Companies:** Dairy cooperatives are the key players in the dairy supply chain. They work directly with dairy farmers and influence technology adoption at the farm level. The industry leader invests in new technologies and other processing companies play pivotal roles in collecting, processing, and distributing dairy products. Their collaboration with dairy farmers is essential for implementing technology solutions that enhance traceability, quality control, and supply chain visibility. Additionally, these organizations may invest in research and development to create tailored solutions for the dairy industry.

**Technology Providers:** Companies specializing in Supply Chain 4.0 technologies offer solutions ranging from farm management software to IoT devices and predictive analytics platforms. They are the companies that develop and supply technologies such as IoT devices, AI systems, and blockchain solutions tailored to agricultural and supply chain applications. Their partnerships with dairy stakeholders facilitate the customization and deployment of technology solutions. Those aim to address specific industry challenges, such as milk quality monitoring, inventory management, and logistics optimization.

**Government Agencies:** Regulatory bodies and government agencies play a crucial role in overseeing the dairy industry, establishing and enforcing standards related to food safety, environmental sustainability, and animal welfare. They are also responsible for setting agricultural standards, formulating policies that encourage technology adoption, and offering funding initiatives to support innovation within the farming sector. Through their involvement, these agencies can significantly influence the uptake of Supply Chain 4.0 technologies. Their support, which includes

funding programs, policy incentives, and well-defined regulatory frameworks, not only fosters innovation but also facilitates collaboration across stakeholders. Furthermore, by ensuring compliance with industry standards, they help create an environment that encourages the integration of advanced technologies, making them a key driver in the evolution of the sector.

**Consumers:** Their growing focus on sustainability, ethical sourcing, and product transparency encourages dairy stakeholders to implement technologies. That results in improved traceability and accountability throughout the supply chain. By meeting consumer expectations, dairy farmers and companies can distinguish their products in the market and establish trust with consumers.

## 1.2 Rationale/Justification

The rationale behind conducting a stakeholder analysis is complicated and crucial for understanding the dynamics of technological integration in the dairy industry. And, it focuses on the role of dairy farmers in driving Supply Chain 4.0 adoption in the New Zealand context.

Firstly, dairy farming constitutes a significant portion of New Zealand's agricultural sector, contributing substantially to the nation's economy and employment. According to the Ministry for (Ministry for Primary Industries (MPI), 2020), the dairy industry in New Zealand generated NZ$18.1 billion in export revenue in the 2019-2020 financial year. It is highlighted as a significant economic impact. Therefore, any technological advancements within the dairy supply chain have far-reaching implications for the overall economy.

Secondly, the dairy industry faces numerous challenges. It includes fluctuating milk prices, environmental concerns, and changing consumer preferences. Supply Chain 4.0 technologies offer potential solutions to these challenges by enabling greater efficiency, sustainability, and adaptability. For instance, IoT sensors can monitor environmental conditions on farms, AI algorithms can optimize feed formulation for livestock. Blockchain technology can enhance traceability and transparency in supply chain operations (Ahmad et al., 2021).

Thirdly, dairy farmers are central to the adoption and implementation of Supply Chain 4.0 technologies due to their integral role in milk production and supply chain

management. As primary producers, their decisions regarding technology adoption, investment, and farm management practices significantly influence the entire supply chain. Therefore, understanding the perspectives, motivations, and barriers faced by dairy farmers is essential for successful technology deployment and industry transformation.

The New Zealand dairy industry operates within a distinctive environment that includes a mix of small to medium-sized farms alongside larger corporate enterprises. These variations in farm size and ownership structures play a significant role in determining how feasible and scalable different technology solutions are. Smaller dairy farms often face constraints such as limited financial resources and technical expertise, which can make it challenging to adopt advanced technologies. In contrast, larger corporate farms typically have more capacity—both in terms of funding and expertise—to invest in innovation and integrate new technologies into their operations (Kaine et al., 2019).

Moreover, effective collaboration among stakeholders and the alignment of their interests are essential for overcoming the challenges associated with technology adoption and unlocking the full potential of Supply Chain 4.0. Dairy cooperatives, processing companies, technology providers, government agencies, and consumers all share a common interest in ensuring the sustainability, efficiency, and reputation of the dairy industry. By actively engaging with these stakeholders and gaining a deeper understanding of their perspectives, dairy farmers can access valuable support, resources, and expertise. This collaborative approach helps the dairy industry to thrive in an increasingly competitive and technologically advanced global market while facilitating the seamless integration of technology and accelerating the transformation.

In conclusion, identifying the dairy farmers' role in Supply Chain 4.0 adoption in the New Zealand context is essential for several reasons. It provides insights into the economic, environmental, and social implications of technological advancements in the dairy industry. Also, it identifies key challenges and opportunities for innovation and facilitates collaboration among stakeholders to achieve common goals. By understanding the motivations, concerns, and power dynamics of dairy farmers and other stakeholders, policymakers, industry leaders, and technology providers can

develop tailored strategies. At the same time, they can be involved in promoting sustainable and inclusive technology adoption in the New Zealand dairy supply chain.

## 1.3 Research Problem

The research problem addressed in this study revolves around the role of dairy farmers in driving the adoption and integration of Supply Chain 4.0 technologies within the New Zealand dairy industry. It provides the potential benefits of advanced digitalization, automation, and data analytics in enhancing supply chain efficiency and sustainability. However, the extent to which dairy farmers contribute to and influence technological advancements remains underexplored.

One of the central issues is the lack of comprehensive understanding regarding the motivations, barriers, and decision-making processes of dairy farmers concerning technology adoption. While studies have investigated the adoption of specific technologies or practices in agriculture (e.g., precision agriculture, robotic milking systems), there is limited research focusing specifically on Supply Chain 4.0 technologies and their implications for dairy farmers in the New Zealand context (Gloy et al., 2017).

It is essential to explore the challenges that impede technology adoption in the dairy industry. Key barriers include high implementation costs, limited technical expertise, and resistance to change (Borchers et al., 2020). Klerkx et al., (2019) emphasise that financial constraints and the perceived complexity of new technologies can significantly discourage adoption. Many farmers are hesitant to invest in unfamiliar systems due to concerns about uncertain returns on investment and potential disruptions to well-established farming routines.

The cost of integrating new technologies into existing systems also poses a significant challenge. Initial investments for Supply Chain 4.0 technologies can be substantial, and ongoing maintenance and training costs add to the financial burden (Van der Burg et al., 2019). This financial strain can be particularly challenging for small to medium-sized farms lacking sufficient capital reserves.

Moreover, New Zealand dairy farmers face growing competition from international markets where advanced supply chain technologies are being rapidly adopted. As noted by Eastwood et al., (2019), this lag in technology adoption can lead to inefficiencies and higher production costs, diminishing New Zealand's competitive edge globally.

Additionally, the diversity within the dairy farming sector, in terms of farm size, ownership structure, and geographic location, further complicates the research problem. Small to medium-sized family-owned farms operate alongside larger corporate entities, each encountering unique challenges and opportunities when it comes to adopting and implementing technology solutions. Recognizing and addressing the varied needs and circumstances of dairy farmers is essential for developing customized interventions and support mechanisms that can effectively facilitate technology adoption throughout the industry (Sauer & Latacz-Lohmann, 2015).

Another critical aspect of the research problem is the role of stakeholders beyond dairy farmers in shaping the adoption landscape. Dairy cooperatives, processing companies, technology providers, government agencies, and consumers all play significant roles in influencing the adoption and diffusion of Supply Chain 4.0 technologies. The interactions, power dynamics, and alignment of interests among these stakeholders impact the pace and direction of technological innovation in the dairy supply chain (Sundmaeker et al., 2010).

Moreover, the research problem encompasses broader societal concerns related to sustainability, environmental stewardship, and food security. Supply Chain 4.0 technologies offer opportunities to optimize resource use, minimize waste, and enhance product traceability, aligning with global agendas such as the United Nations Sustainable Development Goals (SDGs). However, the adoption of novel technologies to achieve these goals should be done with careful examination. Because it is important to address potential trade-offs and unintended consequences (United Nations, 2015).

Addressing the research problem requires a multidisciplinary approach integrating insights from agricultural economics, supply chain management, technology adoption, and stakeholder theory. This empirical research involves dairy farmers and dairy processing companies as key stakeholders. This study aims to shed light on the complex dynamics underlying Supply Chain 4.0 adoption in the New Zealand

dairy industry. The findings will contribute to theoretical knowledge, inform policy development, and guide practical interventions aimed at enhancing the sustainability and competitiveness of the dairy supply chain.

## 1.4 Research Objectives

To achieve a comprehensive understanding of the role of dairy farmers in driving Supply Chain 4.0 adoption along with the Stakeholder analysis, the following research objectives are outlined:

1. To investigate the current level of adoption and utilization of Supply Chain 4.0 technologies among dairy farmers in New Zealand, focusing on key technologies such as IoT sensors, data analytics platforms, and automation systems.

2. To identify the motivations, barriers, and decision-making factors influencing dairy farmers' adoption of Supply Chain 4.0 technologies, considering factors such as farm size, ownership structure, geographic location, and technological literacy.

3. To assess the potential economic, environmental, and social impacts of Supply Chain 4.0 adoption on the New Zealand dairy industry, including implications for supply chain efficiency, sustainability, and stakeholder relationships.

These research objectives aim to provide a comprehensive understanding of the drivers, challenges, and implications of Supply Chain 4.0 adoption in the New Zealand dairy sector. Further, it expects to lay the foundation for evidence-based policy-making and industry-wide initiatives aimed at promoting technological innovation and sustainability.

## 1.5 Research Questions

In line with the outlined research objectives, the following research questions are formulated to guide the investigation into the role of dairy farmers in driving Supply Chain 4.0 adoption within the New Zealand dairy industry:

1. **Current Adoption and Utilization:**
    - What is the current level of adoption and utilization of Supply Chain 4.0 technologies among dairy farmers in New Zealand?
    - Which key technologies (e.g., IoT sensors, data analytics platforms, automation systems) are being utilized, and to what extent?
2. **Motivations, Barriers, and Decision-Making Factors:**
    - What are the primary motivations driving dairy farmers to adopt Supply Chain 4.0 technologies?
    - What barriers and challenges do dairy farmers face in the adoption of these technologies?
    - How do factors such as farm size, ownership structure, geographic location, and technological literacy influence the decision-making process for adopting Supply Chain 4.0 technologies?
3. **Role of Stakeholders:**
    - How do dairy cooperatives and processing companies influence the adoption of Supply Chain 4.0 technologies among dairy farmers?
    - What role do technology providers play in facilitating the adoption of these technologies?
    - How do government policies and initiatives impact the adoption landscape for Supply Chain 4.0 in the dairy sector?
    - What are the perceptions and expectations of consumers regarding the adoption of Supply Chain 4.0 technologies in the dairy industry?

4. **Impacts of Adoption:**
    - What are the potential economic impacts of Supply Chain 4.0 adoption on the New Zealand dairy industry, particularly in terms of supply chain efficiency and profitability?
    - How does the adoption of Supply Chain 4.0 technologies affect environmental sustainability practices within the dairy sector?
    - What social implications arise from the adoption of these technologies, particularly concerning stakeholder relationships and community dynamics?

By addressing these research questions, the study aims to provide a detailed understanding of the various factors influencing the adoption of Supply Chain 4.0 technologies by dairy farmers in New Zealand. And, then the broader impacts of this technological transformation on the dairy industry.

## 1.6 Chapter Outline

### Chapter 1: Introduction

This chapter sets the stage for the research by providing an overview of the study's focus. It highlights the significance of the dairy industry in New Zealand and examines the growing relevance of Supply Chain 4.0 technologies in enhancing efficiency and competitiveness. The chapter outlines the research objectives and key questions that guide the study while also presenting the overall structure of the thesis to provide a clear roadmap for readers.

### Chapter 2: Literature Review

This chapter delves into existing scholarly work on Supply Chain 4.0, with a specific focus on its application in the dairy sector. It explores critical technologies such as the Internet of Things (IoT), big data analytics, blockchain, and artificial intelligence (AI), analyzing their potential benefits and the challenges associated with their adoption. Additionally, the chapter reviews prior studies on the role of various stakeholders in the digital transformation of supply chains, examining the broader implications of these technological advancements within the dairy industry.

**Chapter 3: Methodology**

This chapter outlines the research design and methodology employed to address the research questions. It details the data collection methods used to gather relevant information, including surveys and interviews with dairy farmers and representatives from dairy processing companies. Additionally, the chapter outlines the data analysis techniques applied to interpret the collected data, ensuring that the findings are systematically examined and accurately reflect the research objectives. The methodology is designed to provide a robust framework for understanding the adoption of Supply Chain 4.0 technologies in the New Zealand dairy industry, incorporating qualitative to offer comprehensive insights.

**Chapter 4: Findings and Discussion**

This chapter presents the results of the research, detailing the current level of adoption and utilization of Supply Chain 4.0 technologies among New Zealand dairy farmers. It discusses the motivations, barriers, and decision-making factors influencing adoption, and analyses the role of dairy processing companies in shaping the adoption landscape. The chapter also assesses the economic, environmental, and social impacts of Supply Chain 4.0 adoption on the dairy industry. The findings are discussed in relation to the existing literature reviewed in Chapter 2.

**Chapter 5: Conclusion and Recommendations**

This chapter provides a detailed summary of the research findings, directly addressing the key research questions and examining the role of dairy farmers in adopting Supply Chain 4.0 technologies. The chapter also explores the broader implications of these advancements, emphasizing the importance of financial incentives, specialized training programs, and strong industry partnerships to accelerate adoption. This also highlights the limitations of the research and recommendations for future research opportunities to assess long-term impacts, refine implementation strategies, and ensure the industry remains adaptive in an increasingly digital world.

# Chapter 2

# Literature Review

## 2.1 Introduction

Supply Chain 4.0 represents a significant change in supply chain management, utilizing advanced digital technologies to improve visibility, connectivity, and responsiveness across the entire supply chain (Farziyeva & Dhanik, n.d.). Evolving from the principles of Industry 4.0, this modern approach integrates key innovations such as the Internet of Things (IoT), artificial intelligence (AI), blockchain, and big data analytics. These technologies facilitate real-time, data-driven decision-making and foster seamless collaboration among supply chain stakeholders, ultimately improving efficiency and resilience (Ivanov, Dolgui, et al., 2019b)

IoT sensors are a cornerstone of Supply Chain 4.0, allowing for real-time data collection across multiple aspects of the supply chain, such as inventory levels, product quality, and environmental conditions (Rubmann et al., 2015). These sensors can be strategically placed at key points, including farms, manufacturing sites, warehouses, and distribution centers, ensuring continuous monitoring and providing valuable insights that enhance operational efficiency and decision-making.

Artificial intelligence (AI) plays a crucial role in enhancing supply chain efficiency and adaptability by processing vast amounts of data to uncover meaningful insights (Ivanov, 2020). Through machine learning algorithms, AI can forecast demand trends, streamline production schedules, and detect potential risks or disruptions, allowing businesses to take proactive measures and strengthen risk management strategies (Cortes et al., 2019).

Blockchain technology, on the other hand, provides a secure and transparent approach to record-keeping, ensuring trust and traceability throughout the supply chain (Ivanov, Dolgui, et al., 2019b). By maintaining an immutable, decentralized ledger of transactions, blockchain fosters transparency among supply chain participants while minimizing risks associated with fraud, counterfeiting, and unauthorised data modifications (Iansiti & Lakhani, 2017).

Big data analytics leverages vast amounts of structured and unstructured data to uncover patterns, trends, and hidden correlations that conventional analytical approaches may overlook (H. Chen et al., 2020). By aggregating and processing data from multiple sources—including IoT sensors, enterprise resource planning (ERP) systems, and external inputs such as weather forecasts and market trends—big data analytics enables both predictive and prescriptive insights. These capabilities help businesses anticipate demand fluctuations, mitigate risks, and optimize supply chain operations with greater accuracy and efficiency (Li et al., 2019).

The adoption of Supply Chain 4.0 technologies offers numerous potential benefits for dairy farmers and the broader dairy supply chain. For dairy farmers, IoT sensors can monitor herd health, milk production, and environmental conditions, enabling proactive management and optimization of farm operations (Oliveira et al., 2019). AI algorithms can analyse farm data to optimize feed formulation, breeding programs, and resource allocation, improving productivity and profitability (O'Neill et al., 2020).

Recent developments in dairy digitalization have further emphasised the transformative potential of Supply Chain 4.0 technologies. Masi et al. (2021) highlight the critical role of digital transition and Industry 4.0 technologies in enhancing food sustainability and achieving sustainable food systems, particularly within the dairy sector. Their research demonstrates that the integration of blockchain, IoT, big data analytics, and AI significantly contributes to the digitalization of food systems, creating more resilient and responsive supply chains that can adapt to evolving market demands and sustainability requirements.

Building upon this foundation, recent scholarly work by Javaid et al. (2022) has examined the impact of Industry 4.0 technologies for successful implementation of smart farming practices in dairy operations. Their findings suggest that the convergence of digital technologies creates new opportunities for precision agriculture. It also enables dairy farmers to optimize resource utilisation while improving animal welfare and environmental sustainability. This technological convergence represents a paradigm shift from traditional farming methods to data-

driven agricultural practices that enhance both productivity and sustainability outcomes.

Dairy cooperatives and processing companies can harness Supply Chain 4.0 technologies to improve traceability, quality control, and sustainability across the entire supply chain (Kamble et al., 2020) . Blockchain technology offers a secure, tamper-proof system for recording product origin, production methods, and certifications, strengthening consumer trust and enhancing brand reputation (Li et al., 2019). Meanwhile, big data analytics enables smarter decision-making by optimizing production planning, streamlining inventory management, and improving logistics efficiency. By leveraging these advanced tools, dairy businesses can reduce operational costs, minimize waste, and create a more transparent and resilient supply chain (Zarei-Kordshouli et al., 2023).

Despite the promising benefits, adopting Supply Chain 4.0 technologies in the dairy industry comes with several challenges and obstacles. A major hurdle is the high cost and complexity of implementation, which can be particularly daunting for small to medium-sized dairy farms that often operate with limited financial resources and technical expertise (Kaine et al., 2019). Additionally, ensuring seamless interoperability between various digital systems and technologies presents another significant challenge. Effective integration requires strong collaboration and coordination among supply chain stakeholders to align different platforms, data formats, and operational processes (Ivanov, Dolgui, et al., 2019b).

Furthermore, concerns regarding data privacy, security, and ownership may inhibit the sharing and utilization of data across the supply chain (H. Chen et al., 2020). Regulatory compliance, particularly regarding food safety and animal welfare standards, adds another layer of complexity to technology adoption in the dairy industry (Sundmaeker et al., 2010). Moreover, cultural and organizational barriers, such as resistance to change and lack of awareness or trust in new technologies, may impede adoption efforts (Klerkx et al., 2019).

In summary, the adoption of Supply Chain 4.0 technologies presents both opportunities and challenges for the dairy industry, with implications for dairy farmers, cooperatives, processing companies, and other stakeholders. This study aims to contribute to a deeper understanding of the dynamics and implications of

technology adoption in the New Zealand dairy supply chain by examining the theoretical foundations, key concepts, and empirical evidence and challenges in the literature.

## 2.2 Theoretical Review

### 2.2.1 Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM), introduced by Davis (1989), remains one of the most widely recognised frameworks for understanding how individuals adopt new technology. According to TAM, two key factors influence technology acceptance: perceived usefulness (PU) and perceived ease of use (PEOU). Perceived usefulness refers to the extent to which a person believes that using a specific system will improve their job performance. Meanwhile, perceived ease of use reflects the belief that the system is user-friendly and requires minimal effort to operate. Together, these factors shape an individual's willingness to embrace new technologies.

In the context of Supply Chain 4.0, TAM can be applied to understand dairy farmers' adoption of new technologies such as IoT sensors, data analytics platforms, and automation systems. Studies have shown that when farmers perceive these technologies as useful in improving productivity and operational efficiency, they are more likely to adopt them (Davis, 1989). Moreover, if these technologies are perceived as easy to use, the likelihood of adoption increases further. And it positively influences the intentions of the user's behaviours (Davis, 1989; Venkatesh & Davis, 2000).

Research by Wu et al., (2019) applied TAM to investigate the adoption of IoT in agriculture. The study found that PU significantly influenced farmers' intentions to adopt IoT-based solutions, as these technologies provided real-time data that enhanced decision-making and productivity. Similarly, PEOU was crucial, as many farmers lacked technical expertise and were concerned about the complexity of new systems. This highlights the need for user-friendly interfaces and comprehensive training programs to facilitate adoption.

However, TAM has limitations, particularly its focus on individual attitudes while neglecting external factors such as social influence and facilitating conditions (Venkatesh & Davis, 2000). In the case of dairy farmers, external pressures from cooperatives, market demands, and regulatory requirements also play significant roles in technology adoption. It suggests the need for an extended model to capture these dynamics comprehensively.

### 2.2.2 Diffusion of Innovations (DOI) Theory

Rogers' Diffusion of Innovations (DOI) theory (2003) provides a broader framework for understanding how new ideas and technologies spread within a social system. According to DOI, the adoption process is influenced by five attributes: relative advantage, compatibility, complexity, trialability, and observability.

Relative advantage refers to the perceived benefits of the innovation over existing practices. For dairy farmers, Supply Chain 4.0 technologies offer advantages such as improved milk quality, enhanced traceability, and increased operational efficiency (Srinivasan & Swink, 2018). Compatibility with existing values, past experiences, and needs of potential adopters is also crucial. Technologies that align with farmers' existing practices and beliefs are more likely to be adopted (Pannell et al., 2006).

Complexity, or the perceived difficulty of understanding and using the innovation, can deter adoption. Technologies that are easier to understand and implement are adopted more readily. Trialability allows potential adopters to experiment with the innovation on a limited basis. It can help to reduce uncertainty and enhance adoption rates. Observability, or how easily others can see the results of innovations drives the adoption of new technologies. The farmers are more likely to adopt it when they observe the benefits realized by their peers (Rogers, 2003).

Research by Klerkx et al., (2010) applied DOI to the adoption of precision agriculture technologies. The study found that relative advantage and compatibility were significant predictors of adoption, while complexity negatively influenced adoption rates. Trialability and observability were also important, suggesting that demonstration projects and peer networks could facilitate the diffusion of Supply Chain 4.0 technologies among dairy farmers.

### 2.2.3 Unified Theory of Acceptance and Use of Technology (UTAUT)

The Unified Theory of Acceptance and Use of Technology (UTAUT), developed by Venkatesh et al. (2003), integrates elements from eight prominent models of technology acceptance, including TAM and DOI. UTAUT posits that performance expectancy, effort expectancy, social influence, and facilitating conditions are the key determinants of technology adoption.

Performance expectancy refers to the degree to which individuals believe that using the technology will help them achieve gains in job performance. In the dairy farming context, if farmers expect that Supply Chain 4.0 technologies will lead to higher productivity and profitability, they are more likely to adopt them (Venkatesh et al., 2012). Effort expectancy is similar to PEOU in TAM and relates to the ease of use of the technology. Social influence reflects the impact of others, such as peers, cooperatives, and industry leaders, on the individual's decision to adopt the technology. Facilitating conditions refer to the availability of resources and support necessary for technology use.

A study by Farooq et al. (2017) applied UTAUT to understand the adoption of mobile-based agricultural services among farmers. The findings indicated that performance expectancy and facilitating conditions were significant predictors of adoption. Social influence was particularly relevant in rural areas where community leaders and peer farmers played a crucial role in shaping adoption decisions. This suggests that for Supply Chain 4.0 adoption, building strong support networks and providing adequate resources and training are essential.

While UTAUT provides a comprehensive framework, it has been criticized for its complexity and the potential overlap of constructs (Bagozzi, 2007). Despite this, its holistic approach makes it valuable for understanding the multifaceted nature of technology adoption among dairy farmers.

### 2.2.4 Stakeholder Theory

Stakeholder Theory, proposed by Freeman (1984), emphasises the importance of identifying and managing the interests of all stakeholders involved in a business. In the context of Supply Chain 4.0 adoption, this includes not only dairy farmers but

also cooperatives, processing companies, technology providers, government agencies, and consumers.

Stakeholder Theory posits that businesses must create value for all stakeholders to achieve long-term success. For dairy farmers, this means that the adoption of Supply Chain 4.0 technologies should not only improve their productivity but also meet the expectations and requirements of other stakeholders (Freeman, 2010). For instance, consumers increasingly demand transparency and traceability in food production, which can be addressed through blockchain technology (Tian, 2017). Processing companies and cooperatives seek efficiency and quality improvements, which can be achieved through automation and data analytics.

Research by (Kanda et al., 2019) applied Stakeholder Theory to the adoption of sustainable technologies in agriculture. The study found that aligning the interests of various stakeholders, such as farmers, consumers, and policymakers, was crucial for successful technology adoption. In the case of Supply Chain 4.0, this alignment can be facilitated through collaborative initiatives, policy support, and market incentives that encourage the use of digital technologies in the dairy sector.

**Contemporary Developments in Stakeholder Theory and Analysis**

Building upon Freeman's foundational work, significant theoretical and methodological advances have emerged, providing more sophisticated frameworks for stakeholder analysis. The seminal contribution by (Mitchell et al., 1997) introduced the stakeholder identification and salience model. That categorises stakeholders based on three key attributes: power (the ability to influence organisational decisions), legitimacy (socially accepted and expected relationships), and urgency (the degree to which stakeholder claims call for immediate attention). This framework has become particularly relevant for understanding Supply Chain 4.0 adoption, where different stakeholders possess varying degrees of these attributes. It further and consequently applies different levels of influence on technology implementation decisions.

Recent scholarly developments have further refined this theoretical foundation. Wood, Mitchell, Agle, and Bryan (2021) provided a comprehensive 20-year

reflective analysis of stakeholder identification and salience theory. That highlights both progress and persistent challenges in the field. Their review emphasises the evolution of stakeholder analysis from a primarily descriptive tool to a more dynamic framework that accounts for changing stakeholder relationships over time. This temporal dimension is particularly crucial in the context of digital transformation initiatives like Supply Chain 4.0. As a result, stakeholder salience may shift as technology adoption progresses and new capabilities emerge.

The contemporary business environment has also witnessed the emergence of stakeholder capitalism and the integration of Environmental, Social, and Governance (ESG) considerations into stakeholder analysis frameworks. Recent research demonstrates how companies can enhance stakeholder buy-in through strong ESG performance, creating a virtuous cycle where stakeholder support facilitates further sustainable technology adoption (Chen & Liu, 2023). This development is particularly relevant for dairy farmers adopting Supply Chain 4.0 technologies, as these innovations often align with sustainability objectives valued by multiple stakeholder groups, including consumers, regulatory bodies, and financial institutions.

Methodological advances have also enhanced the practical application of stakeholder theory. The multilateral stakeholder salience approach represents a significant extension of the original Mitchell, Agle, and Wood framework, offering more nuanced analysis for complex stakeholder environments where multiple competing interests must be balanced simultaneously (Harrison et al., 2022). This approach is particularly valuable in agricultural technology adoption contexts. It clarifies that dairy farmers must navigate relationships with diverse stakeholders who may have conflicting priorities regarding technology implementation, cost implications, and operational changes.

Furthermore, recent empirical studies have validated and refined the original theoretical propositions, demonstrating the continued relevance and applicability of stakeholder salience theory across various industries and contexts. These studies provide evidence-based insights into how stakeholder attributes interact to influence organisational decision-making processes. It offers practical guidance for dairy

farmers seeking to effectively manage stakeholder relationships during Supply Chain 4.0 adoption initiatives.

Stakeholder Theory highlights the interconnected nature of supply chain relationships and the need for a collaborative approach to technology adoption. By addressing the interests and concerns of all stakeholders, dairy farmers can enhance their capacity to adopt and benefit from Supply Chain 4.0 technologies. The contemporary developments in stakeholder theory provide more sophisticated tools and frameworks for understanding these complex relationships, enabling more strategic and effective stakeholder management throughout the technology adoption process.

## 2.3 Empirical Review

### 2.3.1 Adoption of IoT in Dairy Farming

The Internet of Things (IoT) has revolutionized various sectors, with agriculture—particularly dairy farming—benefiting significantly from its advancements. By integrating real-time monitoring and data-driven insights, IoT has enabled farmers to optimize productivity and streamline operations. Technologies such as smart sensors, wearable devices, and automated milking systems are becoming indispensable tools in modern dairy farming (Kamilaris et al., 2017). These innovations empower farmers to closely monitor livestock health, track milk yield, and assess environmental factors with remarkable accuracy. With access to real-time data, farmers can make proactive decisions, enhance resource efficiency, and improve overall herd management, ultimately leading to higher profitability and sustainability (Wolfert et al., 2017).

Contemporary research has further validated the transformative impact of IoT in dairy farming operations. (Singh et al., 2022) developed an intelligent communication ecosystem that integrates blockchain and IoT-enabled technologies specifically for cattle animal welfare, demonstrating how real-time wireless technology plays a key role in meeting sustainability requirements. Their research emphasizes the necessity for dairy farmers to adopt real-time monitoring technologies to meet growing food demands while maximizing productivity. The

study explores limitless possibilities for technological interventions in dairy cattle management, highlighting how intelligent systems for sensing, monitoring, and data analytics can drastically improve the dairy ecosystem while ensuring animal welfare standards.

Wolfert et al. (2017) highlight the significant impact of IoT in dairy farming, particularly in improving animal health monitoring, boosting milk yield, and lowering labour costs. Wearable sensors allow farmers to continuously track vital signs, detect early signs of illness, and receive real-time alerts about potential health issues. This early detection system helps maintain animal well-being while ensuring a steady supply of high-quality milk. Additionally, automated milking systems minimize the need for manual labour, freeing up farmers to focus on other critical aspects of farm management and overall operational efficiency (Sonka, 2014).

Recent technological advancements have expanded the application of IoT beyond traditional monitoring functions. Research by (Mahmud et al. (2023) demonstrate the novel application of IoT in long-distance livestock transportation, particularly in livestock enumeration and identification for precise traceability. Their work focuses on technological advancements in identifying behavioral patterns in 'shy feeder' cows and real-time monitoring during transportation, representing a significant expansion of IoT applications in the dairy supply chain. This research illustrates how IoT technology is evolving to address complex logistical challenges within the dairy industry, enabling better tracking and management of livestock throughout the entire supply chain journey.

While IoT has the potential to transform dairy farming, its adoption is not without challenges. One of the biggest roadblocks is the higher upfront cost of purchasing and setting up IoT devices, along with the necessary infrastructure. For small and medium-sized farms operating on tight budgets, these expenses can be difficult to justify (García et al., 2020). Beyond the financial hurdle, another major challenge is the technical knowledge required to install, operate, and interpret data from these advanced systems. Many farmers, particularly those accustomed to traditional farming methods, may find it overwhelming to navigate the complexities of IoT technology (Verdouw et al., 2021). Without the right training and support, they risk underutilizing or even abandoning these tools. To address these issues, (García et

al., 2020) suggests for initiatives such as hands-on training programs to familiarize farmers with IoT technology, as well as financial incentives like subsidies or grants to make the investment more feasible. By lowering these barriers, IoT can become more accessible, helping farmers maximize efficiency and productivity in the long run.

Empirical research from New Zealand highlights an increasing uptake of IoT technologies among dairy farmers. A study by (Crick et al., 2020) found that farmers who integrated IoT systems experienced notable gains in efficiency and profitability. The study also identified several factors that influence adoption, such as farm size, financial capacity, and farmer perceptions of technology. Larger farms with greater financial resources were more likely to implement IoT solutions, suggesting disparities in adoption rates between different farm sizes.

In conclusion, IoT adoption in dairy farming has demonstrated significant advantages in enhancing productivity, efficiency, and animal welfare. However, challenges related to high costs and the need for technical expertise continue to limit widespread implementation. Overcoming these barriers remains essential for ensuring broader adoption across farms of all sizes. Policy-makers and industry stakeholders should collaborate to provide the necessary support and resources to encourage IoT adoption across all farm sizes.

### 2.3.2 Utilization of Big Data Analytics in Dairy Supply Chains

Big data analytics has emerged as a powerful tool for enhancing decision-making and optimizing supply chain operations in the dairy industry. By analyzing large volumes of data generated from various sources, dairy farmers can gain valuable insights into production processes, market trends, and consumer preferences (Dubey et al., 2016). This enables them to make informed decisions that improve efficiency, reduce waste, and increase profitability (Desforges et al., 2017).

A study by Wamba et al. (2017) demonstrates the impact of big data analytics on supply chain performance in the dairy industry. The researchers found that dairy farmers who utilized big data analytics experienced significant improvements in demand forecasting, inventory management, and product quality. By analysing data on milk production, weather patterns, and market demand, farmers were able to

optimize their supply chain operations and reduce the risk of overproduction or shortages.

One of the key applications of big data analytics in dairy farming is predictive maintenance. By analysing data from IoT sensors and other monitoring devices, farmers can predict equipment failures and perform maintenance before breakdowns occur, reducing downtime and maintenance costs (Kusiak, 2017). Additionally, big data analytics can help farmers optimize feeding strategies by analysing data on cow health, milk yield, and feed composition, leading to better nutrition and higher milk production (Kamilaris et al., 2017).

Empirical research from New Zealand supports the positive impact of big data analytics on dairy farming. A study by Eastwood, Grant, et al. (2019) found that farms using big data analytics reported better supply chain coordination and higher profitability. The study also highlighted the importance of collaboration between farmers, technology providers, and researchers to develop effective analytics solutions tailored to the dairy industry.

Despite the benefits, the adoption of big data analytics in dairy farming faces several challenges. One major challenge is data integration, as data from different sources and systems need to be combined and analysed cohesively (Marjani et al., 2017). Additionally, there is a need for skilled personnel who can analyse and interpret complex data sets, which many farms may not have (Sivarajah et al., 2017). To overcome these challenges, Marjani et al. (2017) recommend the development of user-friendly analytics platforms and training programs to enhance farmers' data literacy.

In summary, big data analytics offers significant opportunities for improving supply chain efficiency and decision-making in the dairy industry. However, addressing the challenges related to data integration and skills is essential for maximizing the potential of big data analytics. Collaborative efforts between industry stakeholders can help develop the necessary tools and training to support widespread adoption.

### 2.3.3 Blockchain Technology for Traceability and Transparency

Blockchain technology is transforming the way supply chains operate by improving transparency and traceability. In the dairy industry, it acts as a secure digital record, tracking every stage of production, from milk collection at farms to processing, packaging, and distribution (Tian, 2017). Because these records cannot be altered, they help ensure the authenticity and quality of dairy products. This is especially relevant today, as consumers increasingly want to know where their food comes from and expect greater accountability from producers.

The emergence of "Dairy 4.0" has been significantly enhanced by blockchain technology integration. Recent comprehensive research by de Lima et al. (2023) examine the opportunities and challenges in adopting fourth industrial revolution technologies in milk production and its derivatives. Their study reveals that blockchain, especially when combined with other technologies such as IoT, enables data interoperability, cost reduction, transparency, auditability, integrity, and authenticity. This research demonstrates how blockchain technology serves as a foundational element in the digital transformation of dairy operations, creating more trustworthy and efficient supply chain networks that benefit all stakeholders from farmers to consumers.

A study by Antón et al. (2017) explores how blockchain technology is applied in the dairy supply chain. With blockchain, each stage of production—from milking to processing and distribution—is securely recorded and easily verifiable. This makes it possible to trace any quality or safety concerns back to their source, allowing for swift corrective action. Moreover, blockchain helps build consumer confidence by offering transparent and reliable information about the origin and quality of dairy products.

Recent practical implementations have demonstrated blockchain's effectiveness in dairy supply chains. Research by Raman et al. (2022) developed a blockchain-enabled supply chain platform specifically for the Indian dairy industry, focusing on safety and traceability. Their proposed platform combines smart contracts, quick response code (QR code) technology, and IoT, demonstrating the potential to redefine dairy supply chains across socio-economic, operational, and sustainability

parameters. This practical application shows how blockchain technology can be successfully integrated with other digital technologies to create comprehensive solutions that address multiple challenges simultaneously within dairy supply chains.

Integrating blockchain technology into the dairy industry brings multiple advantages, such as better traceability, reduced fraud, and increased supply chain efficiency (Kamath, 2018). If a batch of milk is found to be contaminated, blockchain allows for quick identification of the source, helping to contain the issue and implement corrective measures without delay. Additionally, by minimizing paperwork and automating record-keeping, blockchain simplifies supply chain operations, cutting costs and speeding up transactions.

Despite its potential advantages, integrating blockchain technology into dairy farming presents multiple challenges. A significant hurdle is the absence of standardized protocols and interoperability among various blockchain systems, making seamless data exchange difficult for stakeholders (Casino et al., 2019). Moreover, adopting blockchain requires substantial investment in technological infrastructure, which can be particularly challenging for smaller farms with limited financial resources (Swan, 2015). Casino et al. (2019) emphasise the importance of establishing industry-wide standards and fostering collaboration to develop scalable and cost-efficient blockchain solutions.

Empirical research from New Zealand suggests increasing interest in using blockchain for dairy supply chains. A study by Saberi et al. (2019) found that the adoption of blockchain was primarily motivated by the demand for improved traceability and greater consumer confidence. The study also emphasised that successful implementation depends on cooperation among key stakeholders, including farmers, technology developers, and regulatory authorities, to ensure the effective integration of blockchain technology within the dairy sector.

In conclusion, blockchain technology offers significant benefits for traceability and transparency in the dairy supply chain. However, addressing the challenges related to standardization and implementation is crucial for wider adoption. Collaborative

efforts between industry stakeholders can help develop effective blockchain solutions that enhance supply chain integrity and consumer trust.

### 2.3.4 Role of Stakeholders in Supply Chain 4.0 Adoption

The successful implementation of Supply Chain 4.0 technologies in the dairy industry relies on the joint efforts of multiple stakeholders, including dairy farmers, cooperatives, processing companies, technology developers, government agencies, and consumers. Each of these groups plays a vital role in influencing the adoption process and ensuring that new technologies are effectively integrated into the industry (Siems et al., 2023).

Research by Klerkx et al. (2010) underscores the significance of stakeholder collaboration in adopting agricultural innovations. Their study found that well-established networks and partnerships among farmers, technology providers, and research institutions were key factors in successful technology adoption. For example, cooperatives can support farmers by offering financial assistance and training programs, while technology providers contribute specialised knowledge and customized solutions to facilitate seamless integration.

The role of government agencies is also critical in promoting Supply Chain 4.0 adoption. Government policies and initiatives can provide incentives for technology adoption, support research and development, and ensure the necessary infrastructure is in place (Eastwood, Bines, et al., 2019). For example, subsidies and grants can help offset the high initial costs of adopting new technologies, making them more accessible to small and medium-sized farms.

Consumers are also instrumental in driving the adoption of Supply Chain 4.0 technologies. Growing consumer expectations for greater transparency, higher quality, and more sustainable food production have encouraged dairy farmers to implement technologies that improve traceability and minimize environmental impact (Antón et al., 2017). By aligning with consumer preferences, farmers can strengthen their market position, enhance trust, and foster long-term customer relationships.

Empirical research from New Zealand highlights the critical role of stakeholder collaboration in the adoption of Supply Chain 4.0 technologies. A study by Siems et al. 2023) found that successful implementation depended on strong partnerships between farmers, cooperatives, and technology providers. Additionally, the study emphasised the importance of government involvement in offering financial incentives and establishing regulatory frameworks to support technology adoption.

In conclusion, stakeholders play a pivotal role in integrating Supply Chain 4.0 technologies into the dairy industry. Cooperation among farmers, cooperatives, technology providers, government agencies, and consumers can facilitate the adoption process and ensure effective implementation. Considering the perspectives and requirements of all stakeholders is essential for maximizing the potential benefits of these technologies.

### 2.3.5 Economic, Environmental, and Social Impacts of Supply Chain 4.0 Adoption

The integration of Supply Chain 4.0 technologies in the dairy industry has notable economic, environmental, and social benefits. These advancements help streamline operations, improve resource management, and strengthen collaboration among industry stakeholders. Additionally, they play a key role in making the dairy sector more sustainable and competitive in a rapidly evolving market (Ivanov, Tsipoulanidis, et al., 2019).

Recent comprehensive research has further validated these multi-dimensional impacts. Sinha et al. (2023) conducted an extensive review of "Dairy 4.0: Embracing Digital Technology for Sustainable Farming," which demonstrates how blockchain and other digital technologies are revolutionizing different sectors while enabling customers to trace the production and quality of their products. Their research emphasizes that in the quest to feed a growing global population using sustainable methods, these technologies provide critical solutions that address economic efficiency, environmental sustainability, and social responsibility simultaneously. This holistic approach to digital transformation represents a paradigm shift towards more integrated and sustainable dairy farming practices.

From an economic perspective, adopting these technologies leads to higher productivity and profitability by optimizing production processes and minimizing waste. The use of IoT sensors and data analytics allows farmers to monitor milk production and animal health in real-time, leading to more informed and timely decision-making (Dubey et al., 2016). Automated milking and feeding systems reduce labour costs while also enhancing efficiency and accuracy. By improving operational effectiveness, these innovations help dairy farms maintain profitability and adapt to changing industry demands (Wolfert et al., 2017).

From an environmental perspective, implementing Supply Chain 4.0 technologies supports more sustainable farming practices. Precision agriculture tools, including IoT and big data analytics, help farmers use resources more efficiently, lower chemical inputs, and minimize overall waste (Kamilaris et al., 2017). By continuously monitoring soil conditions, weather patterns, and other environmental factors, farmers can apply fertilizers and water more precisely, reducing excess use and mitigating negative environmental effects.

Additionally, blockchain technology plays a crucial role in improving traceability throughout the dairy supply chain. By providing a transparent and tamper-proof record of production processes, blockchain ensures that dairy products meet sustainability standards and comply with environmental regulations (Tian, 2017). This increased level of transparency not only benefits producers but also builds consumer confidence in the industry's commitment to sustainable practices.

From a social standpoint, the integration of Supply Chain 4.0 technologies strengthens stakeholder relationships and fosters greater consumer trust. Enhanced transparency and traceability allow consumers to access reliable information about food safety and quality, addressing concerns regarding the origin and production of dairy products. This increased visibility helps build stronger connections between farmers and consumers, reinforcing confidence in the industry (Kamath, 2018).

Moreover, the adoption of advanced technologies creates new opportunities for skill development and employment, particularly in rural areas. As digital tools become more prevalent in dairy farming, there is a growing need for specialised knowledge

in managing and maintaining these systems. This shift not only encourages workforce upskilling but also contributes to economic growth in farming communities by generating new job opportunities (Eastwood, Klerkx, et al., 2019).

Empirical research from New Zealand highlights the positive outcomes associated with the adoption of Supply Chain 4.0 technologies in the dairy industry. A study by (Saberi et al., 2019) found that farms implementing these technologies experienced notable gains in productivity, environmental sustainability, and collaboration among stakeholders. The research also emphasised that while these advancements offer substantial benefits, challenges such as high implementation costs and the need for technical expertise must be addressed to ensure widespread and effective adoption.

The adoption of Supply Chain 4.0 technologies in the dairy industry offers substantial economic, environmental, and social benefits. By enhancing efficiency, sustainability, and stakeholder relationships, these technologies contribute to the overall competitiveness and sustainability of the dairy sector. Collaborative efforts and support from industry stakeholders are essential to overcome adoption challenges and realize the full potential of Supply Chain 4.0.

# Chapter 3

# Research Methodology

## 3.1 Introduction

Adopting Supply Chain 4.0 technologies included digitalization, automation, and advanced data analytics. It promised significant efficiency, transparency, and responsiveness improvements in supply chains. In the dairy industry, where New Zealand is a leading global player, the role of dairy farmers in driving the adoption of these advanced technologies was crucial. This study aimed to explore how dairy farmers influence the adoption of Supply Chain 4.0 within the context of New Zealand's dairy industry. The methodology adopted for this study included qualitative research through semi-structured interviews, employing the snowball sampling technique. Also, it used the secondary data to analyse the perspectives of other stakeholders, especially the dairy processing companies.

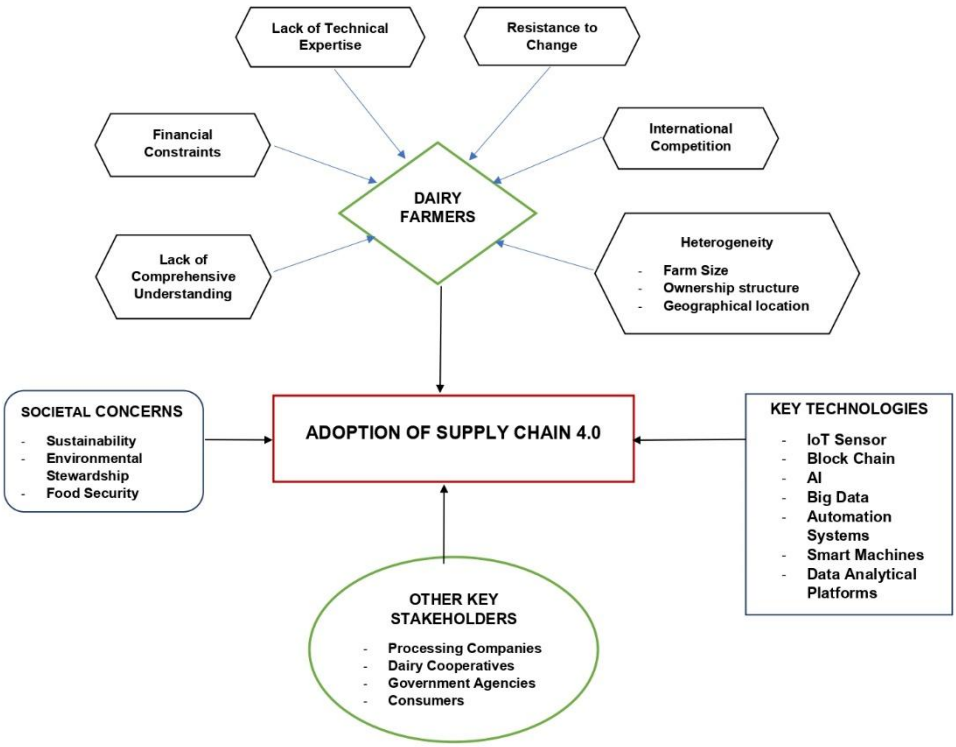


**Figure 3.1 Research Scope**

Source: Developed by the Author

## 3.2 Research Design

This research adopted a qualitative approach to gain in-depth insights into the role of dairy farmers in the adoption of Supply Chain 4.0. Qualitative research was particularly suitable for exploring complex phenomena where the context and experiences of participants are critical to understanding the issues at hand (Creswell & Poth, 2018). The study used semi-structured interviews to allow for flexibility in questioning while ensuring that key topics were covered consistently across interviews.

### 3.2.1 Research Onion Framework

To further enhance the structure and clarity of the methodology for studying the role of dairy farmers in the adoption of Supply Chain 4.0 technologies, the Research Onion framework developed by Saunders, Lewis, and Thornhill (2011) was incorporated. This framework provided a systematic and comprehensive approach to designing research methodology through layered stages. It was like 'an onion' with multiple layers that allow it to move to different layers. Each layer of the Onion added a different aspect to the research process, research philosophy, research design, approach, strategy, time horizons, and data collection.

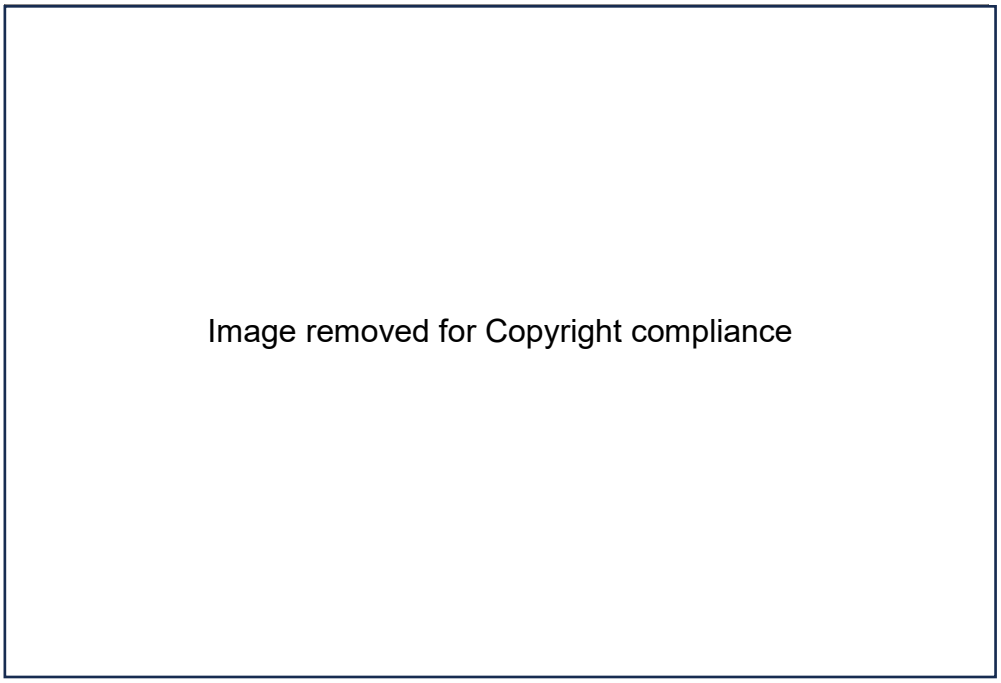


**Figure 3.2 Research Onion**

Source: (Saunders et al., 2011)

This methodological structure not only enhanced the clarity of the research process but also ensured that the findings were robust, reliable, and deeply informative regarding the practical realities of integrating Supply Chain 4.0 technologies in the dairy industry.

## 3.3 Philosophical Stance

### 3.3.1 Phenomenology

This study adopted a phenomenological approach to understand the subjective experiences of dairy farmers regarding their interaction with technology adoption. Phenomenology focused on exploring how individuals perceived and made sense of their experiences, making it particularly suitable for understanding the complex and personal factors influencing farmers' decisions to adopt Supply Chain 4.0 technologies (Moustakas, 1994). By capturing the lived experiences of dairy farmers, this approach provided deeper insights into the challenges and opportunities they encounter in the process of technology adoption.

## 3.4 Research Approaches

### 3.4.1 Inductive Approach

The study utilised an inductive research approach, generating insights and theories from the data collected through qualitative methods. An inductive approach was appropriate for capturing the complexity of human behaviours and social interactions within the dairy industry (Thomas, 2006). This approach allowed the researcher to develop a grounded understanding of the factors influencing Supply Chain 4.0 adoption, based on the experiences and perspectives of dairy farmers and other stakeholders.

## 3.5 Research Strategies

### 3.5.1 Case Study

Employing case studies allowed for an in-depth investigation of the specific contexts within which dairy farmers operate and how these influence their technology adoption decisions. A case study approach provided detailed and contextualized

insights into the practices, challenges, and outcomes of adopting Supply Chain 4.0 technologies (Yin, 2018). By examining multiple case studies, the research could identify common patterns and unique variations in adoption practices across different farms.

### 3.5.2 Ethnography

Considering an ethnographic component can immerse researchers in the daily practices of dairy farming, providing deeper insights into the practical challenges and opportunities of technology integration. Ethnography involved prolonged engagement with participants. It also allowed researchers to observe and understand the intricacies of their daily routines, interactions, and decision-making processes (Hammersley & Atkinson, 2019). This approach could uncover nuanced factors that influence technology adoption, which would not be apparent through interviews alone.

## 3.6 Time Horizons

### 3.6.1 Cross-Sectional Study

This research adopted a cross-sectional approach. It captured a snapshot of the current state of Supply Chain 4.0 technology adoption among dairy farmers at a specific point in time. A cross-sectional study enabled the examination of existing adoption patterns, current implementation levels, and immediate impacts across different farming operations simultaneously (Bryman, 2016). By surveying dairy farmers at various stages of technology integration during the data collection period, the research could identify factors influencing adoption decisions and compare experiences across different farm characteristics, sizes, and operational contexts. This approach provided efficient insights into the present landscape of Supply Chain 4.0 adoption in the dairy sector. It also allowed for the identification of current trends, challenges, and opportunities without the time and resource constraints associated with longitudinal observation.

## 3.7 Data Collection Methods

### 3.7.1 Semi-Structured Interviews

Semi-structured interviews were chosen as the primary data collection method due to their ability to elicit detailed and rich information from participants. This approach allowed the interviewer to follow a predetermined set of questions. Also, it provided the flexibility to explore new topics that emerge during the conversation (Kvale & Brinkmann, 2009). The semi-structured format ensured that all relevant aspects of Supply Chain 4.0 adoption were discussed. It also allowed participants to share their unique perspectives and experiences.

## 3.8 Population, Sample, and Sampling Method

### 3.8.1 Population

The population for this study consisted of dairy farmers and other stakeholders involved in the dairy industry in New Zealand. This included individuals or organizations involved in milk production, regardless of farm size, ownership structure, or geographic location within New Zealand. The population encompassed a diverse range of dairy farming operations, from small family-owned farms to large corporate entities, representing the broader dairy industry in the country.

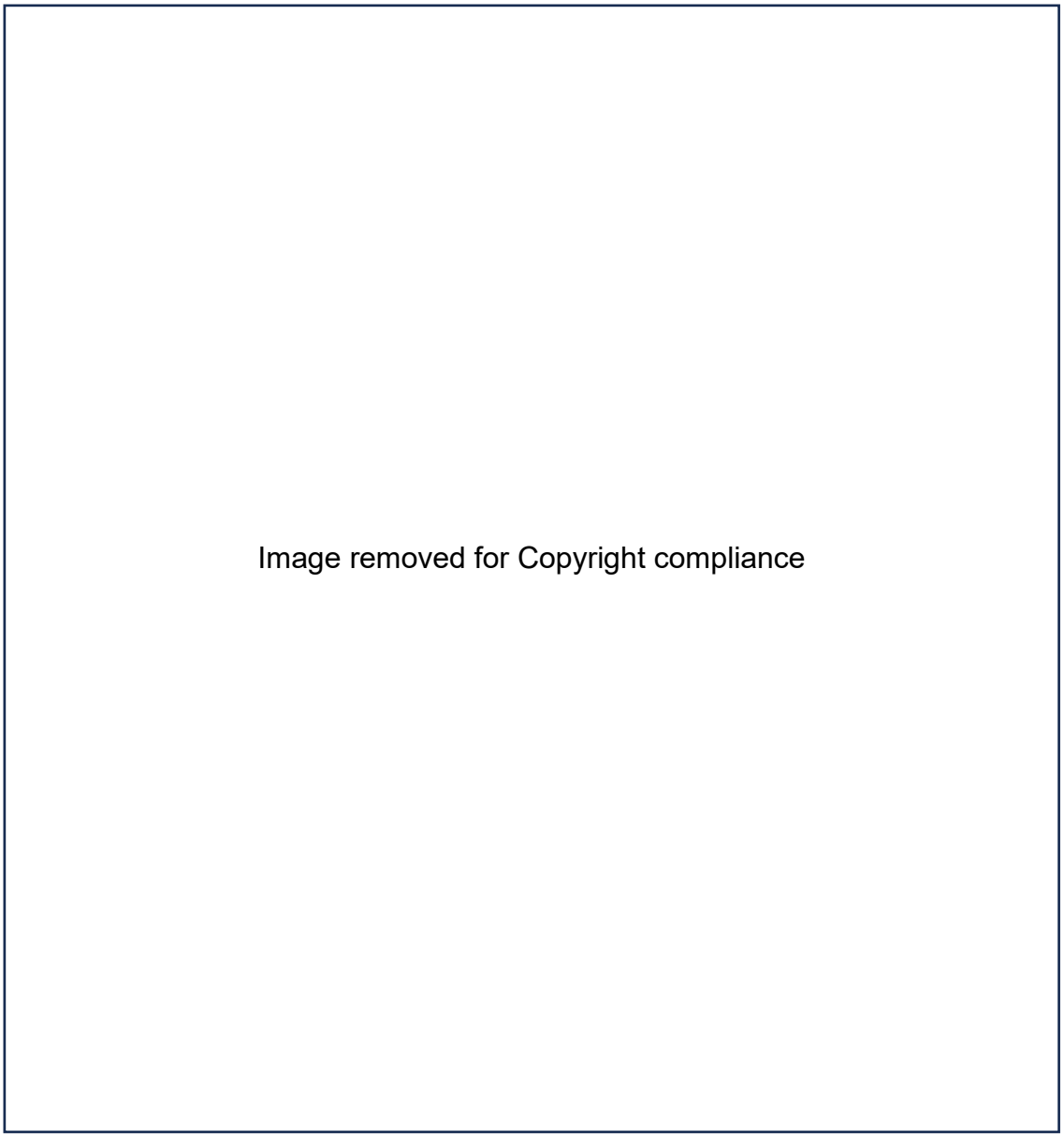


**Figure 3.3 Regional Distribution of Dairy Cows in New Zealand**

Source: (DairyNZ, 2023)

### 3.8.2 Sampling Strategy

#### Snowball Sampling Technique

The snowball sampling technique used to identify and recruit interview participants. This non-probability sampling method was particularly effective for reaching hard-to-access or specialized populations, such as dairy farmers and processing company representatives directly involved in Supply Chain 4.0 initiatives (Noy, 2008a).

### Effectiveness of Snowball Sampling in This Research

1. **Access to a Niche Community:** Dairy farmers in New Zealand form a relatively small and tightly-knit community. Due to geographical dispersion and the private nature of farming operations, traditional sampling methods were not effective in reaching a sufficient number of participants. Snowball sampling leveraged existing relationships to penetrate this community (Atkinson & Flint, 2001).
2. **Trust and Credibility:** Trust was crucial when researching sensitive topics such as business practices and technology adoption. Initial participants who trusted the researcher could vouch for them to other potential participants, facilitating access and enhancing the credibility of the study (Shenton, 2004).
3. **Rich, In-Depth Data:** Snowball sampling could lead to richer data as participants recruited through personal networks were willing to share detailed and genuine insights. This was essential for understanding the multifaceted role of dairy farmers in driving Supply Chain 4.0 adoption (Patton, 2014).

### Implementation of Snowball Sampling

The process begins with a few key informants who are knowledgeable about the subject matter. These initial participants then referred the researcher to other potential participants, creating a network of interviewees through referrals.

**Table 3.1 Snowball Sampling Process**

| Step | Description |
|---|---|
| Initial Contact | Identified and approached initial key informants (processing companies). These individuals known as seeds, were selected based on their knowledge and willingness to participate. |
| Establishing Trust | Building trust with these initial contacts was crucial. This could be achieved through transparent communication about the research objectives, confidentiality measures, and the potential benefits of the study for the dairy community. |

| Step | Description |
|---|---|
| Data Collection and Referral Process | After conducting in-depth interviews with the initial participants, researchers asked them to refer to other dairy farmers who might be interested in participating. These referrals often came from the participants' professional or personal networks, which helped in reaching a broader and more diverse group of dairy farmers. |
| Expansion | Continued the referral process until a diverse and comprehensive sample was achieved or until new data no longer provided additional insights (data saturation). |

Source: Developed by the Author

**Sample Size**

Initial contacts with representatives from processing companies (six in number) provided a starting point for expanding the participant pool to include dairy farmers (eight in number), who were central to the study. The farm size, ownership structure, and geographical locations in Canterbury – New Zealand were the key attributes of the samples of farmers.

The sample size of 14 interviews conducted in this study is well-supported by established qualitative research methodology and empirical evidence on data saturation. Guest, Bret al., 2006) seminal study demonstrated that saturation often occurs within 12 interviews. (Hennink et al., 2017) research found that qualitative studies consistently reach saturation between 9-17 interviews when studying relatively homogeneous populations. This aligns with the fundamental principle that qualitative research prioritizes depth over breadth. Smaller samples enable intensive analysis that yields rich, detailed understanding rather than statistical generalizability.

The 14 interviews conducted allowed for thorough exploration of emerging themes until no new insights or patterns were identified. It adhered to the data saturation criterion that serves as the gold standard for determining adequate sample size in qualitative inquiry.

## 3.9 Data Collection

### 3.9.1 Primary Data Collection

The primary data for this study was collected through semi-structured interviews with dairy farmers and processing company representatives. The interviews were designed to explore the participants' experiences, attitudes, and perceptions regarding the adoption of Supply Chain 4.0 technologies. Key areas of focus included:

- **Understanding of Supply Chain 4.0:** Participants' knowledge and awareness of Supply Chain 4.0 technologies.
- **Adoption Drivers and Barriers:** Factors that facilitated or hindered the adoption of these technologies.
- **Impact on Operations:** How the adoption of Supply Chain 4.0 affects daily operations, productivity, and sustainability.
- **Stakeholder Collaboration:** The role of collaboration and communication among different stakeholders in the supply chain.

**Interview Process**

1. **Initial Contact and Consent:** Initial contact was made through email or phone to introduce the study and invite participation. Research Information Sheets and Consent Forms were provided to ensure participants were fully informed about the study's objectives, procedures, and confidentiality measures.
2. **Conducting Interviews:** Semi-structured interviews were conducted either in person or via online platforms, depending on the participants' preferences and geographic locations. Each interview was approximately 45 to 60 minutes long.
3. **Recording and Transcription:** With participants' consent, interviews were audio-recorded and later transcribed precisely for analysis. This ensured that all information is accurately captured and available for detailed examination.

**Interview Guides**

**Processing Companies**

- **Introduction:** Can you briefly describe your role and experience in the dairy industry?
- **Understanding of Supply Chain 4.0:** What is your understanding of Supply Chain 4.0? How familiar are you with its technologies?
- **Adoption Drivers and Barriers:** What factors have driven or hindered your adoption of Supply Chain 4.0 technologies?
- **Impact on Operations:** How has the adoption of these technologies affected your operations? Can you provide specific examples?
- **Stakeholder Collaboration:** How do you collaborate with other stakeholders in the supply chain to implement these technologies?

**Dairy Farmers**

- **Introduction:** Can you briefly describe the farm size and the years of your experience in the dairy industry?
- **Understanding of Supply Chain 4.0:** What are the new software, types of equipment, and technologies you have used so far?
- **Adoption Drivers and Barriers:** Was it easy for you to implement them? What were the difficulties you faced? Why did you decide to accept them?
- **Impact on Operations:** How has the adoption of these technologies affected your operations? Can you provide specific examples?
- **Stakeholder Collaboration:** How do you collaborate with other partners of your business to implement these technologies?

### 3.9.2 Secondary Data Collection

Secondary data was used to complement the primary data collected from interviews. This data included reports, publications, and industry analyses that provide additional context and insights into the adoption of Supply Chain 4.0 in the dairy industry. The secondary data was used to analyse other stakeholders of the dairy industry.

**Table 3.2 Sources of Secondary Data**

| Source | Type of Data |
|---|---|
| Industry Reports | Insights and statistics on the adoption of digital technologies in the dairy supply chain |
| Academic Journals | Peer-reviewed articles on Supply Chain 4.0 and its impact on agriculture and dairy industries |
| Government Publications | Policies and initiatives related to digital transformation in the dairy sector |
| Company Reports | Case studies and implementation reports from dairy processing companies |

Source: Developed by the Author

The integration of secondary data helped to triangulate the findings from the primary data, enhancing the reliability and validity of the study.

## 3.10 Data Analysis

### 3.10.1 Thematic Analysis

The data analysis process involved several steps to ensure a comprehensive understanding of the role of dairy farmers in driving Supply Chain 4.0 adoption. The qualitative data from interviews was analysed using thematic analysis, while the secondary data was used to support and contextualize the findings.

Thematic analysis was employed to identify and interpret patterns and themes within the qualitative data (Braun & Clarke, 2006). The steps involved in the thematic analysis include:

**Table 3.3 Thematic Analysis Process**

| Analysis Step | Description |
|---|---|
| Familiarization | Transcribing interviews and reviewing the data to understand the content of the gathered data |
| Initial Coding | Identifying significant features of the data and generating initial codes |
| Searching for Themes | Grouping initial codes into potential themes that capture key aspects of the data |
| Reviewing Themes | Refining themes to ensure they accurately represent the data |
| Defining Themes | Clearly defining each theme and giving it a concise name |
| Writing Up | Integrating themes into a coherent narrative that addresses the research questions |

Source: Developed by the Author

## 3.11 Ethical Considerations

Ethical considerations were paramount in this study to ensure the integrity and credibility of the research process. It was crucial to inform participants the purpose of the research, their voluntary participation, and their right to withdraw. Confidentiality, anonymity, and informed consent prior to the data collection were also important factors during the data collection process. Further, how the collected information was used and stored must be precisely communicated to the participants.

**Table 3.4 Key Ethical Considerations**

| Ethical Consideration | Description |
|---|---|
| Informed Consent | Participants were fully informed about the purpose of the study, the nature of their participation, and their right to withdraw. |

| Ethical Consideration | Description |
|---|---|
| Confidentiality | The confidentiality of the participants was maintained by anonymizing their identities and any identifying information. Any identified information was anonymized in all reports and publications resulting from this study |
| Data Security | All data collected was securely stored and only accessible to the research team. |
| Voluntary Participation | Ensuring participation was entirely voluntary and participants could withdraw within one month of joining the project without any negative consequences. |

Source: Developed by the Author

## 3.12 Challenges and Mitigation Strategies

While this study aimed to provide comprehensive insights into the role of dairy farmers in driving Supply Chain 4.0 adoption, it was essential to acknowledge potential limitations. The use of snowball sampling, while effective for reaching specific populations, introduced bias as the sample was not entirely representative of the broader population. Additionally, the reliance on self-reported data through interviews was subject to social desirability bias, where participants provided responses, they perceived as favourable.

1. **Sampling Bias:** Snowball sampling could lead to sampling bias as the sample was over-represent certain sub-groups within the population. To mitigate this, researchers aimed to initiate the snowball process with a diverse set of seeds representing different regions, farm sizes, and adoption levels of Supply Chain 4.0 technologies (Noy, 2008b).
2. **Ethical Considerations:** Ensuring confidentiality and obtaining informed consent was paramount. Researcher clearly explained the purpose of the study and how the data would be used, ensuring participants were fully aware and agreeable.
3. **Dependency on Referrals:** The success of snowball sampling relies heavily on participants' willingness to refer others. Providing incentives, such as

sharing study findings or highlighting the potential benefits for the dairy industry, could encourage participation.

## 3.13 Detailed Implementation Plan

### 3.13.1 Preparation Phase

Before initiating the data collection process, several preparatory steps were essential to ensure the study's smooth execution:

1. **Ethical Approval:** Obtain ethical approval from the Human Ethics Committee (HEC). This involved submitting a detailed research proposal outlining the study's objectives, methodology, and ethical considerations, including informed consent and data confidentiality procedures.
2. **Developing Interview Guides:** Designed comprehensive interview guides for both dairy farmers and processing company representatives. These guides were pre-tested with a small group of participants to refine the questions and ensure they were clear and effective in eliciting the necessary information.
3. **Pilot Interviews:** A pilot interview was conducted to get a preliminary idea of the interview approach and enhance question clarity. This trial run helped identify the interview process, techniques for building rapport, potential issues and methods for handling sensitive topics.
4. **Identifying Initial Participants:** Identified and established contact with initial participants (seeds) through industry connections, professional networks, and recommendations. These participants were selected based on their knowledge of and involvement in Supply Chain 4.0 initiatives.

### 3.13.2 Data Collection Phase

The data collection phase involved conducting semi-structured interviews and gathering secondary data:

1. **Conducting Interviews:** Semi-structured interviews were conducted either in person or via online platforms, depending on the participants' preferences

and geographic locations. Each interview was approximately 45 to 60 minutes long.

2. **Recording and Transcription:** With participants' consent, interviews were audio-recorded using a native mobile recorder and later transcribed manually for analysis. This ensured that all information is accurately captured and available for detailed examination.
3. **Gathering Secondary Data:** Collected relevant secondary data from industry reports, academic journals, government publications, and company reports to complement the primary data.

### 3.13.3 Data Analysis Phase

The data analysis phase involved:

1. **Thematic Analysis:** Conducted thematic analysis of the transcribed interview data to identify key themes and patterns.
2. **Triangulation:** Compared the findings from the primary data with the secondary data to validate and enhance the credibility of the results.

## 3.14 Verification Statement on AI Usage

This statement serves to verify that the research study titled *"The Role of Dairy Farmers in Driving Supply Chain 4.0 Adoption: A Case Study from the New Zealand Dairy Supply Chain"* has been conducted entirely without the use of artificial intelligence (AI) technologies. The research, including its conception, methodology, data collection, and analysis was executed manually by the researcher. It ensured that all intellectual contributions were solely attributable to human expertise and rigorous academic inquiry.

According to Springer (2023) editorial policies on artificial intelligence in scholarly writing, AI-assisted copyediting does not require explicit disclosure as it aids human-generated text for clarity without independent content creation. However, in the interest of full transparency, its use was acknowledged while ensuring that the originality and integrity of this work remain unharmed.

### Use of AI-Assisted Tools for Language Editing

To enhance the readability and grammatical accuracy of this thesis, Grammarly, an AI-assisted language editing tool, was used for grammar, spelling, punctuation, and style refinement. The use of such tools was strictly limited to language enhancements and did not contribute to content generation, data analysis, or interpretation.

### No AI-Assisted Processes Were Employed

In preparing the manuscript, the researcher undertook every phase of the study without the assistance of AI-based systems. The qualitative data collection was performed via semi-structured interviews with dairy farmers and processing company representatives. Each interview was carefully planned, conducted, and transcribed by the researchers, with all coding and thematic analyses carried out manually and use of NVivo14. No AI or machine learning algorithms were utilized in the transcription, coding, or subsequent thematic analysis processes. This accurate, hands-on approach ensured that the identification of key themes and the interpretation of data were directly informed by the researchers' expertise and contextual understanding of New Zealand's dairy industry.

### Manual Data Collection and Analysis

The study's methodology relied on established qualitative research methods:

- **Data Collection:** Semi-structured interviews were used to gather in-depth insights. The selection of participants, the design of the interview guides, and the process of obtaining informed consent were all managed directly by the researchers.
- **Data Analysis:** The analysis employed thematic analysis techniques as outlined by Braun and Clarke (2006), with all data coding and theme development performed manually and use of NVivo14. The researchers cross-validated the findings through triangulation of multiple data sources, thereby ensuring that the derived conclusions accurately reflect the experiences of Supply Chain 4.0 adoption among New Zealand dairy farmers.

- **Interpretation and Synthesis:** The integration of primary and secondary data sources into a comprehensive narrative was entirely based on manual synthesis by the research team, with rigorous oversight to maintain objectivity and academic integrity.

### Assurance of Academic Accuracy

The research adhered strictly to the ethical and methodological standards required for scholarly publications, including those set forth by Springer. Throughout the research process, all procedures were carried out with direct human supervision. The absence of AI-based systems means that every analytical decision—from the formulation of research questions and design of interview protocols to the nuanced interpretation of qualitative data—was made based on the researchers' deep understanding and expert judgment. This approach guaranteed that the findings, recommendations, and theoretical contributions were the result of deliberate, thoughtful analysis rather than automated processes.

### Declaration

In summary, I, the author, hereby declare that the entirety of the research and the accompanying manuscript were developed without the use of any artificial intelligence technologies except Grammarly to enhance the readability and grammatical accuracy of this thesis. All data collection, analysis, and writing were executed manually by the researcher, ensuring that the study's contributions were purely a result of expert human insight. This verification is provided in full compliance with Springer's requirements and is intended to affirm the integrity and originality of our research work.

## 3.15 Conclusion

The methodology outlined in this chapter provided a robust framework for exploring the role of dairy farmers in driving the adoption of Supply Chain 4.0 technologies in the New Zealand dairy industry. This employs qualitative research through semi-structured interviews, using the snowball sampling technique, and integrating secondary data. It helped to gain in-depth insights into the factors influencing

technology adoption and the collaborative efforts of stakeholders in the supply chain. This approach ensured a comprehensive understanding of the complexities and dynamics involved in adopting Supply Chain 4.0, highlighting the critical role of dairy farmers and other stakeholders in shaping the future of the dairy industry in New Zealand. The findings from this study contributed to the broader discourse on digital transformation in agriculture. It also provided practical insights for policymakers, industry leaders, and practitioners seeking to enhance supply chain efficiency and sustainability through advanced technologies.

# Chapter 4

# Findings and Discussion

## 4.1 Introduction

This chapter presents the findings and discussion of the research conducted on the role of dairy farmers in driving the adoption of Supply Chain 4.0 technologies within the New Zealand dairy industry. It focuses on the utilization of Internet of Things (IoT) sensors for milk quality and temperature monitoring, automated milking systems, blockchain, pivot irrigation systems, implanted chips for monitoring cow health and behavior, and Artificial Intelligence (AI)-integrated cow collars. The analysis is based on data collected through semi-structured interviews with dairy farmers and representatives of the dairy processing companies, as well as relevant secondary data. The findings are categorized into key themes derived from the interviews. It offers insights into the motivations, barriers, and impacts associated with advanced digital technology adoption in the dairy supply chain. The discussion integrates these findings with relevant theoretical frameworks. Direct quotations from interview participants are incorporated to provide credibility and show perceived views.

## 4.2 Overview of Data Collection

This study employed semi-structured interviews to explore how dairy farmers contribute to adopting Supply Chain 4.0 technologies in New Zealand. The flexible interview format helped participants to openly share their experiences, challenges, and perspectives while ensuring that key research topics were thoroughly covered. This qualitative approach provided in-depth insights into the factors influencing technology adoption and the barriers and opportunities experienced by processing companies within the dairy supply chain.

### 4.2.1 Interview Process

The initial step was identifying the key participants involved in the New Zealand dairy supply chain. It primarily focuses on dairy farmers and processing companies. The

semi-structured format used to conduct the interviews allowed for natural conversation while covering predefined topics. It also ensured that key research questions remained the focus.

Each interview lasted between 60 and 90 minutes, depending on participant responses. Interviews were conducted in person where possible, or via online platforms like MS Teams to accommodate participants' locations and schedules. The semi-structured nature of the discussions allowed for deeper exploration of specific topics that emerged. Questions covered participants' understanding of Supply Chain 4.0 technologies, their adoption experiences, challenges faced, benefits realized, environmental considerations, future expectations, and the impacts on farm operations and industry relationships.

To ensure the relevance of their specific roles in the supply chain, tailored interview guides were developed for dairy farmers and processing company representatives. These guides were piloted with a small group before the main interviews to refine the questions for clarity and effectiveness. With participants' consent, interviews were audio-recorded and transcribed for precise analysis to facilitate an accurate and comprehensive analysis of the data.

### 4.2.2 Sample Size and Demographics

This study included a total of 14 participants covering **eight dairy farmers** and **six representatives from processing companies**. The snowball sampling technique was used to recruit participants, starting with a few key informants in the dairy industry who then referred the researcher to other potential participants. This approach was effective in accessing a specialized population, particularly within the close-knit community of dairy farmers in New Zealand. Further, it helped to reach dairy farmers due to the interconnected nature of the dairy supply chain.

- **Dairy Farmers**: The eight dairy farmers represented diverse farm sizes and ownership structures, including small family-owned farms (25%), medium-sized cooperatives (37.5%), and larger corporate entities (37.5%). The participants were spread across the Canterbury region of New Zealand. It covered the key dairy-producing areas such as Culverden, Hororata, Dunsandel, Lincoln, Ruapuna, and Tai Tapu. They had varying levels of

exposure to digital technologies, ranging from early adopters of Internet of Things (IoT) sensors, automated milking systems, pivot irrigation systems, implanted chips, and Artificial Intelligence (AI)-integrated cow collars to those just beginning to explore the possibilities of digital integration.

- **Processing Companies and Cooperatives**: The six participants from processing companies and cooperatives played a crucial role in the dairy supply chain, facilitating the adoption of new technologies. Their responsibilities included overseeing the digital technologies integration across the supply chain, providing technical support, financial assistance, and training. Their insights provided a broader perspective on the challenges faced by smaller farms and the role of cooperatives in supporting digital transformation.

### 4.2.3 Key Demographics

- **Age of Dairy Farmers**: The range of ages ranged between 30 to 65 old among the participants. The majority fell between 45 and 60. This generational difference made a remarkable impact on technology adoption, as younger farmers are more open to new technologies. It also highlighted that younger farmers showed greater enthusiasm for innovation and experimentation while mature farmers were keen to go with traditional farming techniques.
- **Farm Size**: Small farms with fewer than 100 cows and large farms with over 1000 cows were included in the study. The size of the farm was a crucial factor in adopting novel technologies. Large farms had more resources, technical expertise, and financial capabilities, while smaller farms faced great difficulty in facilitating the required resources to acquire supply chain 4.0 technologies.
- **Geographical Distribution**: Key dairy-producing areas that are known for their strong dairy industries from Canterbury of New Zealand considered for the study. They included areas like **Culverden, Hororata, Dunsandel, Ruapuna, Tai Tapu, and Lincoln.** It is highlighted that the regional factors**,** such as climate conditions, access to technology providers, and the level of support from local cooperatives differ from area to area. This regional

diversity allowed for a broader understanding of how location influences technology adoption.

- **Years of Experience**: This showed an important impact in adopting supply chain 4.0 technologies, with the dairy farmers having an average of **20 years of experience** in the industry. Some farmers had over 30 years of experience and it provided valuable insights into the evolution of dairy farming practices. Those with longer industry tenure were able to compare their existing operations with past practices. and the gradual shift towards digital technologies in recent years. Participants with longer industry tenure were able to compare their current operations with past practices, offering a historical perspective on the adoption of Supply Chain 4.0 technologies.

### 4.2.4 Summary of Data Collection Process

It was crucial to capture a broad view of the role of dairy farmers in adopting supply chain 4.0 technologies. The design of data collection process is designed to achieve it while incorporating the views of processing companies and cooperatives. The use of semi-structured interviews allowed for an in-depth understanding of the participants' experiences. The snowball sampling technique helped access a diverse and representative sample of the New Zealand dairy industry. It resulted and ensured that the data collected was rich, delicate, and reflective of the complex dynamics involved in the adoption of digital technologies in the dairy supply chain.

NVivo14 qualitative data analysis software was used for thematic analysis of the transcriptions of the interviews. That helped to identify recurring patterns and themes. The findings presented in the subsequent sections of this chapter explore deeper into the themes that emerged from the interviews. It also provides a detailed analysis of the factors influencing the adoption of Supply Chain 4.0 technologies in New Zealand's dairy sector.

## 4.3 Thematic Analysis of Dairy Farmers' Responses

The responses of dairy farmers provided several key themes related to their understanding, motivations, and challenges in adopting Supply Chain 4.0 technologies. A thorough thematic analysis of the interview data is used to identify

these themes and it focuses on the participant's experience with IoT, AI, blockchain, automation, and other advanced technologies.

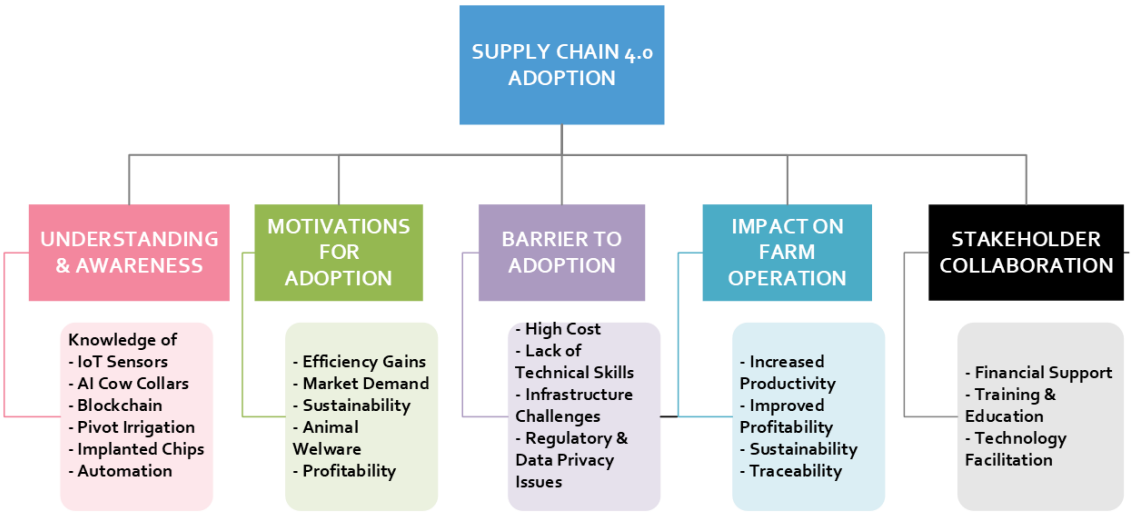


**Figure 4.1 Key Themes for Supply Chain 4.0 Adoption Process**

Source: Developed by the Author

### 4.3.1 Understanding and Awareness of Supply Chain 4.0 Technologies

The level of understanding and awareness of Supply Chain 4.0 technologies among dairy farmers varied significantly across the sample. Some farmers showed a high level of familiarity with these technologies and the potential benefits of these technologies, while others were only beginning to explore their possibilities.

**Knowledge of IoT Sensors**: Many farmers who used advanced technologies for farm automation and monitoring were familiar with Internet of Things (IoT) applications. Tracking cow health, monitoring milk production, and optimizing feed management were major benefits gained with the use of IoT devices. One farmer noted, *"The sensors help to keep track of the cows' health. We can catch issues early before they become big problems"* (NZDF01).

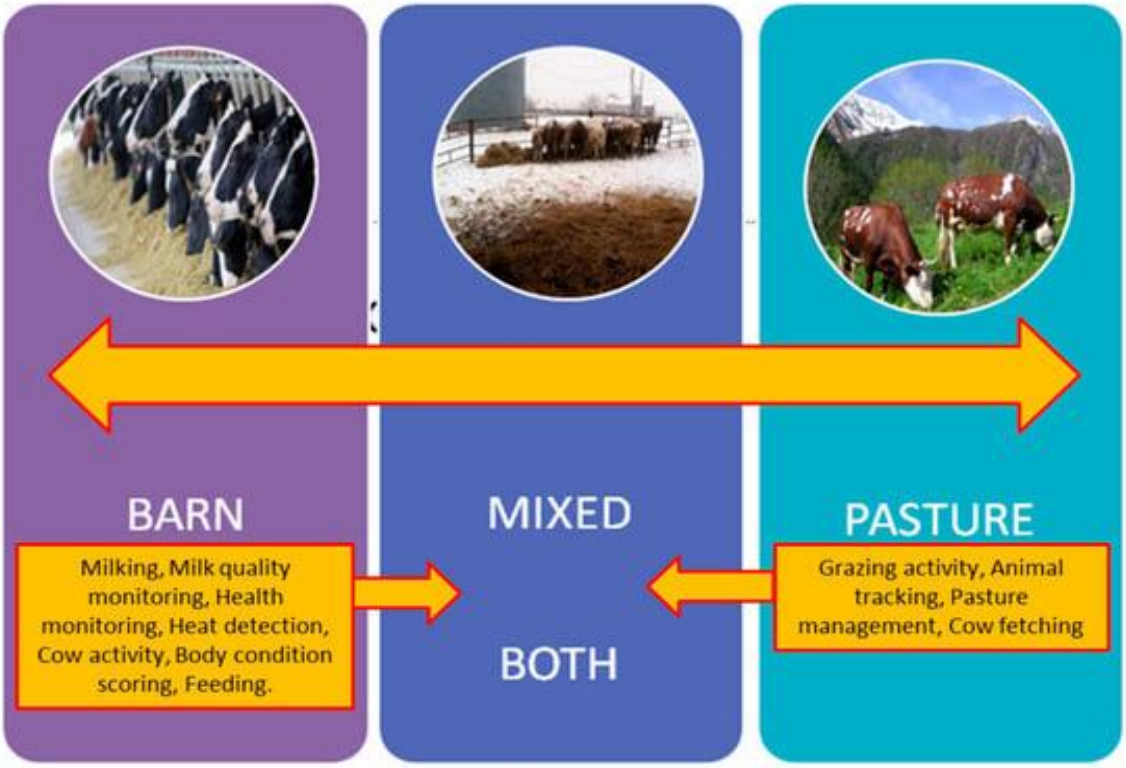


**Figure 4.2 Internet of Things (IoT) Sensors Application in Dairy Cattle Farming**

Source: (MDPI, 2023)

Participating in training programs or having worked with technology providers was key for farmers to be exposed to technological innovations. They expressed confidence in the potential of IoT to streamline their operations. Further, they pointed out the benefits of real-time data collection such as more efficient decision-making and immediate adjustments to farming practices.

**Knowledge of Blockchain**: Familiarity with blockchain technologies among farmers is generally lower than with IoT. Only a few farmers showed a basic understanding of blockchain and its application in the dairy industry. However, those who were aware of blockchain technology indicated its usefulness in ensuring product traceability and improving transparency in the dairy supply chain. One participant mentioned, *"I've heard that blockchain can help trace where our milk goes. It helps to prove that it's coming from a good, clean farm. That could be a selling point"* (NZDF08).

Farmers who had limited exposure to blockchain were typically more doubtful of its benefits. They view it as a complex technology that requires significant investment without immediate clear returns. This doubtfulness was more dominant among smaller dairy farms with fewer resources to experiment with such innovations.

**Knowledge of Pivot Irrigation Systems:** The use of **pivot irrigation systems** was well understood and popular among larger dairy farms. It helps those in regions where water management is critical for pasture growth. These automated watering processes ensure water distribution across large areas to feed production and improve sustainability.

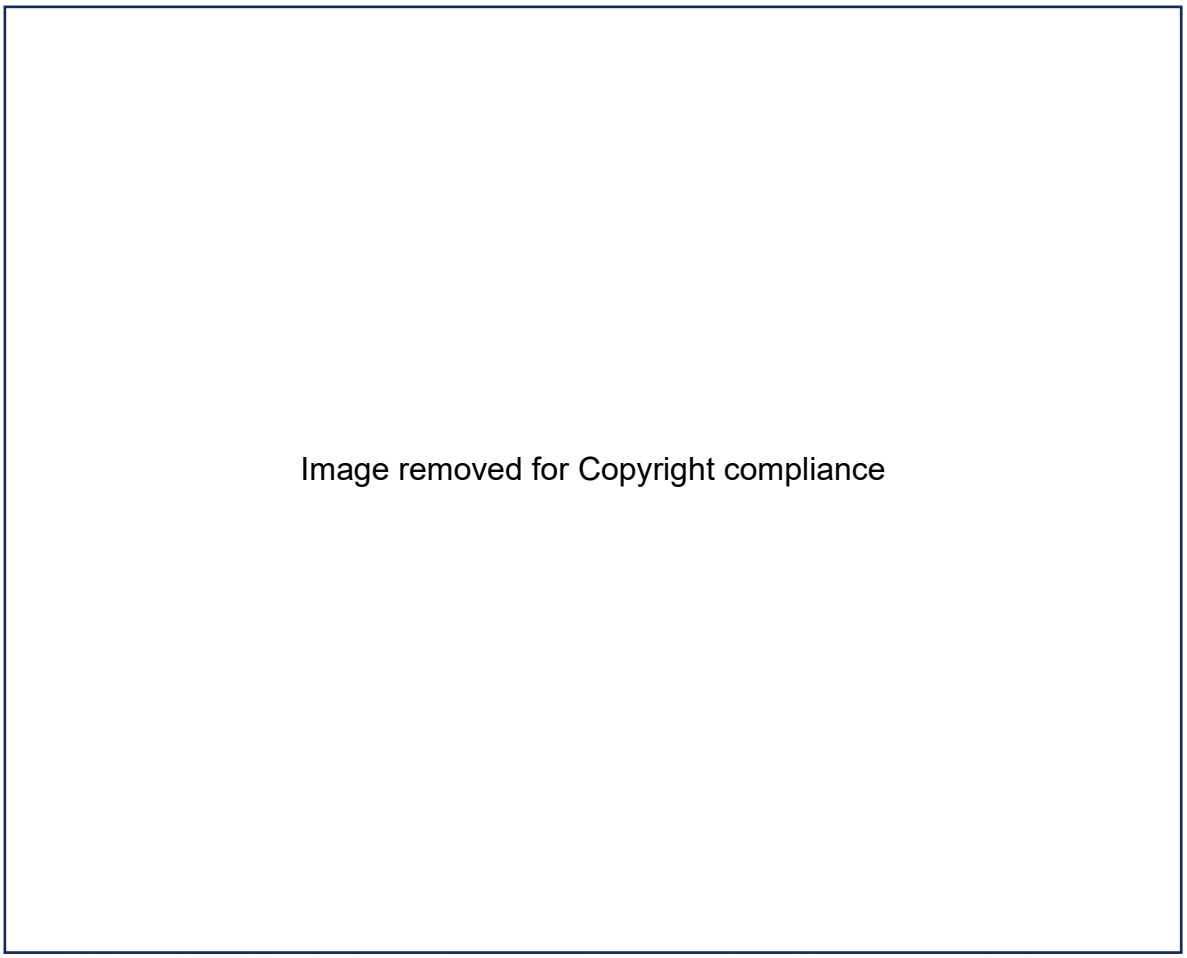


**Figure 4.3 Pivot Irrigation System**

Source: (DairyNZ, 2011)

One farmer explained, *"Before we installed the automated pivots, we relied on manual irrigation, which was time-consuming and inconsistent. Now, we can control*

*everything remotely even from our homes through the mobile. It helps to adjust water levels based on soil moisture and save on water use"* (NZDF05).

However, the adoption of pivot irrigation was influenced by farm size, water availability, and investment capacity. Larger dairy operations were more likely to implement pivot irrigation, while smaller farms relied on traditional irrigation methods due to cost constraints.

**Knowledge of Implanted Chips:** This was an emerging area of interest among dairy farmers who are keen on novel technologies. These chips, often implanted under the skin of cows, provide real-time health tracking, heat for reproduction, disease monitoring, and individual animal identification. Farmers who had adopted this technology highlighted its benefits in precision farming. Automated health alerts, records of the raw milk output of each cow against the feeding, and improved breeding decisions were identified as the most important benefits.

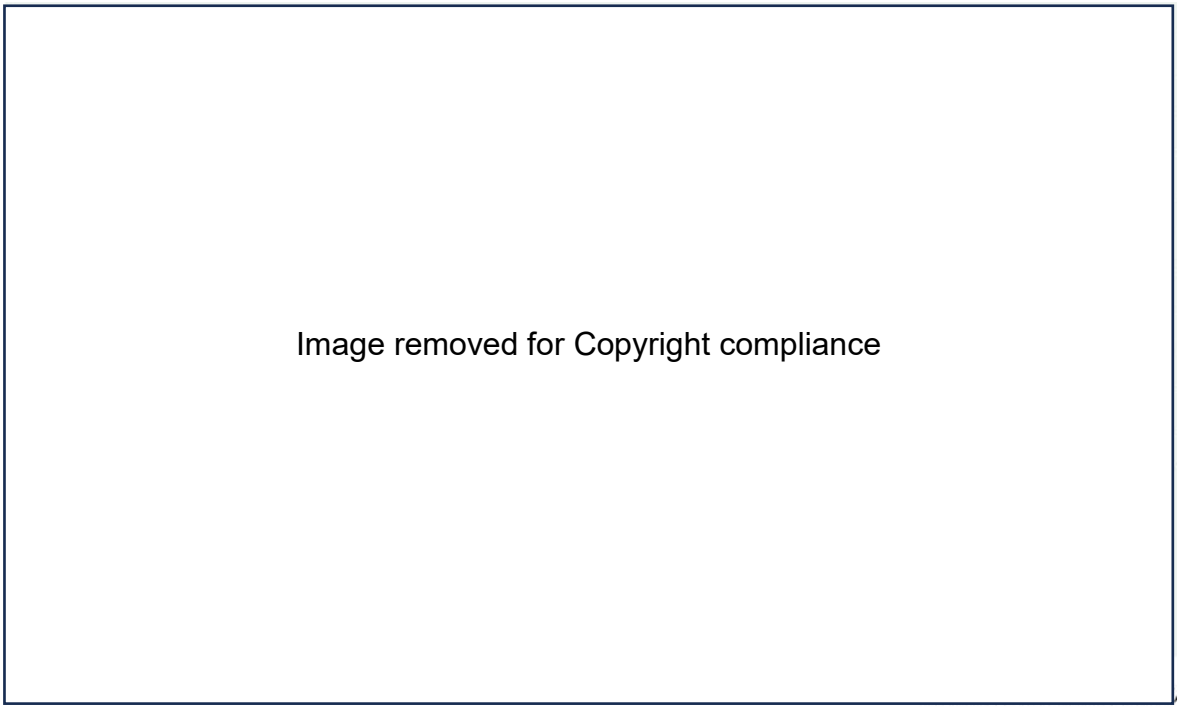


**Figure 4.4 Trend in Production Worth for all Cows**

Source: (DairyNZ, 2023)

One participant shared, *"We use implanted chips to track cows. It helps us to identify the reproductive cycles and detect early signs of illness. This way, we can address quickly before problems get serious. That saves us both time and money"* (NZDF01).

Despite these advantages, many farmers were hesitant to adopt implanted chips due to concerns about cost, data security, and animal welfare. Some were also doubtful about the benefits. Return on investment, particularly for smaller-scale farmers, was the key, and they rather preferred to rely on manual monitoring.

**Awareness of Artificial Intelligence (AI) in Dairy Farming:** This is still in the early stage of adoption in the dairy industry. However, awareness of AI applications is growing among dairy farmers in New Zealand. AI-integrated cow collars are the most used AI application by highly technical dairy farmers.


**Figure 4.5 Use of AI collars – Concept of Virtual Fencing for Feeding cows**

Source: (Goliński et al., 2023)

One farmer who had integrated AI-powered cow collars into their herd management said, *"The AI collars help to control the herd, their behaviour, individual data, and overall health. We get an alert immediately if something goes wrong. That helps us to take action before it affects milk production"* (NZDF08).

However, the initial cost and complexity become barriers for the farmers from full-scale adoption. While some wished to explore AI solutions, others felt that their current technology—such as IoT sensors and automation—was sufficient for their needs.

**Awareness of Automation**: Many farmers across the sample were familiar with, understood, and used this technology in their farm operations, such as automated milking systems or feeding systems. They have recognised these technologies as time-savers that could reduce labour costs and improve efficiency. One farmer explained, *"Automation has taken a lot of pressure off us. We don't need to spend hours manually milking the cows anymore, and that frees up time for other tasks"* (NZDF07).

However, larger farms had implemented advanced automated systems, while smaller farms remained with their traditional farming practices due to cost concerns. Since these automated processes require and link with the financial capacity of the farm, only the wealthier farmers can afford to invest in such automated systems.

**Discussion**: The analysis revealed that understanding and awareness of Supply Chain 4.0 technologies were influenced by several factors, including farm size, financial resources, and exposure to training or educational opportunities. Larger, more technologically advanced farms tended to have greater awareness of these technologies. And they were more willing to experiment with new systems. In contrast, smaller farms with limited resources and access to technology providers were less likely to be aware of or adopt these innovations.

Among the specific technologies examined, IoT sensors and automation systems were the most widely recognised and implemented, particularly among larger farms. These technologies were recognised for improving efficiency, reducing labor costs, and providing real-time monitoring capabilities. AI cow collars and implanted chips are still at the emerging stage. But they showed promise in herd management by offering data-driven insights into animal health and behavior. However, blockchain technology remained one of the least understood innovations, with only a few farmers recognizing its potential for enhancing transparency in the supply chain.

Similarly, pivot irrigation was primarily adopted by larger farms, where water management was a critical concern

This deviation highlights the importance of targeted education and support to bridge the knowledge gap between different types of dairy farmers. Further, government initiatives, training programs, and financial subsidies could play a crucial role in adopting these emerging technologies among dairy farmers.

The Technology Acceptance Model (TAM) (Davis, 1989) explains that perceived usefulness (PU) and perceived ease of use (PEOU) drive technology adoption. Studies by Eastwood et al. (2019) and Kamble et al. (2018) confirm that farmers who recognise tangible benefits from digital farming tools are more likely to adopt them. This aligns with findings in the literature, which highlight that the adoption of digital tools depends not only on their technical effectiveness but also on how they align with farmers' practical needs and experiences. One farmer noted, *"I wasn't sure about these technologies at first, but once I saw how IoT sensors helped track cow health in real-time, I became more interested"* (NZDF01). This aligns with Wolfert et al. (2017), who highlighted that practical exposure increases farmers' confidence in new technologies. Additionally, according to UTAUT's social influence construct (Venkatesh et al., 2003), farmers who learned about these technologies through peers, cooperatives, or government programs were more likely to adopt them due to external validation and credibility.

These findings suggest that while awareness of Supply Chain 4.0 technologies is growing, adoption rates vary depending on perceived relevance, farm size, and access to support networks. Encouraging further exposure to these innovations through hands-on demonstrations, peer networks, and financial incentives may accelerate the digital transformation of dairy farming.

### 4.3.2 Motivations for Adopting Supply Chain 4.0 Technologies

Farmers had various reasons for adopting Supply Chain 4.0 technologies across the sample. However, the factors generally focus on improving operational efficiency, meeting market demand, enhancing sustainability, and increasing profitability.

**Efficiency Gains**: Efficiency was the most frequently cited motivation for adopting new technologies. Farmers reported that automating processes like milking and feeding allowed them to run their operations more smoothly. Further, they were keen to reduce manual labour, and allocate their time to other essential tasks. As one farmer noted, *"We wanted to save time and labour. Automated systems have made that possible. Now we can focus on improving the overall quality of the farm instead of getting engaged in daily repetitive tasks"* (NZDF03).

The ability to monitor livestock health and milk production in real-time through IoT sensors and AI cow collars also contributed to efficiency gains. Farmers emphasised that these technologies allowed them to make quicker, data-driven decisions that ultimately improved productivity.

**Market Demand**: In recent days, transparency, traceability, and ethically sourced products have become major requirements of customers. It has led farmers to consider and explore technologies like blockchain. These farmers recognised the value of such technologies to enhance product traceability and provide consumers with detailed information about the origins of their products. One participant cited, *"Consumers want to know where their food comes from and that it's been produced sustainably. Blockchain can help us show that"* (NZPC03).

The farmers have identified this increased demand for transparency and traceability in the food supply chain as a strong incentive. It motivates farmers to adopt novel technologies, and they expect that could help them meet these new consumer expectations and maintain a competitive edge in the market.

**Sustainability**: Environmental sustainability was another significant motivator for farmers. Farmers want to comply with precise environmental regulations and reduce their environmental footprint. Hence, supply chain 4.0 technologies, such as

accurate farming tools like automated pivot irrigation systems and data analytics, allowed farmers to optimize their use of water, fertilizers, and feed. It helps to minimize waste and reduce their impact on the environment. As one farmer mentioned, *"The sensors give data and it helps us to use resources more wisely. We're using less water and fertilizer. It is better for the environment and saves us money in the long run"* (NZDF05).

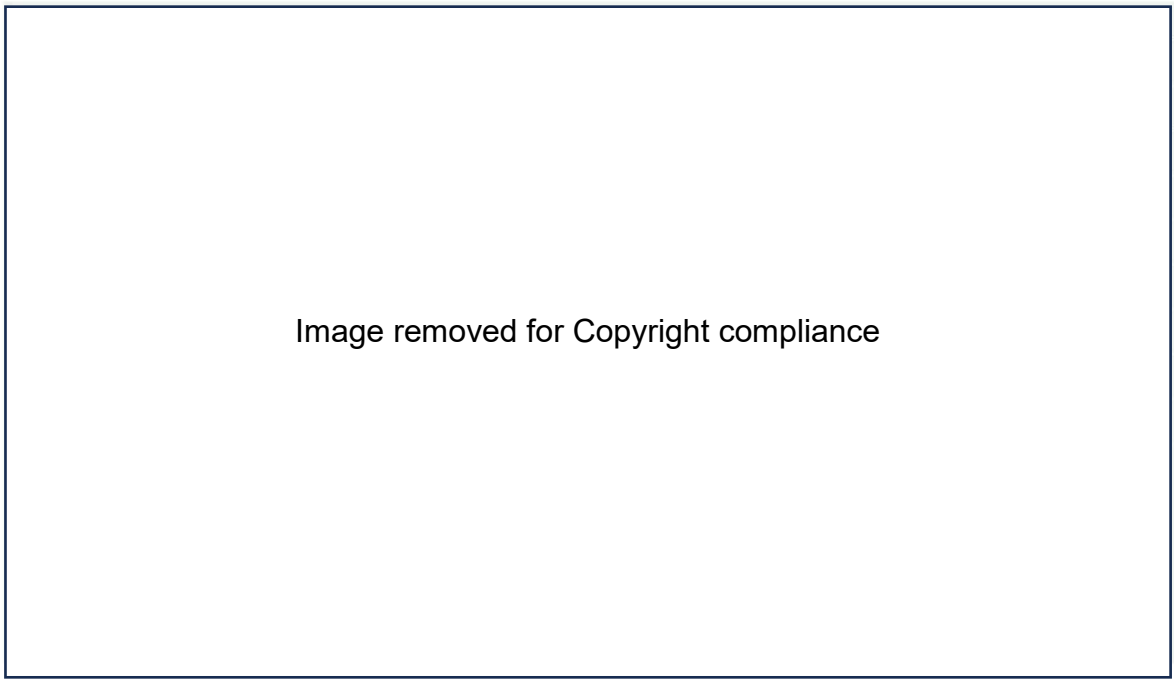


**Figure 4.6 The trend in the number of tuberculous dairy cattle since 2006/07**

Source: (DairyNZ, 2023)

**Improved Animal Welfare:** Continuously tracking health indicators and behaviour patterns of the herd help farmers to maintain better animal welfare in dairy farms. Advanced monitoring systems like AI-integrated cow collars and implanted chips help farmers to achieve this. Additionally, those focus on animal health leads to longer lifespans, reduced mortality rates, and higher overall herd productivity.

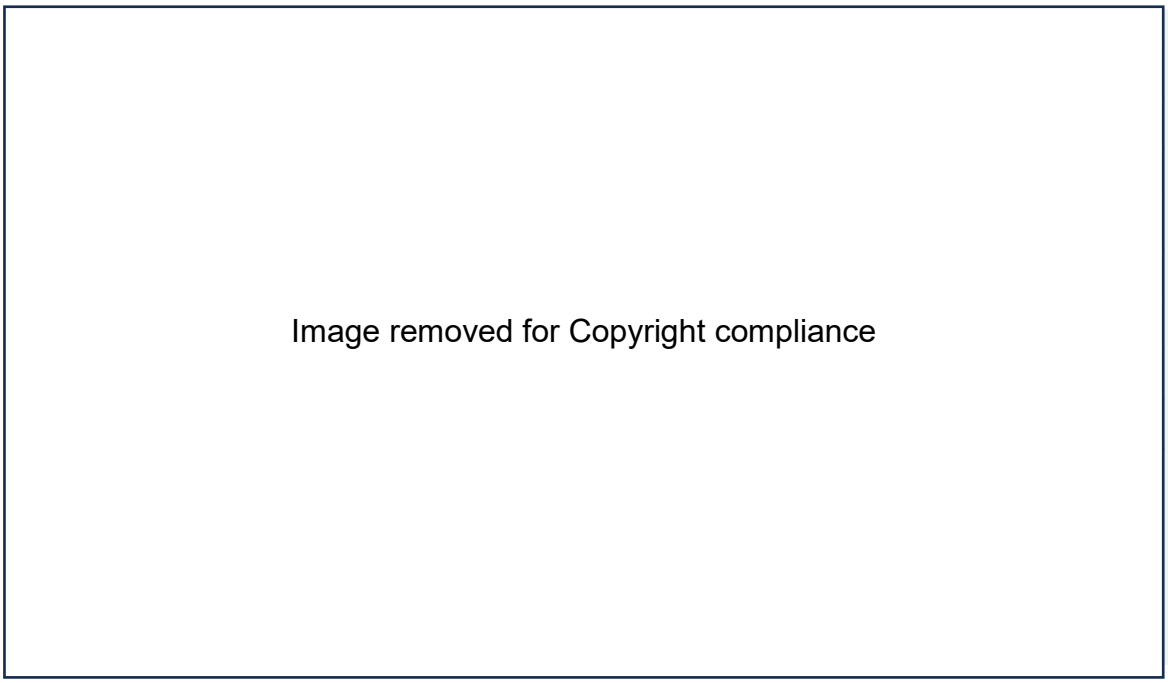


**Figure 4.7 Trend in the number of infected herds since 2006/07**

Source: (DairyNZ, 2023)

**Profitability**: Profitability was a common motivation among farmers. Farmers who had already adopted advanced technologies reported improvements in milk yield and cost savings. That translated into higher profitability. For example, one farmer explained, *"With the use of automated milking systems, we've seen an increase in milk production and a decrease in labour costs. It's been worth the investment"* (NZDF05).

However, the initial cost of implementation of these technologies has hindered the profitability through technology adoption. This will be discussed in the next section.

**Discussion**: Both operational and market factors have influenced in adoption of Supply Chain 4.0 technologies among dairy farmers. Efficiency gains and profitability can be identified as primary drivers for many farmers. Farmers consider the potential to reduce costs and increase productivity as powerful incentives. Furthermore, improved animal welfare, market demand for transparency, and the growing importance of sustainability play crucial roles in encouraging farmers to explore these new technologies.

The Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) states that performance expectancy influences adoption. Farmers saw measurable performance gains from automation and AI-driven monitoring systems, reinforcing their willingness to adopt. Research by Klerkx et al. (2010) supports this, showing that dairy farmers adopt technology primarily for productivity gains. Additionally, TAM's perceived usefulness (Davis, 1989) explains why farmers willing to invest in these technologies believed in their long-term benefits. One interviewee explained, *"Using automated milking reduced our workload significantly and gave us better data on milk quality"* (NZDF02). This finding is consistent with studies by Kamilaris et al. (2017), which highlight efficiency gains as a major driver of adoption in precision agriculture.

Beyond economic and operational benefits, external support and industry collaboration also play a vital role in accelerating the adoption of these technologies. Farmers who had access to cooperative support, government incentives, and training programs demonstrated a higher likelihood of integrating Supply Chain 4.0 innovations into their practices. Moreover, exposure to successful implementation cases within the industry serves as an influential factor, as farmers tend to trust and follow the experiences of their peers. This highlights the importance of continued investment in farmer education, policy-driven incentives, and industry partnerships to foster widespread technological adoption in the dairy sector.

### 4.3.3 Barriers to Adoption

While farmers benefited from adopting Supply Chain 4.0 technologies, farmers also experienced significant barriers that hindered their willingness to be involved in these innovations. Barriers included high initial investment costs, lack of technical expertise, infrastructure issues, and concerns over data privacy. Small and medium-sized farmers expressed greater difficulty in overcoming these challenges compared to larger operations.

**Cost**: The most frequently expressed barrier to adoption was the high cost of implementing new technologies. Smaller farms faced difficulties in arranging required capital investment for advanced systems like IoT sensors, blockchain integration, AI-integrated equipment, or automation equipment. One participant

explained, *"The cost is the biggest issue for us. We simply don't have the capital to invest in these expensive technologies, even though we can see the benefits"* (NZDF04).

Since the benefits of these technologies were not immediately clear, even larger farms with more financial resources hesitated to invest in such technologies. They expressed their concerns about the long-term return on investment

**Lack of Technical Expertise**: Older farmers were hesitant to adopt new technologies due to limited technical knowledge. Many of them were unfamiliar with digital systems and found them complex. They also worried about their ability to operate and maintain these technologies. One farmer said, *"We're not highly technical people. It's difficult to learn how to use these new systems. We worry about what will happen if something goes wrong"* (NZDF06).

A lack of training and technical support made farmers more reluctant. Some felt that they would struggle to troubleshoot problems or fully understand how the systems worked.

**Infrastructure Challenges:** Poor internet connectivity in rural areas posed a major challenge to adopting Supply Chain 4.0 technologies. Many of these systems, particularly IoT devices, required stable internet connections to function effectively. One farmer stated, *"We struggle with internet connectivity out here. The technology is great, but if the internet goes down, it's useless"* (NZDF06).

Farmers in remote areas emphasised the need for government and industry investment in rural broadband networks to enable broader technology adoption.

**Resistance to Change**: Resistance to change was another notable barrier. Some farmers were more comfortable with traditional farming practices. These farmers expressed uncertainty about the benefits of digital technologies. One participant stated, *"We've been doing things a certain way for years, and it's worked for us. I'm not convinced that all this new technology is really worth the hassle"* (NZDF07).

This resistance was often linked to a fear of the unknown and a reluctance to disrupt established routines. And they were not ready to change anything when the perceived benefits of the technology were not immediately visible.

**Data Privacy Issues:** Dairy Farmers in New Zealand are very keen on the ownership, privacy, and security of data. This discourages the adoption of novel technologies. They worried about how the data is used, who has access to it, and whether it might impact their business operations.

The primary concerns affecting Supply Chain 4.0 technology adoption in the New Zealand dairy industry based on the frequency of mentions and farmers' perceptions can be ranked and shown as follows:

**Table 4.1 Ranking of Farmers' Concerns in Technology Adoption**

| Rank | Concern | Description |
|---|---|---|
| 01 | High Cost of Implementation | This is the most cited barrier majority among small to medium-sized farms. The initial investment in novel technologies such as IoT, AI, Blockchain, and automation is a major concern. Even larger farms with greater financial resources remain cautious due to the uncertainty of long-term returns on investment. |
| 02 | Lack of Technical Expertise and Training | Many farmers struggle with the complexity of new technologies. Limited access to training programs and workshops further discourages adoption. This was highly seen in rural areas. |
| 03 | Infrastructure Challenges | Poor internet connectivity limits the use of IoT-based systems and AI-integrated equipment. It makes real-time monitoring difficult for farmers. |
| 04 | Data Privacy and Security | Farmers cowry about data ownership, security, and potential misuse of digital |

| | | |
|---|---|---|
| | | farming data. This is enhanced by the absence of clear regulatory protections. Without guarantees regarding data protection, many hesitate to adopt new technologies. |
| 05 | Resistance to Change and Preference for Traditional Methods | Some farmers are doubtful about the technology's benefits and prefer traditional farming methods that they have done for decades. These long-standing habits and successful past practices contribute to this resistance. |
| 06 | Regulatory and Policy Uncertainty | The lack of clear government policies regarding digital farming, data security, and financial incentives creates hesitation in adopting new technologies. Farmers seek better financial subsidies and regulations. |

Source: Developed by the Author

**Discussion**: The barriers to adopting Supply Chain 4.0 technologies were significant and varied across the sample. Initial cost and lack of technical expertise were the most commonly cited barriers. Then, infrastructure challenges, data privacy and resistance to change also played a role in limiting the uptake of these innovations. These findings suggest that overcoming these barriers will require targeted support, including financial assistance, technical training, and infrastructure development, particularly in rural areas where connectivity remains a major issue.

The Diffusion of Innovations (DOI) Theory (Rogers, 2003) suggests that financial constraints and complexity slow adoption among late adopters. Research by García et al. (2020) and Sundmaeker et al. (2010) confirms that cost remains the biggest constraint for small-scale farmers. The interviewed farmers reflected on these adoption patterns. Financially stable farms were the early adopters while others fell back due to financial and technical constraints. According to UTAUT (Venkatesh et al., 2003), farmers are less likely to adopt a technology if they find it too complex or difficult to learn. Many farmers hesitate because they do not receive enough training

or technical help. This shows that ease of use and external support are important for adoption. One respondent stated, *“The technology is great, but the upfront costs are just too high for us to justify, and we need better training and technical assistance to be familiar with these new technologies”* (NZDF02). Similarly, Eastwood, Klerkx, et al. (2019) found that while large dairy farms in New Zealand rapidly integrate Supply Chain 4.0, smaller farms struggle due to financial barriers and lack of training.

Beyond individual and financial constraints, government and policy and regulations also influence technology adoption. A lack of clear regulatory guidelines and financial incentives has created uncertainty among farmers, particularly regarding data privacy and long-term investment security. Many farmers expressed concerns about the absence of well-defined policies governing data ownership and usage. That discourages them from adopting blockchain and cloud-based solutions. Furthermore, limited government subsidies and financial aid programs for technology adoption were seen as barriers preventing smaller farms from keeping pace with industry advancements. Strengthening policy frameworks, increasing financial incentives, and implementing structured digital literacy programs could play a critical role in bridging this gap and fostering wider adoption of Supply Chain 4.0 technologies across all farm sizes.

### 4.3.4 Impact on Farm Operations

Despite the barriers to adoption, farmers who adopted Supply Chain 4.0 technologies gained positive impacts on their farm productivity, efficiency, profitability, sustainability, and traceability.

**Increased Productivity**: The adoption of automation and IoT technologies led to measurable improvements in farm productivity. Farmers who had implemented automated milking systems, reported increased milk yields and a reduction in labour costs. One participant shared, *"We’ve seen a 10% increase in milk production since we started using automated systems. It’s made a huge difference"* (NZDF02).

Monitoring livestock health and milk production in real-time helped farmers to address issues before they become major problems. It helps them to improve the productivity.


**Figure 4.8 Growth of Milk solids production per cow and per effective hectare**

Source: (DairyNZ, 2023)

**Improved Profitability**: Many farmers experienced increased profitability as a result of cost saving from reduced labour and improved milk yields. One participant stated, *"We're seeing a return on our investment through higher yields and lower costs. The technology has definitely paid off"* (NZDF05).

Digital technologies helped farmers to optimize farm operations and reduce waste. It also facilitates to use resources efficiently and achieve greater profitability.

**Sustainability Improvements:** Those farmers who used data analytics and precision farming tools could reduce their environmental footprint. It led them to achieve improved sustainability of their operations. One farmer reported that the use of IoT sensors had helped them optimize their use of water and fertilizers. One participant expressed *"We're using less water and fertilizer, which is great for the environment and saves us money in the long run"* (NZDF05)**.**

Farmers achieved sustainability improvements while complying with environmental regulations and meet the growing consumer demand for sustainable products.

**Traceability Enhancements**: Adopting blockchain technology has helped farmers to enhance the product traceability. It was a significant benefit that allows farmers

to track their products through the entire supply chain. It also provides consumers real-time information about the origin and quality of their products. One participant stated, *"Blockchain gives us the ability to prove that our products are clean and sustainable. That's becoming more and more important to consumers"* (NZDF08)

Enhanced traceability allowed farmers to differentiate their products in the market and build consumer trust.

**Discussion:** The impact of Supply Chain 4.0 technologies on farm operations was positive for those who had adopted them. Farmers who adopted Supply Chain 4.0 technologies experienced substantial operational benefits, including increased productivity, improved profitability, enhanced sustainability, and greater traceability. These findings suggest that despite initial adoption challenges, the long-term rewards of digital integration are significant.

Furthermore, the adoption of Supply Chain 4.0 technologies has strengthened farmers' ability to meet regulatory and consumer demands. Digital solutions such as blockchain and IoT sensors have provided valuable tools for data collection and reporting. That helps farmers to cope with increasing pressure to comply with environmental and quality standards. Farmers who adopted these technologies found it easier to demonstrate compliance with sustainability requirements. Improving their relationships with regulators and buyers helps them to align with global market expectations.

The Technology Acceptance Model (TAM) (Davis, 1989) again applies here, as farmers noted improved efficiency and usability as key factors in adoption decisions. TAM explains that continued use depends on perceived benefits. It also suggests that when farmers experience positive impacts from technology, their likelihood of continued adoption increases (Davis, 1989). Those who saw tangible improvements in resource optimization and herd management were more inclined to expand their use of digital tools. Studies by Kamath (2018) and Tian (2017) confirm that blockchain and IoT technologies improve efficiency and transparency. A farmer reported, *"Since implementing real-time tracking, we've reduced milk spoilage by nearly 20%"* (NZDF05). This aligns with findings by Crick et al. (2020), who documented similar improvements in operational efficiency through digital farming

solutions. Additionally, DOI's observability explains why farmers who witnessed the benefits of early adopters were more likely to consider adoption themselves. Stakeholder Theory (Freeman, 1984) also applies, as farmers collaborating with cooperatives and processing companies received more structured support, ensuring smoother integration of new technologies.

## 4.4 Thematic Analysis of Other Stakeholders (Processing Companies, Cooperatives, Technology Providers)

### 4.4.1 Collaboration with Dairy Farmers

Collaboration between processing companies and dairy farmers was crucial to facilitating the Supply Chain 4.0 technology adoption. Processing companies and cooperatives played a vital role in facilitating technology adoption by offering financial assistance, training, and infrastructure support. One of the key themes was derived from the role of processing companies in supporting dairy farmers from the interviews.

**Financial Support**: Processing companies and cooperatives provided financial support to help farmers offset the cost of adopting new technologies. This support came in the form of grants, subsidies, and low-interest loans. That helped farmers to invest in advanced technologies. One cooperative representative explained, *"We understand that cost is a major barrier for farmers. So, we offer financial incentives to help them adopt these technologies"* (NZPC05).

Small farms require financial support due to the upfront costs of new technologies. Therefore, it was essential support for them to adopt these technologies.

**Training and Education**: In addition to financial support, cooperatives, and technology providers offered training and education to farmers. It helped farmers to develop the technical skills needed to operate and maintain Supply Chain 4.0 technologies. Many farmers found these programs invaluable in understanding how to integrate news systems effectively. One farmer noted, *"The training we received from our cooperative made all the difference. Without it, we wouldn't know where to start"* (NZDF02).

These training programs including workshops, webinars, and on-farm demonstrations, were widely used to improve confidence in adopting digital solutions.

**Technology Facilitation**: Technology providers worked closely with farmers to customize solutions to their specific needs. They also offered ongoing technical assistance and 24/7 support. Many farmers appreciated this approach, and they considered it as a crucial factor to succeed the technology adoption. One participant mentioned*, "Our technology provider has been incredibly supportive. They've helped us set up the systems and are always available if we have questions or need help"* (NZDF06).

Collaboration between farmers and technology providers ensured a smoother transition to digital farming from traditional practices.

**Discussion:** Collaboration between dairy farmers and industry stakeholders was a key enabler of Supply Chain 4.0 adoption. Financial support, training, and technology facilitation played crucial roles in overcoming barriers to adoption and maximizing the benefits of these technologies. These findings underscore the importance of strong partnerships between farmers, cooperatives, processing companies, and technology providers in driving the digital transformation of the dairy industry.

Stakeholder Theory (Freeman, 1984) underscores the importance of aligning interests among all participants. In this study, stakeholders such as cooperatives and technology providers influenced farmers' decisions by offering technical assistance and incentives. Studies by Eastwood, Grant, et al. (2019) and Siems et al. (2023) confirm that cooperatives accelerate technology integration. One cooperative representative stated, *"We provide subsidies and workshops so farmers can integrate new technologies without overwhelming costs"* (NZPC03). This is consistent with research by (Kanda et al. (2019), which emphasises the importance of industry partnerships in scaling digital transformation.

As Rogers' Diffusion of Innovation (DOI) theory suggests, social influence and trusted networks are key to widespread adoption (Rogers, 2003). Farmers who observed successful implementations by their peers were more inclined to invest in

similar technologies. Additionally, the ongoing engagement of stakeholders through continuous updates, troubleshooting, and feedback mechanisms boosted confidence and encouraged sustained adoption. This highlights the need for industry stakeholders to maintain active involvement beyond initial implementation to ensure long-term success in digital transformation efforts.

### 4.4.2 Challenges and Opportunities for Scaling Supply Chain 4.0

The expansion of Supply Chain 4.0 technologies in the dairy industry presents both challenges and opportunities for stakeholders. While large-scale dairy farms embraced digital transformation, smaller farms struggled due to financial and technical barriers. However, government subsidies and industry-led initiatives offered potential solutions.

**Scalability**: One of the primary challenges identified by stakeholders was the scalability of Supply Chain 4.0 technologies. Larger farms with more financial resources could adopt these technologies more easily. Smaller farms faced significant challenges and difficulties in adopting these innovations. One processing company representative stated, *"Scaling these technologies across the entire industry is difficult because smaller farms don't have the same resources as larger operations. We need to find ways to make these technologies more accessible"* (NZPC01).

The cost of implementation was a significant factor affecting scalability. It made the situation hard for smaller farms to adopt these innovations.

**Policy Support**: Stakeholders emphasised the need for stronger government policy support to encourage the adoption of Supply Chain 4.0 technologies. This support could include subsidies, grants, and infrastructure development. Improving rural broadband access can be identified as one of the most important infrastructure support. One participant explained, *"The government needs to step in and provide more support if we want to see widespread adoption of these technologies. Without policy support, it will be hard for smaller farms to keep up"* (NZPC05).

Government policies were viewed as essential in facilitating digital transformation. It is crucial for farmers who require financial assistance to manage the initial implementation costs.

**Regulatory Barriers**: Concerns about data privacy and security were remarkable barriers to adoption. Due to the confidential nature in the dairy industry, stakeholders are considering this before implementing any of the new technologies. One technology provider stated, *"Farmers are worried about who owns the data and how it will be used. We need clear regulations to address these concerns and build trust"* (NZDF03).

Farmers expected reassurance on their data and a transparent regulatory framework. That would be the solution to enable wider adoption of digital technologies.

**Technological Innovation**: Despite these challenges, stakeholders also identified numerous opportunities for innovation in the dairy industry. Advances in AI, IoT, blockchain, and data analytics were seen as key drivers of growth. They are essential with the updated market trends for traceability. One cooperative representative explained*, "The potential for innovation in this space is huge. If we can overcome the barriers, the sky's the limit for what these technologies can do for the industry"* (NZPC03).

Stakeholders remained optimistic and believed that continued investment in innovation would lead to improvements in efficiency, sustainability, and profitability across the dairy supply chain.

**Discussion:** The scaling of Supply Chain 4.0 technologies presents both challenges and opportunities. While issues such as scalability, policy support, and regulatory barriers pose obstacles, stakeholders remain hopeful about technological advancements driving future growth. A coordinated approach involving government, industry stakeholders, and technology providers is essential to overcoming these challenges and unlocking the full potential of Supply Chain 4.0 in the dairy sector.

UTAUT's facilitating conditions highlight that the availability of financial and technical support enhances adoption (Venkatesh et al., 2003). Stakeholders' role in reducing

these barriers is essential for wider implementation of Supply Chain 4.0 technologies. Research by Ivanov, Dolgui, et al. (2019 a) and Saberi et al. (2019) confirms that targeted policy interventions help small farmers integrate technology. One farmer noted, *"Government incentives made it possible for us to try AI-based feeding systems without taking a huge financial risk"* (NZDF08). These findings align with Sundmaeker et al. (2010), who advocate for stronger policy support in digital agriculture. Additionally, UTAUT's facilitating conditions suggest that when external infrastructure and financial support are provided, adoption rates increase. Farmers who received assistance from cooperatives and processing companies reported smoother transitions into digital farming.

Beyond financial and policy considerations, the success of scaling Supply Chain 4.0 technologies also depends on farmers' digital readiness and adaptability. Interviews revealed that while some farmers were enthusiastic about digital transformation, others were hesitant due to concerns about complexity, lack of digital skills, and the perceived disruption to traditional farming practices. This aligns with (Eastwood, Bines, et al., (2019) who found that digital literacy plays a critical role in determining the success of agricultural technology adoption. Therefore, fostering a digital culture through ongoing education, peer support networks, and user-friendly technological solutions is essential. Ensuring that farmers feel confident and capable in using new systems will enhance technology uptake and long-term sustainability in the dairy industry.

## 4.5 Cross-Theme Analysis and Key Insights

The thematic analysis of dairy farmers' responses and the perspectives of processing company representatives has revealed a complex and interconnected landscape surrounding the adoption of Supply Chain 4.0 technologies in New Zealand's dairy industry. This cross-theme analysis discusses the patterns that emerged from the data, emphasizing how motivations, barriers, and stakeholder collaboration collectively interact to either drive or hinder the adoption of these technologies.

### 4.5.1 Interplay of Motivations and Barriers

The thematic analysis highlights a complex dynamic between the factors encouraging the adoption of Supply Chain 4.0 technologies and the obstacles that hinder their widespread implementation among dairy farmers. While various incentives drive interest in these technologies, continued challenges often limit full adoption.

Efficiency improvements, sustainability objectives, and profitability expectations emerged as key **motivators**. Farmers who recognise the operational advantages in these technologies are persuaded to integrate them into their processes to enhance productivity and cost-effectiveness. Additionally, market expectations for sustainable and transparent food production further encourage interest in these innovations. However, However, **barriers** such as high initial investment requirements, limited technical expertise, lack of training, and infrastructure limitations frequently limit the extent of adoption

For instance, the aspiration to **enhance efficiency** is often offset by the financial burden associated with deploying tools such as IoT sensors, artificial intelligence applications, and automated milking systems. Although automation can reduce labour demands and streamline operations, smaller farms, in particular, find it difficult to justify the substantial expenditure. Even for larger farms with the financial capacity to invest, uncertainties regarding **long-term financial returns** contribute to cautious decision-making, especially when immediate benefits are not easily measurable. Consequently, many farmers prefer to continue with conventional dairy practices that have consistently yielded stable profit margins.

**Sustainability goals** also serve as a strong incentive, with many farmers aiming to optimize resource utilization and minimize environmental impact. However, **limited technical proficiency** often poses a barrier to adopting advanced farming tools and data-driven decision-making platforms. Farmers **lacking adequate training** or access to **technical support** tend to be reluctant to invest in technologies they are not fully familiar with, fearing difficulties in effective integration within their existing operations.

This pattern highlighted the importance of addressing the **barriers** to adoption if the **motivations** for using Supply Chain 4.0 technologies are to be fully realized. Without strategic measures and targeted interventions to reduce costs, enhance training opportunities, and improve infrastructure support, the adoption of these technologies will likely remain limited to larger, more resource-rich farms. Smaller farms may struggle to adopt these technologies. As a result, they may be left behind.

The study found a strong correlation between perceived benefits (efficiency, sustainability) and willingness to adopt, reinforcing TAM's perceived usefulness and UTAUT's performance expectancy models. Research by Kamilaris et al. (2017) and Wolfert et al. (2017) supports this, showing that financial and technical challenges often slow down diffusion. However, financial and technical challenges created resistance, aligning with DOI's (Rogers, 2003) innovation adoption categories, where late adopters often require more incentives and proof before investing in new technology.

### 4.5.2 The Role of Stakeholder Collaboration in Overcoming Barriers

Processing companies, cooperatives, and technology providers facilitated adoption, supporting Stakeholder Theory (Freeman, 1984) how aligned incentives contribute to successful implementation. The analysis highlighted the importance of **stakeholder collaboration** in addressing challenges faced by dairy farmers. Processing companies, cooperatives, and technology providers offer **financial support**, **training**, and **technology facilitation** and play a crucial role in adopting Supply Chain 4.0 technologies.

For instance, cooperatives and processing companies provided **financial support** in the form of subsidies, grants, and low-interest loans. It helped to offset the high costs associated with adopting new technologies faced by dairy farmers. This support was particularly valuable for smaller farms to cover the initial investment. Similarly, **training programs** offered by cooperatives and technology providers helped farmers to bridge the gap in **technical knowledge.** These stakeholders help farmers to build their confidence by providing hands-on training and ongoing technical support to use novel technologies effectively.

**Collaboration between farmers and technology providers** also ensures that new systems are tailored to meet the specific needs of individual farms. Many farmers work closely with technology providers to customize IoT solutions and automated equipment to fit their operational requirements. This cooperation not only facilitates adoption but also raises trust, which is essential for sustained technological integration.

However, while **stakeholder collaboration** addresses many challenges, it is not always sufficient to overcome **infrastructure-related barriers**. Many farmers cite unreliable internet connectivity in rural areas as a significant limitation in utilizing IoT devices and digital tools effectively. While technology providers can offer technical support, resolving broader infrastructure issues requires government intervention and investment.

This suggests that **stakeholder collaboration** is a powerful tool for driving adoption. But it must be complemented by **broader policy support** and infrastructure development to address the systemic challenges that farmers face. Without a coordinated effort that includes government, industry, and technology stakeholders, the benefits of Supply Chain 4.0 technologies will remain unevenly distributed across the dairy industry. By offering tailored solutions and direct engagement with farmers, these stakeholders bridged the gap between innovation and real-world application. Research by Eastwood, Grant, et al. (2019) confirms that well-structured collaborations lead to higher adoption rates.

### 4.5.3 The Impact of Farm Size and Resources on Adoption Patterns

Another significant pattern that emerged from the analysis is the **impact of farm size and resources** on the adoption of Supply Chain 4.0 technologies. Larger farms with more financial resources and access to technical expertise were more likely to implement these technologies. Meantime, smaller farms faced greater challenges.

**Larger farms** had the financial capacity to absorb the initial costs of implementation. They invested in advanced technologies such as automation systems, AI-integrated appliances, IoT sensors, and data analytics platforms. They could also afford to take risks on new technologies. Additionally, larger farms have better access to training programs and technical support, making adoption smoother.

In contrast, **smaller farms** struggle with high costs and often lack the technical knowledge needed for implementation. Many continue using traditional farming methods because they worry about costs, complexity, and disruptions to their current practices. One farmer noted, "We can't afford to take risks on expensive technology that we might not even be able to use properly."

This trend suggests that technology adoption could widen the gap between large and small farms. Larger farms benefit from digital advancements, while smaller farms risk falling behind. To address this issue, targeted support is necessary. This could include **financial assistance, simplified technology solutions**, and **accessible training programs** designed for smaller farms.

### 4.5.4 The Role of Processing Companies in Advancing Supply Chain 4.0 Technologies

Processing companies play a key role in adopting Supply Chain 4.0 technologies because these tools improve efficiency, product quality, and market competitiveness. Digital solutions such as IoT sensors, blockchain, and AI-driven analytics help them to streamline milk collection, ensure real-time monitoring of supply chain activities, and enhance traceability. Furthermore, these technologies reduce delays, cut waste, and optimize logistics. As a result, processing companies can meet consumer and regulatory demands for greater transparency and sustainability. Stakeholder Theory suggests that this collaboration strengthens the overall dairy supply chain ecosystem (Freeman, 1984).

Processing companies also benefit from better quality milk when farmers use advanced technologies. Automation and data insights help farmers manage their herds more effectively, leading to higher milk yields and fewer contamination risks. Real-time monitoring of cow health through AI-integrated devices further improves overall animal well-being, resulting in healthier cows, higher milk production, and better-quality milk. This improves product consistency, strengthens brand reputation, and ensures compliance with international food safety standards. To encourage farmers to adopt these technologies, processing companies provide financial support, training, and technical assistance. A more technologically advanced group of farmers strengthens the entire dairy supply chain, making it more efficient and competitive.

### 4.5.5 The Role of Government and Policy Support

Regulatory bodies influenced technology adoption through incentives and compliance requirements, aligning with UTAUT's facilitating conditions as external support mechanisms that drive technological acceptance (Venkatesh et al., 2003). The role of **government and policy support** identified as an essential factor in driving the adoption of Supply Chain 4.0 technologies. Government policies and support are important for adopting Supply Chain 4.0 technologies. Many stakeholders said stronger policies are needed to solve key problems in the dairy industry, especially for infrastructure and regulations

Besides infrastructure, farmers and industry representatives stressed the need for financial help, such as subsidies and grants, to reduce the high costs of new technology. They also saw government-funded training programs and technical support as necessary to help farmers gain the skills to use these technologies effectively

**Regulations** were another key issue. It needed government intervention. The use of IoT devices, blockchain, and data analytics raised concerns about data privacy and security. If these concerns are not addressed, they may slow down the adoption. Farmers and other stakeholders called for the government to create clear policies that protect data and privacy. It also needed to ensure the promoting of innovations and the sharing benefits of these technologies.

This pattern highlights the importance of **government action** in creating an enabling suitable environment for the adoption of Supply Chain 4.0 technologies. The government can play a critical role in accelerating the digital transformation of the dairy industry. Investment in infrastructure, financial support, and proper regulations will help drive digital progress in the dairy industry.

### 4.5.6 Opportunities for Future Growth and Innovation

Despite the challenges identified in the thematic analysis, there are significant **opportunities for future growth and innovation** in Supply Chain 4.0 adoption. Stakeholders were positive about the potential of these technologies to develop the dairy industry by improving efficiency, sustainability, and transparency.

**Technological innovation** in areas such as IoT, AI, blockchain, automation, and data analytics is expected to keep advancing. These offer new solutions to key challenges faced by farmers. For example, better AI, IoT sensor technology, and data analytics could improve livestock health and environmental tracking. It leads to further gains in productivity and sustainability. Similarly, the continued development of blockchain technology could enhance traceability and transparency in the supply chain. That resulted in meeting the growing demand for ethically sourced and sustainable products.

Advanced technology has also created opportunities in **export markets**. Improved traceability and product quality make it easier to enter new markets for New Zealand dairy products. Meeting global standards for transparency and sustainability can help position New Zealand as a leader in ethical dairy production.

**Collaboration among stakeholders** is crucial for achieving these benefits. Processing companies, cooperatives, technology providers, and government agencies must work together to drive innovation. By fostering teamwork and continuous improvement, they can help farmers overcome challenges and make the most of Supply Chain 4.0 technologies.

### 4.5.7 Key Insights and Implications

The cross-theme analysis highlights several key insights and implications for Supply Chain 4.0 technologies adoption in New Zealand's dairy industry:

- **Motivations and Barriers:** Adoption incentives are often balanced by major challenges. A coordinated approach is needed, including financial support, technical training, and infrastructure development. Financial aid is especially important for small and medium-sized farms to manage high initial costs. Subsidies, grants, and low-interest loans can help. Regular technical training reduces knowledge gaps, while strong infrastructure ensures smooth technology use.
- **Stakeholder collaboration:** Cooperation among farmers, processors, and technology providers is essential. It helps manage costs, technical expertise, and farm-specific needs. However, collaboration alone cannot fix larger issues like infrastructure gaps, which require government action.

- **Farm size and resources:** These factors play a vital role in determining the likelihood of adoption. Larger farms have more capacity to adopt Supply Chain 4.0 technologies. Small farms need targeted support to avoid being left behind in the digital transformation of dairy industry.
- **Government Policy and Regulations:** Policy support is key to tackling the challenges faced dairy industry such as infrastructure development, financial assistance, and data privacy concerns. This included subsidies for technology purchases, funding for research and development, and investment in rural infrastructure. Joint research efforts between government, universities, and technology providers can drive ongoing innovations.
- **Future growth and Innovation:** This industry has strong potential in IoT, AI, blockchain, automation, and data analytics. Continued investment in these technologies and strong collaboration among stakeholders can improve efficiency, sustainability, and transparency.

These insights outline a roadmap for the future of Supply Chain 4.0 adoption in New Zealand's dairy sector. A well-planned, collaborative approach can address both challenges and opportunities in digital transformation.

## 4.6 Comparison of Early and Late Adopters in the Supply Chain 4.0 Technologies

There is a clear distinction between early and late adopters of Supply Chain technologies. In the past, they started with automation tools like pivot irrigation, automatic cup removal in milking, and basic IoT sensors to monitor cows and milk production. Over time, as technology improved, even late adopters began using more advanced versions, such as mobile app-controlled irrigation and better sensor systems. Recently, early adopters have moved toward even more high-tech solutions like AI-powered cow collars, implanted chips for health tracking, and blockchain for supply chain transparency. These are still too expensive or complex for many late adopters, but they are slowly starting to use simpler digital tools like basic IoT sensors, automation systems, and data analytics. As more farmers see the benefits of these technologies, adoption is increasing across the industry. However, late adopters still need financial and technical support to catch up with the early adopters.

Dairy farmers who were open to trying innovations in the past often run larger operations. They have better financial resources and are more comfortable with technology. The main reasons for adopting such technologies were to improve efficiency, increase sustainability, boost profits, and meet market demands for improved quality and traceability. However, even though they are willing to invest in Supply Chain 4.0 technologies, they still face challenges. The main challenge is the difficulty of integrating them into their existing processes. Despite this, early adopters usually have financial resources and strong industry connections. That helps them manage these challenges.

On the other hand, late adopters are more cautious about using digital technologies. They are often reluctant to adopt novel technologies due to their financial limitations and lack of technical knowledge. Furthermore, they face uncertainty about the real benefits of these technologies. These farmers typically operate on a small scale and have concerns about cost and technical proficiency. While they see the potential of digital solutions, they are not always in a position to invest. While early adopters actively seek innovations, late adopters wait until they see proven success among other farmers before making changes. They rely on word-of-mouth and real-life examples before committing to new technologies.

Support from industry stakeholders plays a big role in the adoption for both groups. Early adopters benefit from strong networks, including cooperatives, processing companies, and government agencies that offer financial aid and technical advice. Late adopters, however, need more direct support, such as government subsidies, hands-on training, and simpler technology solutions to help them transition. If these barriers aren’t addressed, the gap between early and late adopters will continue to grow, slowing down the overall adoption of digital farming tools.

In conclusion, the gap between early and late adopters is mainly about resources and willingness to take risks. Early adopters move first, demonstrating how new technology can help. Late adopters are more cautious and need extra support and reassurance before they decide to change. Providing them with education, financial help, and better infrastructure will make it easier for all dairy farmers, no matter their size, to benefit from Supply Chain 4.0 technologies.

## 4.7 Stakeholder Roles in the Adoption of Supply Chain 4.0 Technologies in the New Zealand Dairy Industry

The adoption of Supply Chain 4.0 technologies in the New Zealand dairy industry is driven by multiple stakeholders. Dairy farmers, processing companies, cooperatives, technology providers, and government bodies all play significant roles. However, the main drivers vary depending on the context, financial capability, and technological infrastructure available.

**Dairy Farmers Leading the Way:** Dairy farmers are at the heart of technology adoption since they are directly responsible for implementing new tools in farm operations. Their willingness to adopt digital solutions such as IoT sensors, blockchain, and AI-integrated monitoring systems depends on factors like cost, perceived benefits, and access to training. Some progressive farmers take an active role in driving adoption by experimenting with new technologies and sharing their experiences with others.

**Processing Companies and Cooperatives as Facilitators:** Processing companies and cooperatives play a significant role in encouraging farmers to adopt new technologies. They often offer financial support, training programs, and technical assistance. Many processing companies provide grants or subsidies to help farmers cover the initial costs of digital tools. Additionally, cooperatives organise workshops and on-farm demonstrations to educate farmers on how these technologies work and how they can improve efficiency.

**Technology Providers Driving Innovation:** Technology providers develop customized digital solutions for dairy farming. They work closely with farmers to introduce IoT, AI, and blockchain tools into daily operations. Farmers often depend on these companies for ongoing technical support, making their role essential in the adoption process.

**Government's Role in Policy and Infrastructure Support:** Government agencies contribute to technology adoption by offering subsidies, tax incentives, and funding programs that help reduce financial barriers for farmers. They play a role in regulating data privacy ensuring digital solutions align with industry standards. They also provide infrastructure such as rural broadband connectivity to support digital transformation.

**Conclusion**

While processing companies and cooperatives offer financial and educational support, dairy farmers are the ones who ultimately decide whether to adopt new technologies. Their decisions, influenced by available resources, training, and infrastructure, shape the pace of digital transformation in the dairy industry. Collaboration among these stakeholders is crucial to ensure that Supply Chain 4.0 technologies are widely adopted and effectively implemented.

## 4.8 Conclusion

This chapter established strong theoretical connections between findings and established models. The use of TAM, DOI, UTAUT, and Stakeholder Theory provided a structured framework to analyse the motivations, barriers, and stakeholder influence in Supply Chain 4.0 adoption. The findings indicate that successful adoption depends on a combination of **perceived benefits, external support, and collaborative efforts among key stakeholders**.

The thematic analysis presented in this chapter has highlighted several key findings regarding the adoption of Supply Chain 4.0 technologies in New Zealand's dairy industry. The study identified a range of factors influencing motivations, barriers, and impacts associated with these advanced technologies. It also identifies the critical role of collaboration between dairy farmers, processing companies, cooperatives, and technology providers.

By integrating direct interview quotes and comparisons with existing literature, the study ensures methodological accuracy and empirical depth.

**Key Findings**:

- **Understanding and Awareness**: Dairy farmers' awareness of Supply Chain 4.0 technologies varied widely, with larger, more resource-rich farms showing higher levels of knowledge about IoT, AI, blockchain, and automation. Smaller farms, with limited exposure to technological innovations, displayed a lower awareness and more uncertainty about the benefits of these technologies.

- **Motivations for Adoption**: Efficiency gains, sustainability improvements, market demand for transparency, and profitability were the primary drivers for adopting Supply Chain 4.0 technologies. These motivations were strong among farmers who recognised the operational benefits of automation and real-time data collection.
- **Barriers to Adoption**: The most significant barriers included the high cost of implementation, lack of technical expertise, infrastructure challenges, data privacy, and resistance to change. These barriers were most observed among smaller farms. They struggled to justify the financial and technical investment required for these technologies.
- **Stakeholder Collaboration**: Collaboration between farmers and processing companies, cooperatives, technology providers were crucial in overcoming barriers to adoption. Financial support, training, and technology facilitation were key forms of assistance. That leads farmers to integrate Supply Chain 4.0 technologies into their operations.
- **Impact on Farm Operations**: Farmers who adopted Supply Chain 4.0 technologies experienced significant benefits, including increased productivity, improved profitability, enhanced sustainability, and better traceability. These technologies helped farmers to optimize their operations and meet the growing consumer expectations and transparency.

**Relation to Research Questions and Objectives**: The findings from the thematic analysis directly address the study's research questions and objectives. The research sought to explore the role of dairy farmers in driving the adoption of Supply Chain 4.0 technologies, as well as the factors that facilitate or hinder this process. The analysis revealed that while motivations for adoption are strong, particularly in relation to operational efficiency and market demand, significant barriers remain, particularly for smaller farms. Collaboration between stakeholders emerged as a critical factor in overcoming these barriers, emphasizing the importance of targeted support and policy intervention.

The study successfully met its objectives by:

- Assessing farmers' awareness of Supply Chain 4.0 technologies,
- Identifying key drivers and barriers to adoption, and

- Evaluating the role of stakeholders in facilitating digital transformation.

**Transition to Next Chapter:** The next chapter builds on these findings by presenting **conclusions and recommendations** for accelerating the adoption of Supply Chain 4.0 technologies in the dairy industry. It will propose practical solutions for overcoming identified barriers, strategies for enhancing stakeholder collaboration, and policy recommendations to support the digital transformation of New Zealand's dairy sector. Additionally, directions for future research will be outlined, along with broader implications for the global dairy industry.

# Chapter 5

# Conclusion and Recommendations

## 5.1 Chapter Overview

Chapter 5 provides a comprehensive conclusion to the study on the role of dairy farmers in driving the adoption of Supply Chain 4.0 within New Zealand's dairy industry. This chapter produces the key findings from previous chapters. It also offers a concise summary of how the integration of digital technologies, such as IoT, AI, big data analytics, and blockchain, has impacted the dairy supply chain. It focuses on the influence of dairy farmers as central agents of adoption. Further, it addresses the challenges they face and the collaborative dynamics among stakeholders that support or hinder technological advancement.

The chapter also delivers strategic recommendations to enhance the dairy sector's efficiency, sustainability, and competitiveness. These recommendations are directed toward policymakers, industry stakeholders, and technology providers. It emphasises the importance of financial support, targeted training, and strengthened partnerships to facilitate broader and more sustainable adoption of Supply Chain 4.0 technologies. Additionally, this chapter identifies research limitations and suggests future research directions that could further explore the long-term impact of digital transformation in dairy farming. Through these insights, Chapter 5 aims to provide actionable guidance to stakeholders while contributing to the broader communication on digitalization in agriculture.

## 5.2 Key Findings Summary

### 5.2.1 Adoption Levels of Supply Chain 4.0

The adoption of Supply Chain 4.0 technologies in the New Zealand dairy industry has shown promising developments. Internet of Things (IoT) sensors, AI-integrated equipment, automated milking systems, big data analytics, and blockchain technology are the key technologies among those technologies. These digital tools play a crucial role in improving operational efficiency. They also enhance product quality and ensure better traceability within the supply chain.

**IoT sensors** have enabled real-time monitoring of livestock health, milk production, and environmental conditions on farms. Farmers have found IoT devices particularly valuable for optimizing feeding practices, tracking cow health, and managing water and energy use. Overall, it improves overall productivity and sustainability. However, larger farms adopt IoT more effectively due to greater financial resources and better access to technical support. In contrast, smaller farms face challenges, including high initial costs and limited technical expertise. That has caused barriers to the full integration of IoT solutions.

**Big data analytics** have also gained a grip in the New Zealand dairy industry, particularly among cooperatives, processing companies, and large-scale farms that use advanced analytics for decision-making. Empirical research shows that those utilizing big data analytics experience significant improvement in demand forecasting, inventory management, and product quality control. For instance, the study found that predictive analytics could optimize milk production by analysing weather patterns, cow health metrics, and supply chain fluctuations. Additionally, cooperatives have increasingly leveraged data analytics for optimizing logistics, reducing wastage, and ensuring traceability, further driving its adoption.

**Blockchain** is in its growing stage in the New Zealand dairy industry. It provides immutable records of transactions and processes across the supply chain. This was evident from interviews with dairy processing companies' representatives who emphasised blockchain's role in ensuring transparency. For example, processors use blockchain to track milk quality from farm to final product, reducing fraud risks. That was the key factor to enhance transparency and trust. This technology is instrumental in verifying product authenticity and building consumer trust. It is important, especially in international markets where traceability and product origin are significant concerns.

**AI-Integrated Cow Collars** assist farmers in managing livestock effectively. They provide real-time tracking of animal health, behavior, and movement. Data from farmer interviews revealed that these collars help detect movement patterns and early signs of illness, improving herd management and overall animal welfare. Additionally, the early detection of diseases through AI-driven monitoring has helped

farmers to reduce veterinary costs. Farmers also reported that AI-generated alerts allowed them to take prompt action, minimizing health-related losses in their herds.

**Automated Milking Systems** allow cows to be milked by machines instead of people. Farmers interviewed explained that cows can enter these systems voluntarily, reducing labor dependency. Sensor data collected in automated milking units helps monitor milk quality and detect health issues such as mastitis. Industry studies indicate that automation leads to consistent milk production and improved hygiene. This aligns with findings from dairy processors who reported increased efficiency and reduced bacterial contamination due to minimized human handling.

**Pivot Irrigation Systems** have become a critical component in precision farming. Interviews with dairy farmers highlighted that these systems optimize water use and pasture growth. It further confirmed that automated irrigation, guided by weather data and soil moisture sensors, conserves water while ensuring high-quality feed production. This is particularly relevant in seasons, where water-efficient farming practices are essential. The adoption of smart irrigation aligns with New Zealand's sustainability goals and regulatory frameworks promoting responsible water usage.

**Implanted Chips** are an emerging technology in dairy farms. They are tiny devices placed under a cow's skin and store unique identification data. They provide continuous health tracking. Interviewed farmers reported that these chips help them to track temperature, activity levels, and disease indicators in real time. These early disease detection through implanted chips help to improve herd health outcomes and reduce treatment costs. Additionally, food safety regulators emphasise that traceability enabled by these chips ensures compliance with export market standards, enhancing consumer confidence in dairy products.

Larger and more financially robust dairy farms have integrated these technologies at a higher rate. However, smaller farms face barriers, such as high costs and limited technical expertise, which inhibit widespread adoption. This inequality underscores the need for support mechanisms tailored to assist smaller farms in adopting Supply Chain 4.0.

### 5.2.2 Influence of Dairy Farmers

Dairy farmers are the primary agents of adoption within the New Zealand dairy supply chain, and their decisions greatly influence the integration and success of digital technologies. As primary producers, dairy farmers are directly responsible for producing milk, which forms the foundation of the supply chain. Their role in ensuring efficient operations is pivotal, making them key drivers of technological adoption in the sector. Farmers who recognise the operational and economic benefits of these technologies tend to adopt them more willingly. For example, many farmers have shown a proactive interest in technologies that improve herd health, reduce labour requirements, and increase yield efficiency. These motivations reflect an understanding of how digital tools can enhance profitability and resilience against market volatility.

However, the adoption process is not without its challenges. Farmers encounter several barriers, including high costs of initial technology investment, maintenance, and a need for technical knowledge. Resistance to change also plays a role, especially among older farmers who may be less familiar with digital solutions. Additionally, there is often a lack of accessible training or support systems, making it difficult for some farmers to maximize the benefits of these tools. Despite these obstacles, dairy farmers who have successfully adopted Supply Chain 4.0 technologies are setting an example within the industry. They highlight the importance of a progressive approach toward modernizing traditional practices. Other farmers take action keeping their eye on successful stories.

### 5.2.3 Stakeholder Collaboration

The collaborative efforts of dairy farmers, cooperatives, processing companies, technology providers, and government bodies have been crucial in shaping the adoption landscape of Supply Chain 4.0 technologies. Industry leaders in New Zealand, play a significant role in promoting technology adoption by providing technical support, financial assistance, and training opportunities. These organizations often serve as intermediaries between farmers and technology providers, facilitating smoother integration of new tools within farming operations.

Technology providers, on the other hand, are responsible for designing, implementing, and supporting digital solutions that meet the unique needs of dairy farming. Technology providers can tailor their products to address specific challenges by collaborating with dairy cooperatives and directly with farmers. Monitoring milk quality, managing supply chain data, and ensuring animal welfare can be identified as key challenges farmers and cooperatives face. Government bodies also play a vital role by establishing policies, standards, and incentives that encourage innovation and investment in digital infrastructure for the dairy industry. Funding programs, grants, and subsidies from the government are instrumental in reducing the financial burden of adoption. That is crucial for smaller farms that may otherwise struggle to afford these technologies.

This multi-stakeholder collaboration has created an ecosystem that supports the gradual digital transformation of the dairy supply chain. However, there is still room for improvement. It can be improved by enhancing accessibility to support services for smaller farms and increasing the awareness of available resources. The dairy industry in New Zealand can achieve a more widespread and inclusive adoption of Supply Chain 4.0 technologies by strengthening these partnerships.

### 5.2.4 Economic, Environmental, and Social Impacts

The adoption of Supply Chain 4.0 technologies has brought about significant economic, environmental, and social impacts within the New Zealand dairy industry. Economically, these technologies have contributed to improved productivity and profitability. Those helped to optimize operations and resource allocation. For instance, IoT devices help farmers track and manage their herds more efficiently, leading to increased milk yields and reduced labour costs. Big data analytics facilitate demand forecasting and risk management, minimizing losses associated with overproduction or supply chain disruptions. Farmers who adopt these technologies generally report higher profitability, which strengthens the overall economic resilience of the dairy sector.

From an environmental perspective, digital tools have enabled dairy farmers to adopt more sustainable practices. IoT sensors and big data analytics, for example, allow for precise resource management, such as water and energy conservation

and optimized fertilizer use. These technologies support environmentally friendly practices by reducing waste and lowering the carbon footprint associated with dairy production. Blockchain technology also enhances sustainability by providing traceable and transparent records. It ensures compliance with environmental standards, further promoting consumer trust in New Zealand's dairy products as sustainably sourced.

Socially, the adoption of Supply Chain 4.0 technologies has influenced the relationships among stakeholders and improved consumer trust. Transparency and traceability achieved through blockchain and big data have positively impacted the dairy industry's reputation. It is crucial in international markets where consumers increasingly demand ethical and environmentally conscious products. Additionally, the adoption of digital tools in the supply chain creates opportunities for skill development, especially among farmers not familiar with digital technologies. Technology adoption also fosters collaboration among farmers, cooperatives, and technology providers, creating a support network that enhances industry resilience.

However, challenges remain in ensuring that all farmers, especially those from smaller farms, can participate in this digital transformation. Economic and technical barriers continue to hinder the broader implementation of these technologies. More comprehensive support structures are necessary to address these issues. Collaborative efforts to create equitable access to resources and training are essential in adopting these technologies. Those would be key to fully realizing the economic, environmental, and social benefits of Supply Chain 4.0 technologies across the entire New Zealand dairy industry.

## 5.3 Conclusions

### Impact of Technological Integration

The integration of Supply Chain 4.0 technologies in New Zealand's dairy industry has had a transformative impact on dairy operations. It has created a shift towards more efficient, transparent, and responsive supply chain management. Key technologies, including IoT sensors, big data analytics, and blockchain, have

collectively improved productivity, operational visibility, and resource management across the dairy supply chain.

The adoption of IoT sensors has helped enable real-time monitoring of herd health, milk production, and environmental conditions. This has allowed farmers to make data-driven decisions to enhance efficiency resulting in increased yields and more consistent product quality. Recent developments have expanded IoT applications beyond traditional monitoring functions. Contemporary research demonstrates novel applications in long-distance livestock transportation, livestock record and identification for precise traceability, and behavioral pattern analysis in dairy cattle management (Mahmud et al., 2023). These advancements represent a significant evolution of IoT technology, enabling comprehensive tracking and management throughout the entire dairy supply chain journey.

With big data analytics, farmers and cooperatives can analyse patterns in production, weather, and demand, allowing for better resource planning and risk management. This predictive capability has proven especially valuable in managing supply chain fluctuations minimizing wastage and maximizing profit margins. Blockchain technology, while less widely adopted, is emerging as a significant tool for ensuring transparency and traceability in the supply chain.

The emergence of "Dairy 4.0" has been significantly enhanced by blockchain integration, with recent research demonstrating how blockchain technology serves as a foundational element in digital transformation, creating more trustworthy and efficient supply chain networks (de Lima et al., 2023). Practical implementations have shown blockchain's effectiveness when combined with smart contracts, QR code technology, and IoT, demonstrating potential to redefine dairy supply chains across socio-economic, operational, and sustainability parameters (Raman et al., 2022).

Blockchain provides verifiable records of product origin and production processes. It leads to gaining consumer trust, particularly in global markets where the demand for traceable, ethically sourced products is high. Contemporary research has further validated blockchain's role in enhancing food sustainability and achieving sustainable food systems, with digital technologies significantly contributing to more

resilient and responsive supply chains that adapt to evolving market demands and sustainability requirements (Masi et al., 2021).

While the technological integration is impactful and has brought these advantages, there remain areas that could be further optimized. The inequality in adoption rates between larger, well-capitalized farms and smaller operations indicates that access and affordability issues are still significant. Smaller farms face challenges related to high setup and maintenance costs, which restrict their ability to fully participate in and benefit from Supply Chain 4.0 advancements. Additionally, persistent issues related to data privacy and the complexity of integrating new technologies with existing farm operations indicate the need for a more supportive ecosystem. It is more important for smaller farmers who may lack the resources or expertise required for seamless adoption.

**Barriers to Adoption**

The research identifies several primary barriers to the adoption of Supply Chain 4.0 technologies. It includes cost, technical expertise, and data privacy concerns. These obstacles have significantly impacted the pace and breadth of adoption across the dairy industry, with smaller farms being most affected.

The high cost of digital technology infrastructure remains the most critical barrier, particularly for AI-integrated devices, IoT devices, and blockchain solutions. Many small to medium-sized farms operate on tight margins and find the initial setup costs, along with ongoing maintenance and upgrades, excessively expensive. While larger farms with substantial capital have been able to overcome this barrier to a certain extent. Overall, the industry suffers from limited access to financial resources tailored to technology adoption. Without financial assistance, smaller farms are unlikely to fully adopt these technologies, leading to a gap in efficiency and output across the industry.

A lack of technical expertise among farmers also poses a significant challenge. They may not be experts in adopting and maintaining digital systems like AI, IoT, big data, and blockchain. It requires skills in data analysis, troubleshooting, and technology management. This gap often results in the underutilization of technology, as farmers may only leverage the basic features of advanced tools without understanding how

to fully capitalize on their capabilities. The limited availability of training programs worsens this issue, especially for those located in rural areas who have restricted access to educational resources and technology workshops. Consequently, while some farmers can implement these technologies, many are unable to use them effectively, thereby limiting their potential benefits.

Data privacy concerns represent another substantial barrier, particularly with the introduction of big data analytics and blockchain technology. The use of data-driven systems requires the collection and sharing of sensitive information related to farm operations, livestock health, and production details. Farmers are understandably cautious about data ownership and security in the dairy industry. They have concerns about unauthorised access or misuse of data by third parties. This situation in further complicated by the lack of regulatory clarity regarding data protection in the agriculture sector. Without concrete assurances on data security and clear frameworks defining data ownership, farmers remain hesitant to adopt technologies that might expose them to data-related vulnerabilities.

**The Role of Support Systems**

The successful adoption of Supply Chain 4.0 technologies depends not only on the technology itself but also on the supportive ecosystem surrounding it. Support systems comprising cooperatives, technology providers, and government bodies have proven essential in helping farmers overcome barriers and maximize the benefits of digital transformation.

Dairy cooperatives in New Zealand play a pivotal role in facilitating technology adoption by providing both financial support and technical training. Cooperatives connect farmers with technology providers and serve as intermediaries. They assist farmers in securing funding for initial investments. They also offer training programs to provide technical assistance. It helps farmers understand how to use these new technologies effectively and apply them to optimize their operations. This support has been particularly valuable for small to medium-sized farms to overcome the lack of resources to independently invest in and adopt Supply Chain 4.0 technologies. Additionally, they also create a community and encourage farmers to share

knowledge and experience. It is crucial to spread successful technology practices across the sector.

Technology providers are also crucial in this ecosystem. They supply not only the necessary hardware and software but also adapt their products to meet the specific needs of dairy farmers. Providers that collaborate closely with farmers and cooperatives can design user-friendly interfaces. They integrate existing farm management systems and develop tailored solutions that address the unique challenges of the dairy industry. This customization is particularly helpful in ensuring that smaller farms with limited technical expertise. Thus, they can still access and benefit from these tools. Moreover, technology providers that offer continuous support, maintenance services, and troubleshooting assistance help ensure the permanency and effectiveness of the solutions they provide.

Government bodies play a fundamental role in shaping the adoption landscape by developing policies and providing financial incentives for technology integration. The availability of grants, subsidies, and low-interest loans has been instrumental in lowering financial barriers for farmers. Especially, those from smaller operations are benefiting from those efforts. Government programs that prioritize digital transformation in agriculture can significantly enhance the adoption rate of Supply Chain 4.0 technologies, making it feasible for more farmers to invest in innovation. Additionally, by establishing regulatory frameworks for data protection, the government can help relieve privacy concerns, making farmers feel more secure in adopting data-driven solutions. Collaborating with industry stakeholders to create standardization in data collection and usage can further build trust in digital systems. That helps to promote wider acceptance among farmers.

Contemporary developments in stakeholder theory provide enhanced frameworks for understanding these complex support relationships. The stakeholder identification and salience model, which categorizes stakeholders based on power, legitimacy, and urgency attributes, has become particularly relevant for Supply Chain 4.0 adoption decisions (Mitchell et al., 1997). Recent theoretical advances emphasize the temporal dimension of stakeholder relationships, recognizing that stakeholder salience may shift as technology adoption progresses and new capabilities emerge (Wood et al., 2021). The integration of Environmental, Social,

and Governance (ESG) considerations into stakeholder analysis frameworks demonstrates how companies can enhance stakeholder buy-in through strong ESG performance, creating virtuous cycles where stakeholder support facilitates further sustainable technology adoption (Chen & Liu, 2023).

Even with these support systems, smaller farms and rural communities still need better assistance programs. These programs should focus on their specific challenges and provide practical solutions. For example, offering more training sessions and easier access to financial help can encourage small farms to adopt Supply Chain 4.0 technologies. Stakeholders -cooperatives, technology providers, and government agencies- must work together to make it happen. Their collaboration can create a strong support system that helps the entire dairy industry move toward digital transformation. This way, all farmers, no matter the size of their farms, can take advantage of new technology and improve their operations.

**Final Remarks**

In conclusion, the integration of Supply Chain 4.0 technologies in New Zealand's dairy industry has the potential to reshape the sector. Digital tools help make farming more efficient, sustainable, and competitive. However, the path to full adoption is complex and multifaceted, requiring coordinated efforts to overcome significant barriers. Small and medium-sized farms often struggle with challenges such as high costs, a lack of technical expertise, and data privacy concerns. The corrective measures from the stakeholders including cooperatives, technology providers, and the government can provide guidance, offer customized solutions, and create a better environment for adoption. These efforts are crucial to mitigate the barriers and move toward a more advanced and connected future.

Recent scholarly developments have further emphasized the transformative potential of these technologies. Research demonstrates that the convergence of digital technologies creates new opportunities for precision agriculture, enabling dairy farmers to optimize resource utilization while improving animal welfare and environmental sustainability (Javaid, Haleem, Singh, Suman, et al., 2022). The development of intelligent communication ecosystems that integrate blockchain and IoT-enabled technologies specifically for cattle welfare shows how real-time

wireless technology plays a key role in meeting sustainability requirements while maximizing productivity (Singh et al., 2022). These technological convergences represent a paradigm shift from traditional farming methods to data-driven agricultural practices that enhance both productivity and sustainability outcomes.

The research underscores the importance of an inclusive approach to technology adoption. All farms irrespective of size, should have the chance to benefit from digital transformation. A supportive ecosystem that encourages collaboration, education, and financial assistance is required to achieve this. Contemporary research validates that in the quest to feed a growing global population using sustainable methods, Supply Chain 4.0 technologies provide critical solutions that address economic efficiency, environmental sustainability, and social responsibility simultaneously (Sinha et al., 2023). This holistic approach to digital transformation represents a paradigm shift towards more integrated and sustainable dairy farming practices. That will help New Zealand's dairy industry lead the way in demonstrating how traditional sectors can successfully integrate advanced technologies to improve productivity, sustainability, and market competitiveness. These findings provide valuable insights for policymakers, industry leaders, and technology developers. They highlight that collective efforts are key to promoting Supply Chain 4.0 adoption and securing the future of the dairy sector.

## 5.4 Recommendations

### Policy and Financial Support

To encourage the adoption of Supply Chain 4.0 technologies within the New Zealand dairy industry, particularly among small and medium-sized farms, the government and financial institutions should implement targeted policy adjustments and financial aid initiatives. A primary recommendation is the establishment of grants and subsidies specifically tailored to support smaller farms in purchasing and integrating digital technologies. These subsidies could cover a percentage of the initial costs associated with IoT devices, AI-integrated devices, automated systems, big data analytics tools, and blockchain systems. It helps to reduce the financial burden that often deters smaller farms from adopting advanced technologies.

Additionally, low-interest loans dedicated to technology adoption in dairy farming could further facilitate access, especially for farms with limited capital.

Beyond direct financial assistance, policymakers should explore tax incentives for farms investing in digital solutions. For example, tax credits could be offered to farms that adopt technologies that contribute to sustainable practices, such as water management or emissions reduction, aligning economic support with environmental goals. By linking financial incentives to sustainability outcomes, such a policy would not only accelerate Supply Chain 4.0 adoption but also encourage the industry to meet higher standards of environmental responsibility.

Furthermore, policymakers should consider developing rural technology infrastructure as part of a broader initiative to support digital transformation. Many farms, particularly those in remote areas, face connectivity issues that prevent the effective implementation of IoT and big data tools. Government investment in better network coverage and high-speed internet infrastructure for rural areas would be a critical step that enables widespread and reliable technology use in dairy farming. These improvements in connectivity could facilitate not only operational advancements on farms but also better access to training resources, online support, and data-sharing platforms.

**Training and Capacity Building**

To enhance the effective use of Supply Chain 4.0 technologies, it is essential to provide targeted training programs that equip farmers with the necessary skills and knowledge. Many farmers may have limited experience with digital tools. That has prevented farmers from leveraging the full capabilities of IoT, AI, big data, and blockchain technologies. A healthy training program tailored to dairy farmers could focus on both the technical and practical aspects of technology adoption, guiding farmers through setup, data interpretation, and troubleshooting. Such training should prioritize user-friendly language and practical, hands-on demonstrations to ensure accessibility for all farmers, regardless of their level of technological expertise.

A potential model for delivering this training could involve partnerships between cooperatives, technology providers, and government authorities. Cooperatives

could facilitate training sessions, utilizing their established networks to reach farmers directly. Technology providers could contribute by offering certified trainers or digital resources that help farmers become proficient in using their tools. Agricultural universities or technical institutes could develop programs specifically focused on Supply Chain 4.0 in dairy farming. It has to create a continuous pipeline of knowledgeable professionals who can support farmers. Short courses, workshops, and online training modules would provide farmers with flexible learning options that they can integrate into their work schedules.

Setting up a mentorship or peer support system can help farmers share knowledge. Experienced farmers who already use digital technologies can guide those who are just starting. This will create a community-based learning environment where farmers help each other.

Mentorship can make it easier for new adopters to learn and use these technologies effectively. It also builds a long-term support network that continues beyond initial training. With the right guidance, farmers will feel more confident using digital tools and will be able to get the most out of them for their farms.

**Enhanced Stakeholder Collaboration**

The successful adoption of Supply Chain 4.0 technologies requires a collaborative ecosystem involving farmers, cooperatives, technology providers, and government bodies. A structured way to engage these groups can make partnerships stronger. One way to do this is by organizing regular industry forums or conferences. These events would bring all stakeholders together to share knowledge, discuss challenges, and plan solutions. Open discussions can help align goals, such as making farming more sustainable or cutting costs. This approach will create a more united effort toward digital transformation in the dairy industry.

One practical recommendation to enhance collaboration is the creation of technology adoption support networks led by cooperatives. Cooperatives, as trusted entities in the farming community, are well-positioned to serve as a link between farmers and technology providers. They can help facilitate bulk purchases of digital tools, which could reduce costs and encourage broader adoption among members. Additionally, cooperatives could provide ongoing technical support with their

dedicated personnel. It would ensure that farmers receive the assistance they need to resolve issues and optimize technology use.

For technology providers, it is essential to prioritize user-centered design and customer support tailored to the agricultural sector. Dairy Farmers face challenges, such as livestock management, milk quality tracking, and supply chain logistics. Technology providers could work closely with farmers and cooperatives and adapt their solutions to address the unique challenges of dairy farming. They could also participate in collaborative projects including pilot programs or field tests. That would allow technology providers to refine their products based on real-world feedback, ensuring they meet farmers' practical needs. Technology providers could also consider offering flexible financing options or lease models, making it more affordable for small and medium-sized farms to access advanced tools.

Government bodies play a vital role in facilitating these partnerships by setting supportive policies and funding joint initiatives. The government could establish public-private partnerships that encourage cooperatives and technology providers to work together on technology adoption initiatives. For example, grant programs could be designed to fund collaborative projects aimed at creating customized digital solutions for the dairy industry. By actively supporting partnerships across the supply chain, government entities can drive collective progress toward the widespread adoption of Supply Chain 4.0 technologies.

## 5.5 Limitations

This study explores the adoption of Supply Chain 4.0 technologies in New Zealand's dairy industry, but it has certain limitations. One major constraint is the sample size, as it includes only eight dairy farmers and six representatives from dairy processing companies. Given the diverse nature of dairy farming across different regions, this sample may not fully capture the industry's complexities. Research methodology literature indicates that qualitative studies often involve smaller, specific samples, which may limit the applicability of findings to broader populations (Lim, 2025). Expanding the study to include more farms and a wider geographical range would offer a more in-depth and representative view of technology adoption within the sector.

Another limitation of this study is its reliance on qualitative data gathered from interviews and surveys. This approach provides rich insights into participant's perspectives and experiences. However, it does not offer a complete picture of the measurable effects of Supply Chain 4.0 technology adoption. Especially on factors such as productivity, profitability, or sustainability. Agricultural research methodologists suggest that researchers would benefit from using mixed methods to enhance the breadth and depth of their analysis, where qualitative methods provide detailed information that can better explain relationships observed from quantitative methods (Katchova & Ahearn, 2018). A more data-driven approach incorporating quantitative analysis could enhance the understanding of these impacts. Financial performance metrics, operational efficiency data, and environmental impact assessments are essential areas to be included. Those could provide clearer evidence of the tangible benefits and challenges associated with digital transformation in the dairy supply chain.

The limited timeframe of this study made it difficult to conduct a long-term analysis. Since the research is based on short-term observations, it may not fully capture the ongoing impact of digital transformation in the dairy sector. Implementing Supply Chain 4.0 technologies is an evolving process. It often takes years to materialize the effects on efficiency, profitability, and sustainability. Without tracking these changes over time, it remains uncertain whether these technologies consistently provide benefits or introduce unexpected challenges. To build a more comprehensive understanding, future studies should expand the scope by including a larger and more diverse sample of dairy farms. This would help capture variations in farm size, levels of technology adoption, and regional differences. It would offer a clearer picture of how digital advancements shape the industry over the long run.

## 5.6 Future Research Directions

To enhance the understanding of technology adoption in the dairy sector, further research is recommended in several key areas. One significant focus is the long-term impact of digital transformation on sustainability and market competitiveness. A particularly relevant research avenue is the analysis of environmental outcomes linked to digital technology use in dairy farming. Future studies could investigate how AI, IoT, Automation, big data, and blockchain contribute to resource

conservation, emissions reduction, and waste minimization. Gathering empirical data on these environmental benefits would provide policymakers and industry leaders with valuable insights, emphasizing the role of digital solutions in supporting sustainability objectives.

Another area for research is the economic resilience provided by technology adoption, particularly in volatile market conditions. Studies could investigate whether farms that have integrated Supply Chain 4.0 technologies demonstrate greater adaptability to price fluctuations, supply chain disruptions, and labour shortages. By comparing digitally enabled farms with traditional ones, researchers could assess the role of technology in creating more stable and competitive operations within the dairy industry. These findings could also highlight best practices for using digital tools to mitigate risks and maximize profitability, guiding future technology investments in the dairy industry.

Research on social factors is equally important, especially in assessing the workforce implications of technology adoption. Social science research on digital agriculture has identified key thematic clusters including adoption patterns, effects on farmer identity and skills, and workforce implications (Klerkx et al., 2019). As digital solutions automate tasks once carried out by farm workers, studies could explore how this transition influences employment, job satisfaction, and the evolving skill demands in rural communities. Examining the social consequences of automation in dairy farming can provide valuable insights for shaping policies on labor, education, and workforce development. This ensures that the shift toward digital farming remains inclusive, addressing the needs of local communities while fostering a sustainable and adaptive agricultural workforce.

The longitudinal studies are essential for understanding how digital transformation impacts dairy farming in the long run. Researchers can gain valuable insights by tracking the same group of farms over several years. It can include the changes in productivity, environmental outcomes, and economic resilience as new technologies are adopted. Such research would provide valuable insights into the real-world challenges and benefits of Supply Chain 4.0 adoption in the dairy industry. Additionally, it would also help determine whether these digital advancements can be sustained and expanded across different farming operations. Universities,

industry groups, and government agencies could collaborate on such studies to ensure practical and useful findings for the dairy sector.

Broadening the geographical scope of research is another important direction for future studies. Digital transformation research in agriculture needs to provide comprehensive analysis of different agricultural contexts, including smallholder farming systems and diverse regional conditions (Zhou et al., 2024). Examining dairy industries in different regions would provide a more comprehensive understanding of technology adoption patterns. It can include developing countries and areas with distinct regulatory, economic, and resource constraints. Dairy farming operates within diverse environments, where factors such as government policies, market conditions, infrastructure availability, and cultural attitudes toward innovation can significantly shape adoption rates and outcomes. Conducting comparative studies across various regions could highlight key differences and common challenges. It can also offer valuable insights for policymakers, industry leaders, and global stakeholders looking to support digital transformation in agriculture.

## 5.7 Chapter Summary

Chapter 5 concludes the study by integrating key findings on the adoption of Supply Chain 4.0 technologies in New Zealand's dairy industry and offering strategic recommendations for enhancing digital transformation in this sector. The chapter highlights how digital tools such as AI, IoT, big data, and blockchain have transformed dairy operations, improving efficiency, transparency, and sustainability. However, challenges like high costs, technical expertise gaps, and data privacy concerns continue to hinder widespread adoption, especially among small to medium-sized farms.

This chapter suggests practical steps to overcome these challenges. It includes policy and financial support, including subsidies and tax incentives, to make digital tools more affordable for farmers. It also highlights the importance of in investing hands-on training and skill development programs. It helps farmers to build their confidence in the use of new technologies. Strengthening strong partnerships

between farmers, cooperatives, technology providers, and government agencies will also play a key role in creating a supportive ecosystem for digital adoption.

Furthermore, the chapter identifies the importance of future research to deepen the understanding of digital transformation in the dairy sector. Longitudinal studies that can track changes over time can provide valuable insights into the long-term effects of digital adoption. Examining these technologies across different geographical and climate conditions will also help determine their broader applicability in the global dairy industry.

Through these conclusions and recommendations, Chapter 5 serves as a roadmap for advancing digital integration in the dairy sector. By addressing existing barriers and identifying opportunities for further research, the chapter encourages for a more inclusive and sustainable transition toward a digitally enabled dairy industry. The goal is not just to introduce new technologies but to ensure they are accessible, practical, and beneficial for farmers at all levels.

# Appendix

## Appendix A: Semi-Structured Interview Guide for Dairy Farmers

### Semi-Structured Interview Guide for Dairy Farmers

**Participant** :

**Contact Details** :

**Date** :

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**Purpose**

This research aims to investigate the adoption of new technologies/IT solutions among New Zealand dairy farmers and examine the role of dairy processing companies in this process. It evaluates the economic, environmental, and social impacts of these technologies on the dairy sector. Further, this research aims to understand the benefits and challenges of adopting these technologies and how they enhance the industry's competitiveness and sustainability.

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**Section 1: Background Information:**

- Can you briefly describe your business model and the details of your farm size, location, type of dairy farming, suppliers, and customers?

  Business Model: Owner/operator/share milker/other
  Farm Size:
  Location:
  Primary purpose of dairy farming: milk production/breeding/organic dairy farming/other
  Suppliers:
  Customers:
- How long have you been in the dairy industry?

**Section 2: Understanding of Supply Chain 4.0:**

- What are the technologies you using in your farm and operations?
- Why did you decide to implement these technologies?
- Have you heard about or used technologies like IoT sensors, Artificial Intelligence, data analytics, or automated milking systems?

**Section 3: Adoption Drivers and Barriers:**

- What motivated you to consider adopting new technologies?
- Were there any specific reasons, events, or experiences that made you adopt these technologies?
- What were the issues you faced when integrating these technologies with your existing systems? cost, lack of knowledge, technical know-how, or any other?
- How did you overcome these barriers?

**Section 4: Impact on Operations:**

- How have these technologies impacted your farm operations?
- Have you observed any changes in the efficiency of your daily operations since adopting these technologies?
- Can you provide specific examples of improvements in productivity, profitability, quality of dairy products, sustainability or reduction in cost?
- How have these technologies affected labor requirements on your farm?
- Have there been any changes in the roles or skills required of your employees?

**Section 5: Stakeholder Collaboration:**

- How do you collaborate with other business partners in the industry (e.g., cooperatives, processing companies, technology providers) to implement these technologies?
- What kind of support have you received from them?

- How do you communicate your needs and feedback to your business partners regarding technology adoption?

**Section 6: Future Prospects:**

- What are your future plans regarding the adoption of new technologies?
- Are there specific technologies or innovations you are particularly interested in adopting in the near future?
- How do you expect these technologies to impact your farm's competitiveness and market position?
- What plans do you have for future collaborations with business partners to further enhance your adoption of new technologies?
- What challenges or concerns do you foresee in the continued adoption of the latest technologies?
- How do you plan to address these challenges moving forward?
- What additional support or resource would help you adopt these technologies more effectively?
- How do you stay informed about emerging trends and innovations in dairy farming technology?
- What specific environmental benefits do you aim to achieve through the adoption of new technologies?

## Appendix B: Semi-Structured Interview Guide for Processing Company Representatives

**Semi-Structured Interview Guide for Processing Company Representatives**

**Participant :**

**Department/Job Role :**

**Organization :**

**Contact Details :**

**Date :**

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**Purpose**

This research aims to investigate the adoption of Supply Chain 4.0 technologies among New Zealand dairy farmers and examine the role of dairy processing companies in this process. It evaluates the economic, environmental, and social impacts of these technologies on the dairy sector. Further, this research aims to understand the benefits and challenges of adopting these technologies and how they enhance the industry's competitiveness and sustainability.

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**Section 1: Background Information:**

- Can you briefly describe your role and experience in the dairy industry?
- How is your company involved in the dairy supply chain?

**Section 2: Understanding of Supply Chain 4.0:**

- What is your understanding of Supply Chain 4.0 technologies?
- How familiar are you with technologies like blockchain, IoT, AI, and big data analytics?

**Section 3: Adoption Drivers and Barriers:**

- What factors have driven or hindered your adoption of Supply Chain 4.0 technologies?
  Driven:
  Hindered:
- How have you addressed these barriers?

**Section 4: Impact on Operations:**

- How has the adoption of these technologies affected your operations?
- Can you provide specific examples of improvements in efficiency, traceability, or product quality?
  Efficiency:
  Traceability:

**Section 5: Stakeholder Collaboration:**

- How do you collaborate with dairy farmers and other stakeholders to implement these technologies?
  Dairy Farmers:
  Other Stakeholders:
- What kind of support do you provide to farmers for technology adoption?

**Section 6: Future Prospects:**

- What are your future plans regarding the adoption of new technologies?
- What additional support would help in promoting the adoption of these technologies in the dairy industry?

# Appendix C: Consent Form

**Lincoln University Policies and Procedures**

## Consent

***Name of Project:*** The Role of Dairy Farmers in Driving Supply Chain 4.0 Adoption : A case Study from the New Zealand Dairy Supply Chain

***Researcher:*** D. P. Manju Prasanna, Mob : 0220 841 847, Department of Agribusiness & Commerce, Lincoln University.

***Purpose of the Study:*** The purpose of this study is to explore how dairy farmers influence the adoption of Supply Chain 4.0 technologies within the context of New Zealand's dairy industry.

***Participation:*** Your participation in this study involves participating in a semi-structured interview that will take approximately 30 minutes.

***Confidentiality:*** All information provided will be kept confidential. Your identity and any identifying information will be anonymized in all reports and publications resulting from this study.

***Voluntary Participation:*** Participation in this study is voluntary. You may withdraw from the study within one month after joining the project without any negative consequences.

***Benefits and Risks:*** There are no direct benefits to you for participating in this study. However, your participation will contribute to a better understanding of the adoption of Supply Chain 4.0 technologies in the dairy industry. There are no known risks associated with participating in this study.

I have read and understood the description of the project above.

1. I have been given sufficient time to consider whether or not to participate in the project and to ask questions.

2. I have been given a copy of the Research Information Sheet and the Consent Form to keep.

**Consent:** By signing this form, you agree to participate in this study and allow the researcher to use the data collected for research purposes.

---

**Participant's Name: ……..**

**Participant's Signature: ……..** **Date: ……**

**Researcher's Signature: ……..** **Date: ……**

☐ **I consent to participate in the project.**

☐ **I consent to the publication of the results (interviewee information will be anonymized).**

2024

# Appendix D: Research Information Sheet

Lincoln University Policies and Procedures

## Lincoln University

### Agri-business and Commerce

### Research Information Sheet

**Introduction and invitation**

I invite you to participate in a project entitled A Study on the Role of New Zealand Dairy Farmers in Driving Supply Chain 4.0 Adoption. The Lincoln University, Human Ethics Committee, reviewed and approved the research.

**The aims of the project**

- This research explores the role of dairy farmers in adopting Supply Chain 4.0 technologies in the New Zealand dairy industry. It evaluates the economic, environmental, and social impacts of these technologies on the dairy sector. Further, this research aims to understand the benefits and challenges of adopting these technologies and how they enhance the industry's competitiveness and sustainability.
- The data obtained from the interview will be used in the thesis for data analysis, and obtain the final results

**Qualified interviewees**

- Our interviewees are dairy farmers and the representatives of the dairy processing companies.

**Interview information**

- During the interview, interviewees need to answer some questions about the research topic. Each interview lasts about 30 minutes.
- The interview will be conducted in person.

**Interview data**

- Researcher and supervisors have access to the data.
- The data will be kept confidential, and Participants' anonymity will be ensured.

**Contact details**

Master Student: D. P. Manju Prasanna
Email address: man.diyalagodapathirathnahalage@lincolnuni.ac.nz
Mobile phone: 0220 841 847
Supervisor: Dr. Robert Radics
Email address: robert.radics@lincoln.ac.nz
Associate Supervisor: Dr. Muhammad Umar
Email address: muhammad.umar@lincoln.ac.nz

2024

## Appendix E: Sample Interview Transcript

### E.1 Interview Transcript with Dairy Farmer, Ref: NZDF03

# NZDF03 - Transcript

23 November 2024, 01.00pm

Interviewer:

Can you briefly describe your business model and the details of your farm size, location, type of dairy farming, suppliers, and customers?

Farmer:

I'm a contract milker. The size of my farm is 610 hectares with 2160 cows. And it's located in …….. (This was deleted to ensure anonymity)

Interviewer:

What is the primary purpose of your dairy farm?

Farmer:

Milk production

Interviewer:

To whom are you supplying milk?

Farmer:

We supply milk to …… (This was deleted to ensure anonymity)

Interviewer:

So, How long have you been in the dairy industry?

Farmer:

I have been in the dairy industry since 2005. And I am working as a contract milker since 2012/13

Interviewer:

What are the technologies you are using in your farm and operations?

Farmer: For dairy purposes, we use a Protrack automatic gate system, and for automatic milking, we have a Rotary Platform system. Additionally, we utilize Protrack tag technology to identify cows. Each cow is drafted by a number, and we input data into the computer, including breeding information. When the cows enter the shed for milking, we can access all their data by entering the drafted number. The software we use for this is called Mindlive. To calculate how much milk a cow has produced over the year, we perform herd testing once a year. We send this data to the company, which calculates the total milk production for each cow. This testing isn't done daily. For irrigation, we employ a pivot irrigation system. The data we get from our sensors helps us use resources more wisely. We're using less water and fertilizer, which is better for the environment and saves us money in the long run. . For irrigation, we employ a pivot irrigation system.

Interviewer:

Are there any technologies you use in your farm to check the quality of milk?

Farmer:

Well, on the farm itself, we do not conduct any quality checking. However, …… (This was deleted to ensure anonymity) performs quality checks after they collect the milk by sending a sample to a lab. We do use a technology called Levno that shows us how much milk is in the storage vats and the temperature of the milk. It also informs us of the time when the company comes to collect the milk. While that app is not linked with …… (This was deleted to ensure anonymity), I have the Levno app on my phone, and it sends me alerts if something goes wrong, such as if we forget to turn on the chiller or if the temperature of the milk is too high.

We also have another app called Onsite, which is related to health and safety. If an outsider comes to the farm, they must sign in to the app before stepping inside. The app outlines the hazards and risks present on the farm, and only after that can they enter. Once they're in, the app sends me an alert notifying me that the person has entered the farm and indicates how long they'll be there. Additionally, the outsider receives my contact number in case they need assistance with anything while on the premises.

Interviewer:

Why did you decide to implement these technologies?

Farmer:

We decided to implement these technologies because they add value and minimize risks on the farm. The Onsite app, for instance, is a requirement from the government, ensuring that all safety protocols are followed. Additionally, these technologies help reduce wastage. For example, if there's an issue with the vats storing milk, the Levno app sends me a message alerting me to the problem so that I can address it promptly. This proactive approach helps us maintain the quality of our milk and ensures the safety of everyone on the farm.

Interviewer:

Have you heard about or used technologies like IoT sensors, Artificial Intelligence, data analytics, or automated milking systems?

Farmer:

Yes, I have heard about them

Interviewer:

What motivated you to consider adopting new technologies?

Farmer:

What motivated us to consider adopting new technologies is their low cost. Our operations are based on two systems: high output and low input. We follow a low-input approach to minimize risks, especially since our income is restricted. The farm owners tend to avoid investing in high-cost technologies because they can lead to significant expenses. As a result, we don't employ high breeding methods or advanced technologies. Instead, we managed to achieve an average quantity of milk using average costs, which aligns well with our business model. This strategy helps us remain sustainable while ensuring we produce enough to meet our requirements.

Interviewer:

Were there any specific reasons, events, or experiences that made you adopt these technologies?

Farmer:

Yes, before adopting technologies like the Protrack tag system, we handled everything manually. For example, if a cow was sick, I had to go find her, bring her to the shed, weigh her, and treat her. Now, it’s much easier—I just need to get her number to weigh her; I don’t have to run after her anymore.

Similarly, before using Levno, we sometimes had to dump milk because we weren’t aware of issues with the milk quality. There were no proper records, which meant that if something went wrong, we wouldn’t know until it was too late.

Interviewer:

What were the issues you faced when integrating these technologies with your existing systems? Cost, lack of knowledge, technical know-how, or any other?

Farmer:

The main issue we faced when integrating these technologies was the cost, especially with the Protrack system, which is quite expensive. We had to make a significant investment, which was challenging for us. Additionally, there were some issues related to the skills required to operate the new systems effectively.

Interviewer:

How did you overcome these barriers?

Farmer:

When it came to overcoming barriers, we couldn't really change the cost of implementing the technologies since it's an ongoing payment. However, in terms of addressing the lack of skills, the LIC (Livestock Improvement Corporation) stepped in and provided training for our workers.

Interviewer:

How have these technologies impacted your farm operations?

Farmer:

Using these technologies has significantly increased the efficiency of our farm. We've seen a reduction in wastage and considerable time savings. For example, with the Protrack system, we can identify sick animals earlier and treat them. This not only helps in maintaining the overall health of our herd but also enhances our milk production quality. Interviewer:

Can you provide specific examples of improvements in productivity, profitability, quality of dairy products, sustainability, or reduction in cost?

Farmer:

Using these technologies has helped us waste less on the farm. When we waste less, we can be more productive. By quickly addressing issues with milk storage and checking cow health, we make the most of our resources.

And we wanted to save time and labor, and the automated systems have made that possible. Now we can focus on improving the overall quality of the farm instead of getting engaged in daily repetitive tasks.

Interviewer:

How have these technologies affected labor requirements on your farm?

Farmer:

We have a total of 9 workers on our farm, which includes myself as the manager and 8 additional staff. If we didn't have the Protrack system in place, I would likely need to recruit one more worker to help manage our operations effectively.

Interviewer:

Have there been any changes in the roles or skills required of your employees?

Farmer:

It's essential for everyone on the farm to know how to operate these systems effectively. While some of the experienced workers are fully aware of how to use the technologies we've implemented, there are still some team members who are not yet familiar with them.

Interviewer:

How do you collaborate with other business partners in the industry to implement these technologies?

Farmer:

The company I work with, …….. (This was deleted to ensure anonymity), has a program called "Lead with Right," which is similar to ISO 65 standards. They have specific requirements for us to meet, including the installation of cameras and monitoring systems. For instance, when it comes to irrigation, we need to provide evidence of how much water we are using.

Interviewer:

What kind of support have you received from them?

Farmer:

The LIC company that provides the Protrack system has a helpline we can contact anytime if we encounter any problems with the technology. Additionally, …….. (This was deleted to ensure anonymity), the company we supply our milk to, has an area manager available for us to reach out to whenever we have concerns regarding milk quality or any other related issues.

Interviewer:

How do you communicate your needs and feedback to your business partners regarding technology adoption?

Farmer:

We directly contact the LIC helpline for Protrack issues and ……. (This was deleted to ensure anonymity) area manager for milk concerns.

Interviewer:

What are your future plans regarding the adoption of new technologies?

Farmer:

In the program, specifically at the Gold Elite level, using technology is important. For example, variable irrigators can improve how we water our fields. Unlike regular irrigation systems that water all areas the same way, variable irrigators let

us adjust the watering based on different types of soil on the farm. If some parts of the land hold moisture well and others need more water, variable irrigators can adapt to these needs. This would help us use water more efficiently and boost crop yields by giving each area the right amount of water. And I also like to start using AI-integrated cow collars.

Interviewer:

Are there any specific technologies or innovations you are particularly interested in adopting in the near future?

Farmer:

I want to start using cow collars because they are efficient and easy to use. They record important details about the cows, including their behaviors and breeding data. This will help us monitor their health better and improve our overall productivity while reducing the need for manual checks.

Interviewer:

What plans do you have for future collaborations with business partners to further enhance your adoption of new technologies?

Farmer:

For xxxx, they have specific requirements that we fulfill to ensure our milk meets their standards. As for other technologies, like using cow collars, that decision lies with the farm owners. They decide whether such investments are necessary based on our operational needs and their budget.

Interviewer:

What challenges or concerns do you foresee in the continued adoption of the latest technologies?

Farmer:

The main challenge we face in dairy farming is the high cost of new technologies. Additionally, climate conditions create various problems. Since dairy farming relies on grass, the quality of grass can change from year to year due to weather. Last year, spring was great, which gave us high-quality grass and high milk production.

This year, however, spring has been unstable, resulting in lower-quality grass and less milk. These changes make the market unpredictable, and our milk production can also vary a lot.

Interviewer:

How do you check the quality and height of the grass?

Farmer:

To check the quality of the grass, we send samples to the lab. Additionally, we use plate meters to measure the height of the plants, but experienced staff can often assess it accurately just by looking. Our farm consists of 610 hectares divided into 46 paddocks. That’s about 12 hectares per paddock.

Interviewer:

How do you plan to address these challenges moving farms?

Farmer:

To improve pasture quality, we have a plan to regrass our farm. Each year, we regrass 10% of the land. The quality of the grass can change with the seasons and as the grass gets older. When there are too many weeds or the grass is too old, we produce less milk. That’s why we aim to regrass the entire farm every 10 years.

Interviewer:

What additional support or resource would help you to adopt these technologies more effectively?

Farmer:

I believe the government should play a larger role in supporting farmers, especially when it comes to adopting new technologies. Many of these advancements can be quite expensive, and a significant number of farmers simply cannot afford them. There's no point in developing innovative technologies if farmers can't access them due to cost constraints. The government needs to provide assistance that doesn't negatively impact farmers' financial margins. Offering subsidies, grants, or low-interest loans for the implementation of these technologies could make a

considerable difference and help ensure that all farmers can thrive and improve their operations.

Interviewer:

How do you stay informed about emerging trends and innovations in dairy farming technology?

Farmer:

We receive newsletters and emails that tell us about new dairy technologies. We also attend seminars where we learn about these advancements. The DairyNZ website provides helpful information about new tools and practices. Additionally, we get updates from LIC (Livestock Improvement Corporation), which keeps us informed about improvements we can make on our farm.

Interviewer:

What specific environmental benefits do you aim to achieve through the adoption of new technologies?

Farmer:

Nutrient leaching is a major issue in our area, especially regarding water quality. Authorities monitor this closely at Ellesmere Lake. If the water quality is poor, they impose restrictions across Canterbury. Right now, farms can only use 190 kg of nitrogen, which I think is not enough. This limit makes it hard for us to perform well, as we need more nitrogen for our farming. We should have technology to provide accurate information about nitrogen use and its effect on water quality. This could help us manage our farming practices while also protecting our water resources.

Sustainability must be balanced with the needs of farmers. If authorities focus only on environmental issues, they may overlook the practical needs of farming. It’s important to find a middle ground that supports both sustainability and farm productivity. If this balance is not found, productivity may drop, and farmers might leave the industry. It is essential to support farmers while promoting sustainable practices for the long-term benefit of both farmers and the environment.

### E.2 Interview Transcript with Representative of Dairy Processing Company, Ref: NZPC02

# NZPC02 - Transcript

10 October 2024, 10.00am

**Processing Company Representative** 15:38
Hello, good morning.

**Interviewer** 15:43
Hello. Good morning, how are you?

**Processing Company Representative** 15:45
I'm good. Thank you. Nice to meet you.

**Interviewer** 15:47
Nice to meet you too. I would like to get some information for my research.

**Processing Company Representative** 16:01
Yes, I'm. I'm not sure how much help I'm gonna be, but if I can help I will.

**Interviewer** 16:06
I understand. Yes. So I just need some information because this research is regarding the supply chain 4.0s. It is about the latest technologies. Some technologies are already being used in the dairy industry. So then my research is about how dairy farmers use these and their role when they adapt and how do they involve with the processing companies.

**Processing Company Representative** 16:32
OK, my role is on the procurement and supply chain side. So I deal with the inbound materials. For also all ingredients and packaging, but excluding the fresh milk side of it, so, I will be able to assist with but on the processing side possibly I can help.

**Interviewer** 17:04
Yeah. Is that so? is it Ok If I record the meeting only the audio.

**Processing Company Representative** 17:08
Of course, yeah, no problem

**Interviewer** 17:23
Thank you. What about your company? Is it doing only the processing? Is there any farming involved?

**Processing Company Representative** 17:34
Yes we have a few of its own farms, but it's mostly contracted farmers who are supplying them.

**Interviewer** 17:45
Great..
What is your understanding about supply chain 4.0 note technologies like AI, blockchain, Internet of Things sensors.

**Processing Company Representative** 17:58
I have a limited understanding.

**Interviewer** 18:02
Mm hmm.

**Processing Company Representative** 18:02
On that, I guess the only involvement that I've had is so, so the bulk of company's businesses and producing infant formula. So, taking milk, drawing it, adding various ingredients, converting it to infant formula for export to predominantly to China, but throughout Australia and New Zealand.
We use, so we have a service provider that has a blockchain based technology to put a QR code on the bottom of each of the cans that we've produced.
And that gives. It's a unique identifier on each of the cans. It's an anti-counterfeit mechanism. It also provides traceability through the supply chain for our customers and end users through the various stages of distributors and warehousing and so on and so forth through the market.

**Interviewer** 18:57
Yeah. Yeah, that's the understanding and the involvement.
So then when you apply those technologies, were there any barriers?

**Processing Company Representative** 19:14
A collection was an issue for quite some time.
So because you are creating an indelible mark on the can.
If the data is lost, then when that is scanned in the market.
It creates a major issue.
So either the end user can get an error suggesting that the product's counterfeit or it's not valid.
Or I can simply lose traceability through the market.
So getting that accurate.
Getting the right service providers and cost.
Was really important and.
Yeah, making sure that everyone's aware of who's responsible for what aspects of the service. The data, the various web portals, the through the APIs and everything on their line.

**Interviewer** 20:15
So then how did you address those various issues like get the data involved with the providers, right, technology providers?

**Processing Company Representative** 20:24
I think so. Yeah, it was.
Yeah, So we ended up changing suppliers and there's a way better the media about how that went, but.

**Interviewer** 20:36
Yeah..

**Processing Company Representative** 20:38
Yeah, I I was getting the right providers but also getting alignment with all three parties. So it's a third party manufacturer essentially.
As the brand owner.
And the service provider's sitting in the middle and so it was important to have all three parties on the same page, making sure that the customer deliverables are being met and that there's clear accountability as to as to who is, who is responsible for, each aspect of the service, because ultimately everything has to be accurate for it to work for it to function.

**Interviewer** 21:01
So then the main driven factor was like everything should be accurate. You know that's why did you go for this kind of technology?

**Processing Company Representative** 21:25
Yeah, just consistency and accuracy, yes.

**Interviewer** 21:33
so then? How these technologies affect your operation, like in your role, like how it affects so was it helpful you to enhance the traceability of the data or an accuracy… something like that.

**Processing Company Representative** 21:47
Yeah.
I didn't have too much benefit in my role.
There was more, something we were providing for the customer, for our, customer. There is huge benefits in terms of really discovering how their product is being distributed out to the market.
Yeah, effort formula was being sold through this complex kind of supply chain through diagnostic channels through Australian supermarkets.
Making its way through to China and there's a vast network of from large scale diagos through to people selling on WeChat channels, all kinds of things. And the customer themselves actually didn't have much of an understanding as to how their supply chain works. They just knew a product was selling. This is great. But then when COVID hit, there was obviously you know a big, big decline in those sales.

**Interviewer** 22:37
Mm. what were the solutions then?

**Processing Company Representative** 22:44
And they didn't really know where things were going. And so using this blockchain technology, associating these with a QR code on the cans.
I didn't start collecting this data in terms of every scan they could see where the product was. They were getting distributors to scan it. They you know, they tied it to like promotional schemes, you know. So there was incentives for distributors to scan these codes.

And that meant that they start to build up data as to how the product was getting to market, which led to, you know, more targeted marketing strategies.
And yeah, ultimately it's probably helped them grow their market share.

**Interviewer** 23:33
So then I know that based on your role, you don't want to be involved with the dairy farmers, right?
Yeah. Yeah. So then in overall how is your organization involved with the dairy farmers when you implement this kind of technology?

**Processing Company Representative** 23:50
So then that technology wasn't affecting the farmers, so, their milk supply.
Yeah. was, was not impacted, it was downstream from them, so.

**Interviewer** 24:03
So then the organisation side you just inform them of the technology details. And they do the things right.
Then in the future, are you expecting to implement or introduce new technologies like AI, robots, automation or any other developed technologies in future?

**Processing Company Representative** 24:32
I'm not sure that in my area that there's any plans that I'm aware of.
I think there's obviously still areas that could be greatly beneficial.
You know, using AI technology around forecasting for example, and you know complex, obviously, milk supplier is a complex modeling exercise at the rest of times so.
You know, using AI to predict how you know the patterns and all the various parameters that play out could contribute to big volumes I think is probably a good area of focus for someone. But yeah, it's not something that I'm directly across.

**Interviewer** 25:15
Yeah. So, based on your area, it would be difficult. But, whoever involved with this, I meant the collecting milk or the checking the quality and doing the production, it will be like most of them will be using the new technologies, right

**Processing Company Representative** 25:31
Yeah, yeah, I mean.

From my side and procurement, obviously I'm buying dairy ingredients from all around the world.
And so that type of technology as far as it provides insights into things like pricing trends, market trends, any upcoming supply issues would be very useful. So you know we use a lot of market analysis tools.
And I guess in terms of how much they are, how much benefit, I guess AI could provide around, yeah, greater or more accurate price trend forecasting that that would be something we'd be quite interested in.

**Interviewer** 26:14
Yeah, that's true.
Right. Superb. Those are the areas that I needed to collect information. and is there any possibility that you can connect me with other people like production quality or the IT. Also the milk collection so that I can get some more information.

**Processing Company Representative** 26:33
Yeah, no problem. If you want to, just, maybe send me an e-mail with the roles or this sort of areas that you're interested in. I'll let you know who the right people is. And they would be in, in their contact details and yeah feel free to reach out and tell them that you can tell them that I sent you the contact.

**Interviewer** 26:43
Yeah, sure those are the questions that I want to get to know. So then these information are very sensitive and will not expose to anyone.

**Processing Company Representative** 27:04
Yeah. Yeah, I think obviously we have a big milk supply team who are working closely with the farmers and you know they would, they would be well placed to talk to what we're doing on the, on the farmer side. Yeah, the programmes we have in place and what they're working on. So yeah, I can definitely give you those contacts.

**Interviewer** 27:23
Yeah, please, please. That will be a great help.  So thank you very much for your time and also the information as well as the support. I'll drop a mail. Yeah, please provide me some more contact so that I can fix meetings with them and discuss further.

**Processing Company Representative** 27:28

No problem.

Sure, no problem. Bye to help. Awesome. Thank you. You too. Cheers. Bye.

**Interviewer** 27:39

Have a nice day then. Thank you. Thank you. Cheers.

## Appendix F: Distribution of Interviewees and Anonymised Identifiers

| Respondent ID | Anonymised Identifier | Size of the Dairy Farm |
|---|---|---|
| NZDF1 | New Zealand Dairy Farmer 01 | Large |
| NZDF2 | New Zealand Dairy Farmer 02 | Medium |
| NZDF3 | New Zealand Dairy Farmer 03 | Small |
| NZDF4 | New Zealand Dairy Farmer 04 | Large |
| NZDF5 | New Zealand Dairy Farmer 05 | Small |
| NZDF6 | New Zealand Dairy Farmer 06 | Medium |
| NZDF7 | New Zealand Dairy Farmer 07 | Medium |
| NZDF8 | New Zealand Dairy Farmer 08 | Large |
| NZPC1 | New Zealand Processing Company Representative 01 | - |
| NZPC2 | New Zealand Processing Company Representative 02 | - |
| NZPC3 | New Zealand Processing Company Representative 03 | - |
| NZPC4 | New Zealand Processing Company Representative 04 | - |
| NZPC5 | New Zealand Processing Company Representative 05 | - |
| NZPC6 | New Zealand Processing Company Representative 06 | - |

## Appendix G: Data Analysis Codebook

### Interview Excerpts and Data Analysis Codes

| Interview Excerpts | Code | Theme |
|---|---|---|
| *"The sensors help to keep track of the cows' health. We can catch issues early before they become big problems." (NZDF01_S2)* | Knowledge of IoT Sensors | Understanding and Awareness of Supply Chain 4.0 Technologies |
| *"I've heard that blockchain can help trace where our milk goes. It helps to prove that it's coming from a good, clean farm. That could be a selling point." (NZDF08_S2)* | Knowledge of Blockchain | Understanding and Awareness of Supply Chain 4.0 Technologies |
| *"Consumers want to know where their food comes from and that it's been produced sustainably. Blockchain can help us show that." (NZPC03_S2)* | Knowledge of Blockchain | Understanding and Awareness of Supply Chain 4.0 Technologies |
| *"The data we get from our sensors helps us use resources more wisely. We're using less water and fertilizer, which is better for the environment and saves us money in the long run." (NZDF03_S2)* | Knowledge of Data Analytics | Understanding and Awareness of Supply Chain 4.0 Technologies |
| *"We attended a training session on new farming technologies, which helped us understand the benefits of automation and AI." (NZDF05_S6)* | Sources of Information – Training & Workshops | Understanding and Awareness of Supply Chain 4.0 Technologies |
| *"We often discuss technology adoption with other farmers. Seeing how others are using AI has given us confidence to try it ourselves." (NZDF04_S6)* | Sources of Information – Peer Networks | Understanding and Awareness of Supply Chain 4.0 Technologies |
| *"Automation has taken a lot of pressure off us. We don't need to spend hours manually milking the cows anymore, and that frees up time for other tasks." (NZDF07_S3)* | Efficiency and Productivity | Adoption Drivers and Barriers |

| | | |
|---|---|---|
| *"We use implanted chips to track cows'. It helps us to identify the reproductive cycles and detect early signs of illness. This way, we can address quickly before problems get serious. That saves us both time and money." (NZDF01_S2)* | Efficiency and Productivity | Adoption Drivers and Barriers |
| *"The AI collars help to control the herd, their behavior, individual data, and overall health. We get an alert immediately if something goes wrong. That helps us to take action before it affects milk production." (NZDF08_S2)* | Efficiency and Productivity | Adoption Drivers and Barriers |
| *"We wanted to save time and labor, and the automated systems have made that possible. Now we can focus on improving the overall quality of the farm instead of getting engaged in daily repetitive tasks." (NZDF03_S2)* | Efficiency and Productivity | Adoption Drivers and Barriers |
| *"The biggest barrier was the initial cost. The technology is expensive, and it was a significant investment for us." (NZDF04_S3)* | Cost Barriers | Adoption Drivers and Barriers |
| *"The cost is the biggest issue for us. We simply don't have the capital to invest in these expensive technologies, even though we can see the benefits." (NZDF07_S3)* | Cost Barriers | Adoption Drivers and Barriers |
| *"We can't afford to take risks on expensive technology that we might not even be able to use properly." (NZDF02_S3)* | Cost Barriers | Adoption Drivers and Barriers |
| *"We're not highly technical people. It's difficult to learn how to use these new systems, and we worry about what will happen if something goes wrong." (NZDF06_S3)* | Technical Expertise Barriers | Adoption Drivers and Barriers |
| *"Connectivity is a major challenge for us. We struggle with internet access, which limits our ability to use real-time data tools effectively." (NZDF04_S3)* | Infrastructure Challenges | Adoption Drivers and Barriers |

| | | |
|---|---|---|
| *"We've been farming this way for years. I'm not convinced that all this new technology is worth the hassle." (NZDF07_S3)* | Resistance to Change | Adoption Drivers and Barriers |
| *"We've seen a noticeable improvement in productivity. The sensors help us monitor the cows better, and the automated milking system has reduced the time and labor needed for milking." (NZDF01_S4)* | Increased Productivity | Impact on Farm Operations |
| *"Since we started using automated milking systems, we've seen an increase in milk production and a decrease in labor costs. It's definitely been worth the investment." (NZDF02_S4)* | Increased Productivity | Impact on Farm Operations |
| *"We've seen a 10% increase in milk production since we started using automated systems. It's made a huge difference." (NZDF05_S4)* | Increased Productivity | Impact on Farm Operations |
| *"We're already seeing a return on investment through higher yields and lower labor costs." (NZDF05_S4)* | Improved Profitability | Impact on Farm Operations |
| *"Before we installed the automated pivots, we relied on manual irrigation, which was time-consuming and inconsistent. Now, we can control everything remotely even from our homes through the mobile. It helps to adjust water levels based on soil moisture, and save on water use." (NZDF05_S4)* | Sustainability Benefits | Impact on Farm Operations |
| *"We've received a lot of support from our cooperative. They provided us with some financial assistance and arranged training sessions to help us get started with the new systems." (NZPC03_S5)* | Cooperative Support | Stakeholder Collaboration and Support |

| | | |
|---|---|---|
| *"The training we received from our cooperative made all the difference. Without it, we wouldn't have known where to start." (NZPC03_S5)* | Cooperative Support | Stakeholder Collaboration and Support |
| *"We work closely with dairy farmers by providing them with training and financial support." (NZPC05_S5)* | Processing Company Support | Stakeholder Collaboration and Support |
| *"Our technology provider has been very supportive, offering training sessions and 24/7 technical support." (NZPC06_S5)* | Technology Provider Collaboration | Stakeholder Collaboration and Support |
| *"Government grants helped us afford the initial cost of new equipment." (NZPC03_S5)* | Government Support | Stakeholder Collaboration and Support |
| *"The government needs to step in and provide more support if we want to see widespread adoption of these technologies. Without policy support, it will be hard for smaller farms to keep up." (NZPC05_S5)* | Government Support | Stakeholder Collaboration and Support |
| *"More training and financial support would definitely help in making these plans a reality." (NZDF02_S6)* | Training Needs | Future Prospects and Recommendations |
| *"Government grants helped us afford the initial cost of new equipment." (NZPC05_S6)* | Financial Support Needs | Future Prospects and Recommendations |
| *"We need training to understand how to use these systems effectively." (NZDF05_S6)* | Technical Support Needs | Future Prospects and Recommendations |
| *"Collaborative research can lead to innovative solutions that are more suited to our unique challenges." (NZPC01_S6)* | Collaboration for Innovation | Future Prospects and Recommendations |
| *"Scaling these technologies across the entire industry is difficult because smaller farms don't have the same resources as larger operations. We need to find ways to make these technologies more accessible." (NZPC01_S6)* | Collaboration for Innovation | Future Prospects and Recommendations |

# Appendix H: Sample Data Analysis Tables

## H.1 Understanding and Awareness of Supply Chain 4.0 Technologies

| | Knowledge of | | | | |
|---|---|---|---|---|---|
| **Respondent ID** | **IoT Sensors** | **Automated Milking Systems** | **Blockchain** | **AI** | **Sources of Information** |
| NZDF1 | High | High | Medium | High | IT Service providers, Processing Companies |
| NZDF2 | Medium | High | Low | Medium | Peer networks, Social media, Events, Advertisements |
| NZDF3 | High | High | Low | High | Workshops organised by processing company, DairyNZ, Newsletter, Email |
| NZDF4 | Medium | High | Low | Low | Internet, Peer networks, Advertisements, Advertisements, Weekly prints |
| NZDF5 | High | High | Medium | High | Social Media, Internet, Peer networks, Internet, Dairy Association |
| NZDF6 | High | High | Low | Medium | Internet, Social media |
| NZDF7 | High | High | Low | Medium | IT companies, Peer Groups |
| NZDF8 | High | High | High | High | Newsfeed, Publications, Forum, Advertisements, Internet, Newspapers |
| NZPC1 | High | High | Medium | Medium | Internal company training |
| NZPC2 | Medium | Medium | High | High | Company IT, research and development teams |
| NZPC3 | High | High | High | High | Technical workshops, Seminars |
| NZPC4 | High | High | High | High | Collaboration with technology providers |
| NZPC5 | High | High | High | Medium | Supplier training sessions |
| NZPC6 | High | High | High | Medium | Industry conference |

## H.2 Adoption Drivers and Barriers

| Respondent ID | Drivers | Barriers |
|---|---|---|
| NZDF1 | Efficiency, Productivity, Labour saving | Technical expertise, Initial Investment |
| NZDF2 | Cost saving, Sustainability | Cost, Technical expertise |
| NZDF3 | Productivity, Cost Saving, Minimizing wastages | Initial investment, Technical Expertise |
| NZDF4 | Efficiency, Sustainability | Lack of knowledge, Cost, Infrastructure |
| NZDF5 | Efficiency, Productivity, Cost Saving | Cost, Need for skilled personnel |
| NZDF6 | Efficiency, Safety | Cost, infrastructure |
| NZDF7 | Efficiency, Productivity | Technical expertise, Cost |
| NZDF8 | Efficiency, Productivity, Product quality, Sustainability | Cost, Initial investment |
| NZPC1 | Efficiency, Traceability | Initial investment |
| NZPC2 | Efficiency, Traceability | Technical expertise, Cost |
| NZPC3 | Accuracy, Productivity | Cost, Need for skilled personnel |
| NZPC4 | Efficiency, Traceability, Productivity | Initial investment, Technical Expertise |
| NZPC5 | Quality, Traceability, Sustainability | Technical expertise, Cost |
| NZPC6 | Productivity, Traceability | Cost, Infrastructure |

## H.3 Impact on Farm Operation

| Respondent ID | Productivity Impact | Profitability Impact | Sustainability Impact |
|---|---|---|---|
| NZDF1 | Increased milk yield, Reduced labour cost | Higher yields, Lower labour cost | Reduced water and fertilizer use |
| NZDF2 | Time-saving, Reduced labour cost | Lower cost, quality improvement | Optimized resource use |
| NZDF3 | Improved animal health, Reduced labour | Lower cost, Improved quality | Minimum wastage of water and fertilizer, Improved water quality |
| NZDF4 | Increased milk yield, Improved health | Lower labor cost, Higher yield | Reduced water and fertilizer use |
| NZDF5 | Reduced labour costs, | Better management, Quality improvement | Optimized resource use |
| NZDF6 | Time-saving, Reduced labour cost | Lower Cost, Higher yields | Reduced water, Optimised resources |
| NZDF7 | Efficient feeding management | Minimum wastage, Lower cost | Optimized resource use |
| NZDF8 | Improved health monitoring, Save time | Better management, Lower cost, Quality improvement | Reduced environmental footprint |
| NZPC1 | Streamlined processes | Improved cost management | Enhanced traceability |
| NZPC2 | Optimize supply chain | Increased market demand | Compliance with sustainability |
| NZPC3 | Optimize processes | Improved cost management | Reduced environmental footprint |
| NZPC4 | Streamlined processes | Quality improvement | Minimum wastage |
| NZPC5 | Optimize supply chain | Lower manpower improved quality | Enhanced traceability |
| NZPC6 | Time-saving | Improved quality and cost management | Reduced environmental footprint |

## H.4 Stakeholder Collaboration and Support

| | Support from | | |
|---|---|---|---|
| **Respondent ID** | **Processing Company Support** | **Technology Provider Support** | **Government Support** |
| NZDF1 | Collaborative initiatives, Grants | Custom solutions, Maintenance services | Partnerships with cooperatives |
| NZDF2 | Collaborative programs | Training Program, 24/7 assistance | Training programs, Subsidies |
| NZDF3 | Joint projects, Financial incentives | Technical support, training sessions | Grants, Subsidies, loans with low interest |
| NZDF4 | Joint projects, Subsidies | Remote troubleshooting, on-site support | Rural connectivity programs |
| NZDF5 | None | Customized solutions, Training | Subsidies, Training programs |
| NZDF6 | Regular meetings, knowledge sharing | Ongoing support | Financial assistance, training sessions |
| NZDF7 | Joint projects | Training, Prompt solutions | Financial assistance, training sessions |
| NZDF8 | Direct support to farmers | Technical support, training sessions | Incentives for sustainable practices |
| NZPC1 | Direct support to farmers | Research collaborations, feedback loops | Partnerships with cooperatives |
| NZPC2 | Joint projects | Training programs | Research & Development grants |
| NZPC3 | Financial incentives | Ongoing technical and maintenance support | Technology adoption subsidies |
| NZPC4 | Collaborative programs | Customized solutions, Training | Financial and technical support |
| NZPC5 | Pilot programs, co-developed solutions | Technical support, training sessions | Smart logistic support |
| NZPC6 | Training sessions | 24/7 assistance | Technical support |

## H.5 Future Prospects and Recommendations

| Respondent ID | Training Needs | Financial Support Needs | Technical Support Needs | Collaboration Needs |
|---|---|---|---|---|
| NZDF1 | More comprehensive training programs | Increased financial incentives | Scheduled maintenance checks, user support | Public-private partnerships |
| NZDF2 | Continuous training | Subsidies | Hands-on support, training on updates | Partnerships |
| NZDF3 | Access to ongoing education | Grants, low-interest loans for new technology adoption | Customized solutions | Collaboration projects |
| NZDF4 | Workshops, Forum | Subsidies, Grants for new projects | User-friendly troubleshooting guides | Collaboration projects |
| NZDF5 | Practical workshops, online assistance | Low-interest loans | 24/7 support | Collaboration projects |
| NZDF6 | Training | Lower initial investment | Online troubleshoot | Public-private partnerships |
| NZDF7 | Latest updates | Capital support | 24/7 helpdesk, remote support services | Collaboration projects |
| NZDF8 | Forum to discuss | Continued subsidies, low-interest loans | Regular maintenance, and troubleshooting help | Joint research initiatives |
| NZPC1 | In-depth technical training | Government grants, cooperative loans | Guidelines, online support | Partnerships, Stakeholder meetings |
| NZPC2 | Updates on the latest technologies | Financial Support | Hands-on support, training on updates | Feedback mechanisms |
| NZPC3 | Updates on the latest technologies | Co-funding for technology investments | 24/7 support | Public-private partnerships |
| NZPC4 | Forum to discuss | Capital support | Update on latest technologies | Industry-wide collaboration projects |
| NZPC5 | In-depth technical training | Low interest loans | Guidelines, online support | Collaborative innovation efforts |
| NZPC6 | Training | Lower initial investment | Regular maintenance | Industry-wide collaboration projects |

## Appendix I: Glossary of Key Terms

**Supply Chain 4.0:** The integration of advanced digital technologies such as IoT, blockchain, artificial intelligence, and data analytics to enhance supply chain efficiency, transparency, and responsiveness.

**IoT Sensors:** Internet of Things (IoT) sensors are devices that collect and transmit data over the internet, used for real-time monitoring and management of farm operations.

**Artificial Intelligence (AI):** The imitation of human intelligence in machines that can analyse data, learn from patterns, and make decisions with minimal human intervention. In agriculture, AI is used for livestock monitoring, automated decision-making, and optimizing farm operations.

**Automated Milking Systems:** Advanced milking technology that automates the process of milking cows, reducing labour and improving efficiency.

**Blockchain:** A decentralized digital ledger that records transactions across multiple computers, ensuring transparency and traceability in the supply chain.

**Data Analytics:** The process of examining data sets to conclude the information they contain, often using specialized systems and software.

**Precision Farming:** Agricultural practices that use technology to monitor and optimize farming processes, enhancing efficiency and sustainability.

# References


Ahmad, M., Zhang, D., & Wang, Y. (2021). Applications of blockchain and Internet of Things in sustainable agri-food supply chains: A systematic literature review. *Computers and Operations Research*, *128*, 105–146.

Antón, D., Kurillo, G., Goñi, A., Illarramendi, A., & Bajcsy, R. (2017). Real-time communication for Kinect-based telerehabilitation. *Future Generation Computer Systems*, *75*, 72–81. https://doi.org/10.1016/j.future.2017.05.006

Atkinson, R., & Flint, J. (2001). Accessing hidden and hard-to-reach populations: Snowball research strategies. *Social Research Update*, *33*, 1–4.

Bagozzi, R. P. (2007). The legacy of the technology acceptance model and a proposal for a paradigm shift. *Journal of the Association for Information Systems*, *8*(4), 244–254.

Borchers, A., Pieper, J., & Runck, B. (2020). Assessment of digital technology adoption and access barriers among crop, dairy and livestock producers in Wisconsin. *Computers and Electronics in Agriculture*, *104954*, 165.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Bryman, A. (2016). *Social research methods* (5th ed.). Oxford University Press.

Büyüközkan, G., & Göçer, F. (2018). Digital supply chain: Literature review and research propositions. *Computers in Industry*, *97*, 157–177.

Casino, F., Kiani, M., & Dasaklis, T. K. (2019). Blockchain-based supply chain traceability: A systematic review. *International Journal of Production Research*, *57*(7), 2325–2341.

Chen, H., Zhang, C., & Li, Y. (2020). *Big Data Analytics in Healthcare. In Big Data Analytics in Healthcare.* Springer. Retrieved from https://link.springer.com/chapter/10.1007/978-981-99-1075-5_2

Chen, Z., & Liu, J. (2023a). Sustainable supply chain management: The role of ESG factors in stakeholder engagement. *Journal of Cleaner Production*, *398*, 136578.

Chen, Z., & Liu, J. (2023b). Sustainable supply chain management: The role of ESG factors in stakeholder engagement. *Journal of Cleaner Production*, *398*, 136578.

Christopher, M. (2016). *Logistics & supply chain management* (5th ed.). Pearson UK.

Cortes, A., Mohri, M., & Rostamizadeh, A. (2019). Predictive analytics in supply chain management: A case study. *Journal of Business Research*, *98*, 362–370.

Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry and research design: Choosing among five approaches*. Sage Publications.

Crick, J. M., Crick, D., & Tebbett, N. (2020). Competitor orientation and value co-creation in sustaining rural New Zealand wine producers. *Journal of Rural Studies*, *73*, 122–134. https://doi.org/10.1016/j.jrurstud.2019.10.019

DairyNZ. (2011). *Guide to Good Irrigation Part 1: good irrigation practices on-farm*. https://www.dairynz.co.nz

DairyNZ. (2023). *dairy_statistics_2022-23_book_-final*. https://www.dairynz.co.nz

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, *13*(3), 319–340.

de Lima, W. B., da Silva, D. D., da Costa, C. A., Pessin, G., de Pádua D. A., & Giaretta, A. (2023). Industry 4.0-based technologies in the dairy supply chain: A systematic literature review. *Trends in Food Science & Technology*, *134*, 51–65.

Derakhti, A., Santibanez Gonzalez, E. D. R., & Mardani, A. (2023). Industry 4.0 and beyond: A review of the literature on the challenges and barriers facing the agri-food supply chain. *Sustainability*, *15*(6), 5078.

Desforges, X., Diévart, M., & Archimède, B. (2017). A prognostic function for complex systems to support production and maintenance co-operative planning based on an extension of object oriented Bayesian networks. *Computers in Industry*, *86*, 34–51. https://doi.org/10.1016/j.compind.2017.01.002

Dubey, R., Gunasekaran, A., Childe, S. J., Papadopoulos, T., & Wamba, S. F. (2016). Big data analytics in supply chain management. *Journal of Business Research*, *69*(5), 1765–1770.

Eastwood, C., Bines, T., & Church, L. (2019). The role of technology in enhancing rural employment and skill development in agriculture. *Journal of Agricultural Economics*, *70*(3), 528–546.

Eastwood, C., Grant, R. W., & He, Z. (2019). The role of big data analytics in enhancing dairy farm supply chain coordination and profitability. *Journal of Dairy Science*, *102*(12), 10578–10588.

Eastwood, C., Klerkx, L., & Ayre, R. (2019). The role of technology in enhancing rural employment and skill development in agriculture. *Agricultural Systems*, *174*, 106–115.

Farooq, M. S., Hao, Y., Jonathan, T., & Maqbool, S. (2017). Understanding the adoption of mobile agricultural services: An application of the UTAUT model. *Computers in Human Behavior*, *71*, 244–254.

Farziyeva, G., & Dhanik, N. (n.d.). *Digital Transition of Supply Chain with Industry 4.0 Applications*. http://www.teknik.uu.se/education/

Freeman, R. E. (1984). *Strategic management: A stakeholder approach*. Pitman.

Freeman, R. E. (2010). *Strategic Management*. Cambridge University Press. https://doi.org/10.1017/CBO9781139192675

García, A., Garcia, R., & Martínez, C. (2020). Challenges in IoT adoption in agriculture: A review. *Computers and Electronics in Agriculture*, *175*, 105–113.

Gloy, B. A., LaDue, E. L., & Cuykendall, C. H. (2017). The adoption of precision agriculture technologies by New York dairy producers. *Agricultural and Resource Economics Review*, *30*(2), 138–149.

Goliński, P., Sobolewska, P., Stefańska, B., & Golińska, B. (2023). Virtual fencing technology for cattle management in the pasture feeding system. *Agriculture*, *13*(1), 91.

Guest, G., Bunce, A., & Johnson, L. (2006). How Many Interviews Are Enough? *Field Methods*, *18*(1), 59–82. https://doi.org/10.1177/1525822X05279903

Hammersley, M., & Atkinson, P. (2019). *Ethnography: Principles in practice* (4th ed.). Routledge.

Harrison, J. S., Barney, J. B., Pratt, M. G., & Hansen, M. T. (2022). Managing stakeholder relationships: The emerging perspective of the multilateral stakeholder approach. *Academy of Management Review*, *47*(2), 180–202.

Hennink, M. M., Kaiser, B. N., & Marconi, V. C. (2017). Code Saturation Versus Meaning Saturation. *Qualitative Health Research*, *27*(4), 591–608. https://doi.org/10.1177/1049732316665344

Iansiti, M., & Lakhani, K. R. (2017). The truth about blockchain. *Harvard Business Review*, *95*(1), 118–127.

Ivanov, D. (2020). Predictive analytics in supply chain management. *International Journal of Production Economics*, *227*, 107–120.

Ivanov, D., Dolgui, A., & Sokolov, B. (2019a). Digital supply chain management: Current state and future prospects. *International Journal of Production Research*, *57*(9), 1–18.

Ivanov, D., Dolgui, A., & Sokolov, B. (2019b). The impact of digital technologies on supply chain management. *International Journal of Production Research*, *57*(12), 3792–3807.

Ivanov, D., Tsipoulanidis, A., & Schönberger, J. (2019). *Global Supply Chain and Operations Management*. Springer International Publishing. https://doi.org/10.1007/978-3-319-94313-8

Javaid, M., Haleem, A., Singh, R. P., & Suman, R. (2022). Enhancing smart farming through the applications of Agriculture 4.0 technologies. *International Journal of Intelligent Networks*, *3*, 150–164. https://doi.org/10.1016/j.ijin.2022.09.004

Javaid, M., Haleem, A., Singh, R. P., Suman, R., Rab, S., & Sirohi, J. (2022). Industry 4.0 applications in smart farming: A review and future research directions. *Sustainable Operations and Computers*, *3*, 275–285.

Kaine, S., Borrelli, P., Frolova, E., & Shrestha, P. (2019). Digital transformation in agriculture: A stakeholder analysis. *Technological Forecasting and Social Change*, *146*, 512–520.

Kamath, R. (2018). The case for blockchain in supply chain management. *Harvard Business Review*, *96*(1), 20–27.

Kamble, S., Gunasekaran, A., & Gawankar, S. A. (2018). Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives. *Business Strategy and the Environment*, *27*(7), 1002–1022.

Kamble, S., Gunasekaran, A., & Gawankar, S. A. (2020). Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications. *Sustainable Production and Consumption*, *21*, 56–73.

Kamilaris, A., Kartakoullis, A., & Prenafeta-Boldú, F. X. (2017). A review of the Internet of Things for agriculture. *Computers and Electronics in Agriculture*, *142*, 155–170.

Kanda, W., Hjelm, O., & Clausen, J. (2019). Responsible innovation processes for sustainability: Advances in European sustainable technology adoption. *Sustainability*, *142*, 1125.

Katchova, A. L., & Ahearn, M. C. (2018). An introduction to mixed methods research in agricultural economics: The example of farm investment in Ontario's Greenbelt, Canada. *Journal of Rural Studies*, *64*, 82–93.

Klerkx, L., Aarts, N., & Leeuwis, C. (2010). Understanding farmer innovation: Lessons from precision agriculture. *Journal of Rural Studies*, *26*(2), 95–105.

Klerkx, L., Jakku, E., & Labarthe, P. (2019). A review of social science on digital agriculture, smart farming, and agricultural innovation systems. *Agricultural Systems*, *173*, 157–165.

Kusiak, A. (2017). Smart manufacturing must embrace big data. *Nature*, *544*(7648), 23–25. https://doi.org/10.1038/544023a

Kvale, S., & Brinkmann, S. (2009). *Interviews: Learning the craft of qualitative research interviewing* (2nd ed.). Sage Publications.

Li, S., Li, Y., & Zuo, M. (2019). Blockchain technology in supply chain management: A comprehensive review and directions for future research. *International Journal of Production Research*, *57*(7), 2131–2150.

Lim, W. M. (2025). What is qualitative research? An overview and guidelines. Qualitative Market Research. *An International Journal*, *28*(1), 1–22.

MacCarthy, B. L., Blome, C., Olhager, J., Srai, J., & Zhao, X. (2016). Supply chain evolution – theory, concepts and science. *International Journal of Operations & Production Management*, *36*(12), 1696–1718.

Mahmud, M. S., Islam, M. M., Kim, J. M., & Hossain, M. S. (2023). IoT-based smart livestock monitoring and tracking system in long-distance transportation. *Internet of Things, 21*, 100722.

Marjani, M. R., Nasaruddin, F. M., & Ngu, A. H. (2017). Challenges of data integration in agricultural big data analytics. *Agricultural Systems*, *151*, 147–156.

Masi, D., Day, S., Godsell, J., & Samuel, D. (2021). Supply Chain 4.0 and food sustainability: A systematic literature review. *Sustainability*, *13*(10), 5587.

Masi, M., Day, S., & Godsell, J. (2021). Supply Chain Configurations in the Circular Economy: A Systematic Literature Review. *Sustainability*, *13*(16), 9267.

McKinsey & Company. (2020). *Supply Chain 4.0: The next-generation digital supply chain*. https://www.mckinsey.com/business-functions/operations/our-insights/supply-chain-40--the-next-generation-digital-supply-chain

MDPI. (2023). *Internet of Things (IoT) sensors application in dairy cattle farming [Figure]*. Retrieved from https://www.mdpi.com

Ministry for Primary Industries (MPI). (2020). *Situation and Outlook for Primary Industries: December 2020. New Zealand Government*. Retrieved from https://www.mpi.govt.nz

Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. *Academy of Management Review*, *22*(4), 853–886.

Monostori, L., Kádár, B., Bauernhansl, T., Kondoh, S., Kumara, S. R. T., & Reinhart, G. (2016). Cyber-physical systems in supply chain management: A review. *Procedia CIRP*, *55*, 123–128.

Moustakas, C. (1994). *Phenomenological research methods*. Sage Publications.

Noy, C. (2008a). Sampling Knowledge: The Hermeneutics of Snowball Sampling in Qualitative Research. *International Journal of Social Research Methodology*, *11*(4), 327–344. https://doi.org/10.1080/13645570701401305

Noy, C. (2008b). Sampling knowledge: The hermeneutics of snowball sampling in qualitative research. *International Journal of Social Research Methodology*, *13*(16), 327–344.

Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry*, *83*, 121–139.

Oliveira, M. I. S., Silva, D. F., Lima, J. S., & Lima, M. A. P. (2019). Internet of Things (IoT): Sensors Application in Dairy Cattle Farming. *Animals*, *35*(4), 3071. Retrieved from https://aimlprogramming.com/services/ai-driven-cattle-feed-optimization-for-dairy-farms/

O'Neill, C., Smith, J., & Brown, K. (2020). AI-Driven Cattle Feed Optimization for Dairy Farms. *Journal of Dairy Science and Technology*, *35*(4), 123–130. Retrieved from https://aimlprogramming.com/services/ai-driven-cattle-feed-optimization-for-dairy-farms/

Pannell, D. J., Marshall, G. R., Barr, N., Curtis, A., Vanclay, F., & Wilkinson, R. (2006). Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture*, *46*(11), 1407–1424.

Patton, M. Q. (2014). *Qualitative research and evaluation methods: Integrating theory and practice* (4th ed.). Sage Publications.

Raman, R. K., Singh, M., Bhardwaj, A., & Jaiswal, A. (2022). Blockchain technology for dairy supply chain traceability and safety: A practical implementation in the Indian context. *Journal of Cleaner Production*, *371*, 133617.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Rubmann, T., Haller, S., & Kuehl, J. (2015). *Industry 4.0: The New Industrial Revolution*. McKinsey & Company.

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, *57*(7), 2117–2135.

Sauer, J., & Latacz-Lohmann, U. (2015). Innovation adoption and farm productivity: A meta-analysis. *Agricultural Economics*, *46*(6), 693–704.

Saunders, M., Lewis, P., & Thornhill, A. (2011). *Research methods for business students* (6th ed.). Pearson Education.

Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information*, *22*(2), 63–75.

Siems, E., Seuring, S., & Schilling, L. (2023). Stakeholder roles in sustainable supply chain management: a literature review. *Journal of Business Economics*, *93*(4), 747–775. https://doi.org/10.1007/s11573-022-01117-5

Singh, S. K., Rathore, S., Park, J. H., & Park, J. H. (2022). Intelligent communication ecosystem for sustainable agriculture using blockchain and IoT-enabled technologies. *Journal of Cleaner Production*, *331*, 129994.

Sinha, A., Kaur, P., Bhatti, S. H., de Sousa Jabbour, A. B. L., & Dhir, A. (2023). Dairy 4.0: Embracing digital technology for sustainable farming. *Journal of Cleaner Production*, *384*, 135700.

Sivarajah, U., Kamal, M. M., Irani, Z., & Weerakkody, V. (2017). Critical review of big data challenges and analytical methods in the public sector. *Journal of Business Research*, *70*, 228–237.

Sonka, S. T. (2014). The role of automation in the dairy industry. *Journal of Dairy Science*, *97*(3), 1187–1193.

Springer. (2023). *Editorial policies. Springer*. Retrieved March 01, 2025, from https://www.springer.com/gp/editorial-policies

Srinivasan, R., & Swink, M. (2018). A study of the impact of digital technologies on supply chain management in agriculture. *Journal of Supply Chain Management*, *54*(4), 49–63.

Sundmaeker, H., Verdouw, C., Wolfert, S., & Beulens, A. (2010). Internet of Things in the agri-food sector. *In 2010 IEEE International Conference on the Internet of Things (Pp. 1–7)*.

Swan, M. (2015). *Blockchain: Blueprint for a new economy*. O'Reilly Media.

Thomas, D. R. (2006). A General Inductive Approach for Analyzing Qualitative Evaluation Data. *American Journal of Evaluation*, *27*(2), 237–246. https://doi.org/10.1177/1098214005283748

Tian, F. (2017). An agri-food supply chain traceability system for China based on RFID & blockchain technology. *Proceedings of the 2017 13th International Conference on Service Systems and Service Management*, 1–6.

United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. Retrieved from Https://Www.Un.Org/Sustainabledevelopment/Development-Agenda/.

Van der Burg, S., Bogaardt, M.-J., & Wolfert, S. (2019). Birth of dairy 4.0: Opportunities and challenges in adoption of fourth industrial revolution technologies in the production of milk and its derivatives. *Procedia CIRP*, *81*, 1–6.

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science*, *46*(2), 186–204.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly*, *27*(3), 425–478.

Venkatesh, V., Thong, J. Y. L., & Xu, X. (2012). Consumer acceptance and use of information technology: Extending the Unified Theory of Acceptance and Use of Technology. *MIS Quarterly*, *36*(1), 157–178.

Verdouw, C., Wolfert, S., & Beulens, A. (2021). The impact of IoT on agriculture: Technical challenges and benefits. *Computers in Industry*, *128*, 20–32.

Wamba, S. F., Gunasekaran, A., Akter, S., Ren, S. J., & Dubey, R. (2017). Big data analytics and firm performance: An integrated framework. *Computers in Industry*, *97*, 1–14.

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming—A review. *Agricultural Systems*, *153*, 69–80.

Wood, D. J., Mitchell, R. K., Agle, B. R., & Bryan, L. M. (2021). Stakeholder Identification and Salience After 20 Years: Progress, Problems, and Prospects. *Business & Society*, *60*(1), 196–245. https://doi.org/10.1177/0007650318816522

Wu, S., Zhang, C., & Li, J. (2019). Understanding farmers' adoption of IoT-based solutions in agriculture: An extension of the Technology Acceptance Model. *Computers and Electronics in Agriculture*, *161*, 34–45.

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage Publications.

Zarei-Kordshouli, F., Paydar, M. M., & Nayeri, S. (2023). Designing a dairy supply chain network considering sustainability and resilience: A multistage decision-making framework. *Clean Technologies and Environmental Policy*, *25*(9), 2903–2927.

Zhou, R., Chen, H., Wang, X., Hou, L., Meng, Y., & Wang, T. (2024). Practices, challenges, and future of digital transformation in smallholder agriculture: Insights from a literature review. *Agriculture*, *14*(12), 2193.