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BLOCKCHAIN TECHNOLOGY FOR FOOD SUPPLY CHAIN: AN INVESTIGATION OF THE IMPLEMENTATION PROCESS AND IMPACT ON SUPPLY CHAIN PERFORMANCE.

School of Management
PhD in Leadership and Management

Academic Year: 2019 - 2023

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ABSTRACT

The food supply chain (FSC) plays a vital role in sustaining human life and achieving economic growth. Food and agricultural products are inherently perishable, sensitive to temperature, dependent on nature for production, and seasonal. As the result, businesses have to face specific and persistent challenges in monitoring food quality and safety, and reducing waste. Moreover, the globalization and complexity of the modern FSC can lead to pressing issues such as information asymmetry, low transparency, and food adulteration.

Businesses and academics have explored Blockchain technology as a potential remedy for the hurdles of managing the FSC. While the technology has grown at an impressive pace, the knowledge regarding Blockchain adoption and its impact is yet fully explored. Therefore, there is a compelling need for researching the Blockchain phenomenon in the FSC setting, contributing to both literature and practice, and ultimately to better management of food products.

To close the gap, this thesis particularly aims to investigate the adoption process of Blockchain and its impact on operational performance. Through a series of three studies, this thesis provided a literature review of the subject, developed an evidence-driven model for Blockchain integration, evaluated the relationships between important determinants to the Blockchain implementation stages, and specified the effects of adopting Blockchain on key performance metrics of the FSC.

The key findings of this thesis are three-fold. First, the thesis provided an extensive and scientific systematic literature review about the current state of Blockchain adoption research in the area of food supply chain management. Specifically, the literature review synthesized four main themes from relevant literature, including the Blockchain adoption process, drivers and barriers to the adoption, and applications of Blockchain in food management. Second, the thesis constituted a holistic model of Blockchain implementation in the specific context of the FSC. Started with combining insights from the literature review and Innovation Adoption theoretical lenses to develop a conceptual model for

Blockchain implementation in the FSC, the thesis then employed a mixed-methods approach to develop the conceptual model further. First, interviews were conducted to explore the process of adopting Blockchain in the FSC. Then, quantitative data was gathered by a survey to statistically assess the key relationships in the implementation model. The result is an evidence-based and feasible model of Blockchain adoption for organizations in the FSC. This model details Blockchain implementation activities and critical determinants of the process (implications from interviews findings), as well as analyses the most important determinants of each adoption stage (implications from the survey findings), all in the FSC setting. Third, this thesis evaluates the impact of a successful Blockchain adoption on the operational performances of an FSC. Using the System Dynamics modelling approach and simulations, the thesis illustrates holistically how Blockchain technology can affect key performance metrics, including inventory level, service level, lead time, and cost, at a supply chain level.

Findings in this thesis subsequently make several key contributions to literature, practice, and policy. The thesis extended the current knowledge of the Blockchain phenomenon in the context of FSC, especially how to implement the technology and what impacts it can have on supply chain performance. Moreover, the thesis provided valid attempts at elaborating Innovation Adoption theories and models to better explain the particular context of Blockchain in the FSC and bringing System thinking and System Dynamics approach to examine supply chain phenomenon. The results of this thesis inform managers in the field about the approach to implementing Blockchain technologies, and what factors they need to understand for successful adoption. The System Dynamics models in this thesis further provide a useful tool for businesses to experiment and explore the impacts of the technology on their operations. Moreover, the findings in this thesis suggest several important implications for policymakers. Particularly, they highlight the important role of regulators in advocating for the industry-wide adoption of Blockchain, provide an in-depth understanding of Blockchain roadmap and impacts for promoting the technology among businesses, and suggest regulatory bodies direct more efforts into onboarding the lesser

technologically capable entities in the FSC (farmers, SMEs, etc) to a Blockchain network.

Keywords: Blockchain, Food supply chain, Implementation, Performance, Innovation Adoption, System Dynamics.

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LIST OF ABBREVIATIONS

CLD	Causal loop diagram
ERP	Enterprise Resource Planning
IA	Innovation Adoption
IoT	Internet of Things
FAO	The Food and Agriculture Organization, United Nations
FSC	Food supply chain(s)
FSCM	Food supply chain management
PCR	Polymerase chain reaction
PoW	Proof of Work
RFID	Radio-frequency identification
SCM	Supply chain management
SD	System Dynamics
SFD	Stock and flow diagram

1 INTRODUCTION

1.1 Research background

In the first part of the Introduction chapter, the author provides an overview of the background and context of the research. This PhD thesis aims to examine the Blockchain adoption process and its impact on food supply chain management. Thus, section 1.1 lays the fundamentals of the thesis by discussing the concept of the food supply chain, challenges to the management of the food supply chain, the basics of Blockchain, and the interface between Blockchain and the food supply chain.

1.1.1 Food supply chain and its challenges

Throughout this thesis, the term “food supply chain” (FSC) is frequently used. Therefore, it is important to first establish the definition of FSC. An FSC is a complex network of individuals and organizations, that is responsible for supplying food to the world population by participating in various stages related to producing, harvesting, storing, transporting, processing, and distributing food products (Zhao et al., 2019; Barbosa, 2021). Through providing competitive management and transportation channels, the FSC transforms and moves food from its first point of production, whether that be from cultivating plants or raising livestock to the point of final consumption, whether that be in a home or food service setting (Manzini and Accorsi, 2012; Routroy and Behera, 2017). Other synonymous terms found in the extant literature include agri-food supply chain (Kamble et al., 2020; Barbosa, 2021), agricultural supply chain (Routroy and Behera, 2017), and agri-food value chain (Zhao et al., 2019), all of which refer to the same concept of the FSC as described earlier.

Many of the challenges in managing the FSC stem from the indigenous characteristics of food products such as perishability, seasonality, sensitivity to temperature and environmental conditions, and dependency on natural resources for production (Fredriksson and Liljestrand, 2015; Ali et al., 2019). To this end, businesses in the FSC constantly need to assure food quality, monitor food safety, and reduce food waste (Bourlakis and Bourlakis, 2004; Akkerman et al., 2010; Fredriksson and Liljestrand, 2015). These tasks can be daunting and costly. For instance, as the condition of food and related products continuously degrades until the final destination, whether it be consumption or being discarded, specialized equipment and setup are essential for meeting strict requirements of surroundings (i.e., temperature, moisture, etc) when transporting and storing food (Ben-daya et al., 2020). Limited shelf-life of food also means that spoilage can occur at any stage of the supply chain, pushing managers and businesses to always seek to improve their distribution channels and operational processes to minimize food waste. In a recent report regarding the food waste issue, the United Nations Environment Programme (UNEP) estimated that around 931 million tonnes of food were wasted in 2019, of which 39% was generated at businesses in the FSC such as food services and retailers (UNEP, 2021). Ghadge et al. (2017) found that food waste can impede the financial performance of businesses in the dairy supply chain, and the same can be said for other types of FSC.

Stakeholders in the FSC further need to invest resources and efforts to set up rigorous processes for checking and monitoring food quality at any time the products change custody, to assure that food is safe to sell and consume. These processes can vary, from manually intensive ones (such as visual inspection) to technologically advanced means (such as PCR testing, spectroscopic techniques, chemical and biosensors, etc) (Hassoun et al., 2022a). Moreover, the modern FSC is increasingly globalized and complex; it has a substantial number of stakeholders and is currently under pressure from pressing global issues such as growing population and climate change (Tsolakis et al., 2014; Coronado Moondragon et al., 2020). Thus, the management of FSC (FSCM) has to tackle additional difficulties such as demand variety, information asymmetry, low visibility, risk of food adulteration and counterfeit products, food security, and ensuring sustainability (Tsolakis et al., 2014; Kamble et al., 2020; Ben-Daya et al., 2020).

In the wake of Industry 4.0 technological advancement, companies and managers in the field are turning to novel technologies and digitalization tools as potential remedies for the aforementioned FSCM's persistent challenges (Tsolakis et al., 2014; Barbosa, 2021; Hassoun et al., 2022b). To this end, a wide range of technologies has been explored for better FSCM, including robotics, smart farming equipment, the Internet of Things (IoT), and Blockchain technology (Hassoun et al., 2022b; Kamble et al., 2020; Barbosa, 2021). Among these technological innovations, Blockchain technology has gained significant interest from both industry and academia in recent years. One primary reason for the rise of this technology is because of the lack of transparency and connectivity in the FSC. Especially when the modern FSC is globalized, siloed, and complex, this issue becomes more pressing. To this end, Blockchain can improve data sharing and communication, provide transparency at the supply chain level, enhance processes, and address issues of food safety and authenticity (Zhao et al., 2019; Kamilaris et al., 2019; Casino et al., 2021; Danese et al., 2021). Thus, Blockchain is viewed by practitioners and academics in the FSCM domain, as a potential remedy for many persistent challenges in managing food products. Since Blockchain is a vital part of this thesis, the next section delves into the topic of this technology in more depth.

1.1.2 Blockchain technology

Before discussing what Blockchain is and how it works, a brief history of this novel technology is summarized. Bitcoin is commonly accredited with the birth of Blockchain, as it is the underlying technology that enables Bitcoin to function since the cryptocurrency's introduction in 2009 (Iansiti and Lakhani, 2017; Batwa and Norrman, 2020). The historical development track of Blockchain is, however, slightly more nuanced. In 1991, Haber and Stornetta published a paper about a novel solution for verifying and maintaining the immutability of digital records, using hash functions, digital certificates, and sequential linking data structure (Haber and Stornetta, 1991). The works of Haber and Stornetta heavily inspired Nakamoto and were referenced in their influential white paper "Bitcoin: A Peer-to-Peer Electronic Cash System" (Nakamoto, 2008). Some other notable works, which helped make Blockchain a reality, were introduced in the late 1990s and early 2000s, such as the concept of proof-of-work (PoW) and the concept of the peer-to-peer network (Sheldon, 2021). Finally, in 2008, Satoshi Nakamoto, whose identity remains unknown until this date, announced the birth of the virtual currency system Bitcoin and its underpinning technology - Blockchain (Nakamoto, 2008). One year later, Bitcoin went live, marking the first, and arguably the most influential application of Blockchain technology (Iansiti and Lakhani, 2017). Given that Blockchain originated as the supporting structure of the virtual medium of exchange Bitcoin, it is not surprising that Blockchain's early applications were largely focused on finance-related purposes (Cole et al., 2019; Batwa and Norrman, 2020). Over time, the applications of the technology started to extend outside of the finance sector, as other areas started to recognize the potential benefits of using Blockchain, including the domain of supply chain management (SCM) (Iansiti and Lakhani, 2017; Cole et al., 2019; Wang et al., 2019).

Fundamentally, Blockchain can be understood as a distributed ledger technology (DLT), in which data is bundled into a block, each block needs verification from the majority of the network before being recorded to the system, and a new block of information is linked to the existing chain of blocks (hence the name Blockchain) in the system using cryptographic hash (Kamilaris et al., 2019; Wang et al., 2019; Belotti et al., 2019). It should be noted that Blockchain and DLT are not interchangeable concepts. DLT is an umbrella term referring to a type of database, that spreads across multiple nodes and does not rely on a central party for updating and maintaining (Ray, 2018; Belotti et al., 2019). Being a type of DLT, Blockchain technology also inherits the indigenous characteristics of a distributed database, as each node in a Blockchain network stores an authentic copy of the data (in the form of blocks), and all the nodes can participate in validating added information using a consensus function (Wang et al., 2019). Nonetheless, not all DLTs follow the same principles of Blockchain. The uniqueness of Blockchain stems from the append-only approach to processing and storing data. In Blockchain, once an information block is recorded, the system immediately moves on to work on a new block and the recorded block can no longer be altered (Belotti et al., 2019). Consequently, Blockchain can warrant the immutability and trustworthiness of the information stored on the system (Belotti et al., 2019; Lin et al., 2020). To better illustrate the basics of Blockchain technology, Figure 1-1 presents a schematic depiction of how data is added to a Blockchain system, what a block contains, and how blocks are linked using cryptographic hash values.

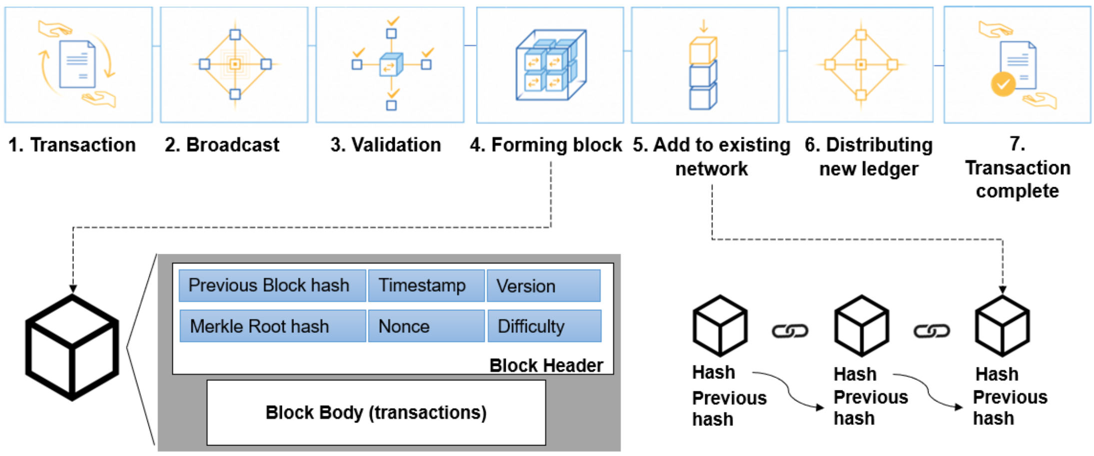

Figure 1-1. Simplification of the Blockchain process (adapted from Nascimento and Polvora (2019) and Kamilaris et al. (2019)).

The process starts with newly generated information (i.e., financial transactions or logistics information) being recognized by the system and broadcasted among all members of the Blockchain network. Subsequently, those members validate and seek agreement on the accuracy of the information (the method of validation varies depending on the consensus mechanism in use). Once the majority, if not all of the network, accepts that the information is correct, they are then bundled into a block of data. A typical block consists of a block header, which contains identification information of the block, and a block body, which contains the to-be-added transactions (See Figure 1-1). Next, the newly formed block is attached to the existing chain of blocks, linking to the preceding block by hash value. The most updated version of the database is now broadcasted to each member of the Blockchain network, and the system starts working on the next block, repeating the same process. This unique mechanism of communicating, validating, and storing information gives the Blockchain system trustworthiness and immutability, as real-time distribution of data (Cole et al., 2019; Kamilaris et al., 2019; Wang et al., 2019).

The main aim of this section is to provide a fundamental understanding of Blockchain technology. For a more comprehensive review of Blockchain technology, including technical aspects such as *consensus mechanisms, smart contracts, data structure, governance structure, etc.*, readers can see specialized works such as Belotti et al. (2019) and Lin et al. (2020).

1.1.3 The interface between Blockchain and the FSC

Blockchain technology quickly advances beyond its root in the finance sector, as businesses realized that the technology can be used to capture and secure not only transactional data but also data regarding physical assets, i.e., custody, locations, and conditions (Cole et al., 2019; Wang et al., 2019). Among those industries, the FSC has been at the forefront of exploring Blockchain as a potential solution for addressing FSCM's persistent challenges such as information asymmetry, lack of trustworthy data, low visibility, and the lack of effective traceability tools for food products in a long and complex supply line (Kamilaris et al., 2019; Zhao et al., 2019; Chen et al., 2020).

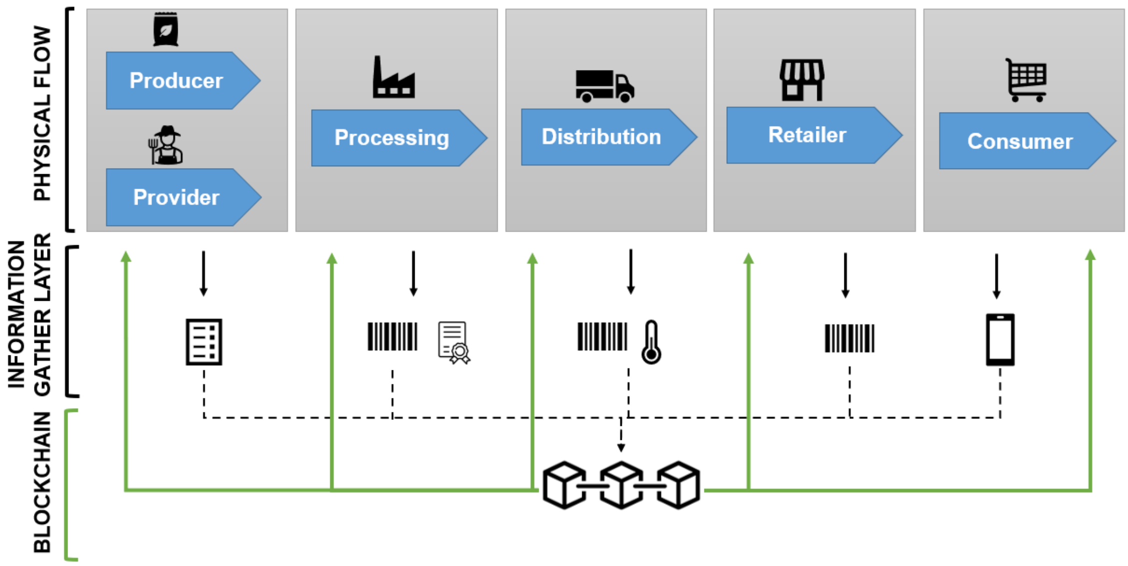

Figure 1-2. A simplified Blockchain-integrated FSC (Adapted from Kamilaris et al. (2019)).

Figure 1-2 presents a schematic depiction of how Blockchain functions in a general FSC setting. There is a basic flow of tangible goods – food and related products in this case – from the point of origin to the point of final consumption. As food moves along the chain, various related information about the product is generated, such as custody, location, transport, conditions, etc. This information is typically captured via paperwork or by information systems and advanced devices such as RFID or sensors. These inputs are validated and stored on the Blockchain system, and then communicated to the FSC stakeholders in real-time.

Numerous applications of Blockchain for food products have been undertaken over the year. Broadly, Blockchain has been used mainly for three areas of FSCM: enhancing traceability, assuring food safety and quality, and promoting sustainability. Businesses in the FSC have utilized Blockchain to enhance the process of tracking food products, particularly due to the technology's ability to foster holistic and reliable traceability across the supply line through its immutability and decentralization features (Kamilaris et al., 2019; Chen et al., 2020). One of the earliest, and arguably one of the most well-known, Blockchain projects for food traceability is Walmart tracking mangos in China using the Hyperleger platform, in which the technology helped the giant retail enterprise drastically reduce the tracking duration (Hyperledger, 2019). In the following years, numerous Blockchain applications in the FSC started to go live, with some notable examples including Origin Trail, Wholechain, Connecting Food, Farmerconnect, Seafooodchain, etc. Other large corporates have also been quick to explore Blockchain technology, evidenced by some exemplar projects such as IBM's Blockchain-enabled Food trust platform (IBM, 2022), and Carrefour's use of Blockchain for its organic brands (Carrefour, 2022). Further, the academic community shared the same enthusiastic sentiment toward Blockchain's potential for food traceability. Numerous research about designing Blockchain solutions for tracing food products have been published in recent years. Some examples include using the technology to trace eggs (Bumblauskas et al., 2020), dairy products (Casino et al., 2020), and beef (Ferdousi et al., 2020).

Aside from improving traceability, companies also recognized that Blockchain can strengthen the process of monitoring food quality and authenticity (Ahmed et al., 2022). Due to the high level of transparency and trustworthiness provided by Blockchain, businesses and consumers can easily verify and audit claims about food's provenance and history, and companies are always held accountable for their products' information (Kamble et al., 2019). Thus, Blockchain technology has been widely adopted to assure the safety of food products, prevent food fraud, and assure the provenance of food items to the end-consumers. Many case studies of such us are reported in the extant literature. Danese et al. (2021) examined five Italian winemakers who adopted Blockchain to prevent counterfeited food products both up and downstream of the wine supply chain. The author found that the risk of wine adulteration is greatly reduced when opportunities for fraud are largely restricted by using Blockchain. Caldarelli et al. (2020) reported a case of an artisan cheese maker who employed Blockchain to assure customers of the authenticity and provenance of their niche products. IBM, Walmart, Chinese retailer JD.com, and Tsinghua University founded the Blockchain Food Safety Alliance to address food safety issues in China (Chen et al., 2020). Attempts at exploring the use of Blockchain for food safety and quality also are seen in academia, for instance, Zhang et al. (2020) designed a Blockchain-based management system for monitoring grain safety and quality.

Moreover, as the food and beverage industry is facing mounting pressure on developing and promoting sustainability (Bourlakis and Bourlakis, 2004; Ghadge et al., 2017), Blockchain technology is being explored as an additional tool for facilitating a sustainable FSC. Kamble et al. (2019) suggested that with the transparency and trust provided by Blockchain, sustainable food products can be validated in a reliable manner, and small stakeholders (i.e., farmers) of the FSC are more included in the overall FSC operation, leading to better share for their produce. Saberi et al. (2019) argued that with the ability to reduce food tampering, Blockchain can reduce social harm and thus contribute to sustainability. The author also stated that Blockchain is a useful tool for monitoring compliance with sustainable practices/requirements from FSC stakeholders. In practice, Blockchain applications in the FSC started to include sustainability in their scopes. For instance, Unilever and SAP collaborated to employ Green Token, a Blockchain solution, for monitoring deforestation-free palm oil products in Southeast Asia (Unilever, 2022). Solutions such as Farmerconnect and TraceX connect smallholder farmers to the wider FSC to boost their income and encourage sustainable farming and conserving practices (Farmerconnect, 2022; TraceX, 2022).

1.2 Research rationale

Following a fundamental discussion regarding the background of the research in section 1.1, section 1.2 provides the research rationale. Several reasons motivated the author to explore the Blockchain phenomenon in the specific context of the FSC. Particularly, this thesis specialises in researching the FSC because the food and agriculture industry has a crucial role in sustaining human life, and the specific area of FSC requires dedicated studies due to its unique managerial challenges. Furthermore, while the research on Blockchain technology has been growing at an impressive pace, some areas of the extant literature are still under-researched. Hence, this thesis aims to address those gaps in the literature for a more comprehensive understanding of Blockchain for FSCM.

First, the FSC is an important part of human societies and economies. In the latest release of the UK Office for National Statistics, food & drink is among the top three categories of spending for a UK household, which accounts for, on average, 14% of a household's weekly expenditure (UK Office for National Statistics, 2022). As one of the largest manufacturing sectors, the food and beverage industry contributes over 4% of the US GDP (worth over $1.5 trillion) and provides approximately 15 million jobs (Foodindustry, 2022). Developing economies are even more reliant on the food and agriculture industry; for example, the agri-food sector accounts for 26% of the GDP in Vietnam and 32% in the Philippines, in 2021 (Oxford Economics, 2022). Therefore, the author is motivated to research the FSC since the outcomes can contribute to this vital aspect of human life. In their 2022 report about global food security and nutrition, The Food and Agriculture Organization of the United Nations (FAO) continued to raise the call for building a better and more reaching global supply of food, in order to meet Sustainable Development Goal number 2 - end hunger (FAO, 2022).

Second, FSC is a unique branch of the SCM, with its specific challenges. As previously discussed in the first chapter, FSCM differs from other branches of SCM such as automotive or electronics supply chain due to inherent characteristics of food products such as perishability, seasonality, and temperature sensitivities (Akkerman et al., 2010; Barbosa, 2021). Therefore, there is a need to conduct specialized research for this particular context, as researchers need to 'adapt and develop solutions that fit the specific demand for food products' (Fredriksson and Lilkestrand, 2015, p16). The author concurs with this perspective and believes that a series of dedicated studies of Blockchain in the FSC is necessary and has strong potential contributions.

Third, Blockchain is an interesting, and exciting, phenomenon that needs further exploration. Comparatively, Blockchain has been introduced to the SCM for far much less time than other prominent technologies in the domain such as RFID or ERP. The work of Tian (2016) about building a traceability solution using Blockchain can be considered one of the first works of Blockchain interfacing FSC in the extant literature. Various literature reviews also concluded that the academic literature just started to explore this subject in 2017 (Zhao et al., 2019; Chen et al., 2020). In 2019, when this PhD project started, it can be said that the body of knowledge regarding the Blockchain phenomenon in the FSC context was still at the early stage of development. The rapid advancement of Blockchain in the food industry, evidenced by a growing number of Blockchain applications for FSCM between 2018 and 2019 (Kamilaris et al., 2019), inspired the author to conduct research in this area to generate meaningful contributions to the literature and practice.

To this end, it was observed that some areas of the extant literature needed strengthening. On one hand, dedicated research for the implementation process of Blockchain in the FSC was lacking at the time. To constitute a comprehensive understanding of an innovation or a new technology's impact on businesses, the integration process is an aspect that cannot be underestimated (Damanpour and Schneider, 2006; Zhu et al., 2006). For instance, the roadmap for adopting technologies such as RFID and ERP in the SCM domain has long been investigated by both academics (e.g., Liang et al. (2007), Hossain et al. (2016)) and practitioners (e.g., SAP (2022)). While acknowledging that there were valid attempts to examine the adoption of Blockchain in a wider SCM context (for instance see van Hoek (2019) and Wong et al. (2020)), at the time of the project, there is a dearth of specialized research about the adoption process of Blockchain technologies for organizations in the particular context of the FSC.

On the other hand, given the infancy stage of the literature at the time, scholars called for in-depth investigations into how specific businesses and processes can benefit from the use of Blockchain technology (Martinez et al., 2019; Wang et al., 2019). Early reviews of the subject conceptualized and anticipated that Blockchain can create positive impacts on several aspects of SCM such as transparency, processes, and performance (Cole et al., 2019; Wang et al., 2019). While these notions served well as the starting point, there is a need for evidence-based research to closely examine and uncover the mechanisms by which Blockchain can affect businesses (Zhao et al., 2019; Martinez et al., 2019), especially the impacts of the technology on SCM performance (Wamba et al., 2020). Further, when referring to the impacts of Blockchain, past studies often discussed the effects of using this technology on trust, visibility, and reputation (Zhao et al., 2019; Caldarelli et al., 2020). The influence of Blockchain on the operation aspect is arguably overlooked, or simplified. Thus, an in-depth look into the changes and impacts brought by Blockchain to the operation of FSC stakeholders is necessary to further strengthen the body of knowledge regarding this novel technology and the FSC, and to provide useful implications for businesses.

Additionally, scholars have strongly advocated for the use of theories in studying the Blockchain phenomenon in the SCM domain (Cole et al., 2019; Wang et al., 2019). Zhao et al. (2019) further called for more research inquiries on the effect of Blockchain on the agri-food value chain from theory perspectives. While early works regarding Blockchain in the FSC provided useful knowledge of the technology, the focus is often on reporting the application and potential of Blockchain without a coherent underpinning theoretical perspective (e.g., Tian (2016) or Bumblauskas et al. (2019)). Therefore, this thesis aims to include relevant and strong theoretical foundations in exploring the Blockchain implementation process and its impacts on the FSC. Particularly, Innovation Adoption theories and concepts, and system thinking are utilized to deliver the studies of this thesis. Chapters 2, 3, and 4 will discuss more in-depth the appropriateness, applicability, and use of these theoretical lenses.

Overall, given the importance of the food industry, the potential of specialized research for FSCM, and the development of the pertinent literature at the time, the author was motivated to dedicate this PhD project to uncover the implementation process and the impacts of Blockchain in the context of FSC, with pertinent theoretical perspectives. This can be seen as a two-prong approach to enhance the understanding of the Blockchain phenomenon in the FSC domain. An influential study in the area of innovation adoption by Zhu et al., (2006) suggested that we have to understand both the journey of adopting a new technology and the business values it can bring to facilitate successful integration. The author highly resonated with this view, and therefore directed this work to uncover how Blockchain can be integrated at the organizational level (the implementation process) and how it can affluence operational performance (the impact), all under the context of the FSC. By understanding both the implementation process and the impact of Blockchain, the author hopes to extend the literature and provide practical insights and recommendations for organizations looking to adopt the technology.

1.3 Research aim and objectives

This PhD thesis aims to contribute to the cumulative knowledge of and inform the practitioners about the Blockchain phenomenon in an FSC setting. Specifically, it seeks to understand *how agri-food businesses adopt Blockchain technology*, and, after successful integration of the technology, *what operational benefits/impacts agri-food businesses can anticipate by using Blockchain*. To achieve this aim, three objectives are set for this thesis:

1- To understand what the extant literature has discovered about Blockchain adoption and benefits.
2- To develop an evidenced model of Blockchain implementation, which can explain and guide the Blockchain implementation process for FSC businesses.
3- To evaluate the impact of a successful Blockchain adoption on the performance of an FSC.

The three objectives are constructed logically, so that not only do they lead to the accomplishment of the thesis' goal, but each sets the foundation for the next one to build upon. Section 1.5 will explain this facet in more detail, when discussing the structure of the thesis and the design of each study (corresponding to a Chapter) in the thesis.

1.4 Philosophical paradigm

This section provides the philosophical paradigm that underpins this PhD thesis. In essence, the thesis follows a pragmatic approach, employing multiple sources of perspectives, data, and methods to study the phenomenon of interest (Blockchain in the FSC).

Fundamentally, pragmatism is oriented toward producing knowledge, focusing on the active process of inquiry to solve the research question, rather than what kinds of knowledge are possible given the assumptions about the nature of reality (Hall, 2013; Morgan 2014). It is clearer to understand the pragmatic approach when contrasting it with two other popular paradigms: post-positivism and constructivism. Table 1-2 highlights the differences between the three paradigms in terms of paradigmatic elements. Note that using post-positivism and constructivism for comparison is a conscious choice. The author is aware of other paradigms such as critical theory or participatory. Nonetheless, post-positivism and constructivism are specifically highlighted since they played important parts in bringing pragmatism into the spotlight. Pragmatism, which advocates for mixing methods in research inquiry, is considered by some as the *third paradigm shift* that followed the quantitative movement (post-positivism) and qualitative movement (constructivism) (Morgan, 2007; Venkatesh et al., 2013). As seen in Table 1-2, pragmatism departs from the philosophical arguments about the nature of knowledge and reality, and instead accepts multiple realities and puts the stance's centrality on the human experience in action. This approach then rejects the notion of incompatibility and argues that both qualitative and quantitative data and analysis can play, equally, important roles in acquiring knowledge through research inquiry (which is a specific realm of the human experience) (Venkatesh et al., 2013; Morgan, 2014). Therefore, the pragmatist approach promotes flexibility in research and enables researchers to use the most effective methodologies and data to accomplish the ultimate goal-answering the research questions.

Table 1-1. Research paradigms and characteristics (Onwuegbuzie et al., 2009).

Paradigmatic Element	**Post-positivism**	**Constructivism**	**Pragmatism**
Ontology	Social science inquiry should be objective.	Multiple contradictory, but equally valid accounts of the same phenomenon representing multiple realities.	Multiple realities (i.e. subjective, objective, intersubjective); rejects traditional dualism (e.g. subjectivism vs objectivism; facts vs values); high regard for the reality and influence of the inner world of human experience in action; current truth, meaning and knowledge are

			tentative and changing.
Epistemology	Researchers should eliminate their biases, remain emotionally detached and uninvolved with the objects of study and test or empirically justify their stated hypotheses.	Subjective knower and known are not separable; Transactional/ subjectivist; co-created findings/meaning.	Knowledge is both constructed and based on the reality of the world we experience and live in; justification comes via warranted assertability.
Methodology	Time- and context-free generalizations are desirable and possible and real causes of social scientific outcomes can be determined reliably and validly via quantitative (and sometimes qualitative) methods.	Hermeneutical/ dialectical; impossible to differentiate fully causes and effects; inductive reasoning; time and context-free generalizations are neither desirable or possible.	Thoughtful/dialectical eclecticism and pluralism of methods and perspectives; determine what works and solves individual and social problems.
Nature of knowledge	Nonfalsified hypotheses that are probably facts or laws.	Individual and collective reconstruction that may unite around consensus.	Intersubjectivity, emic and etic viewpoints; respect for nomological and ideographic knowledge.

One important driver for opting for a pragmatic approach, and subsequently mixed method, is the phenomenon of interest. Venkatesh *et al*. (2013) strongly suggested that the context should drive the choice of research method, as a mixed method is most pertinent when the extant literature is fragmented, inconclusive, and equivocal. The same can be argued for the specific body of research about Blockchain in FSC. Many of the early works in this area focussed on conceptualizing and making sense of the technology's impact (Cole *et al*., 2019, Zhao *et al*., 2019); whereas several case studies of actual Blockchain initiatives (e.g, Bumblauskas *et al*., 2019; van Hoek, 2019) indicated that the implementation and exploration of the technology are still at an infancy stage. Dealing with an area that arguably is still in the dark without a conclusive understanding, this thesis consequently looks to utilize different methods and approaches, including qualitative analysis, quantitative analysis, and analytical approach, to expand the current knowledge regarding the phenomenon of interest. As advocated by many scholars, when the actual phenomenon is believed to be complicated and multidimensional, using a combination of different elements of research, such as paradigms, methodologies, or methods when conducting research can lead to a more in-depth and comprehensive understanding (Mingers and Brocklesby, 1997; Venkatesh *et al*., 2013). This perspective aligns with recent calls within the SCM discipline, inviting further research using a combination of multiple data sources and methods to provide richer explanations for increasingly complex SCM phenomena (Goldsby and Zinn, 2018).

Adopting the tenet of paradigm being epistemological stances, meaning the ontology, epistemology, and methodology are derived from the chosen paradigm (Morgan, 2007), a question remains is that how the studies of this thesis are driven by the said-to-be underpinning paradigm – pragmatism. Part of the answer to this question lies in the previous discussion about the current stage of the phenomenon of interest. By acknowledging and emphasizing the context (Blockchain for FSC), the thesis aligns with the approach of a pragmatist, which prioritizes solving practical problems over assuming the nature of knowledge (Hall, 2013). The other part of the answer is embedded in the research design of the empirical works in this thesis. As the Qualitative study (Chapter 3) and the Quantitative study (Chapter 4) have dedicated sections for the methodologies, the details of their research designs are not delved into here. Rather, it is discussed here how the principle of mixed methods research, for which pragmatism is dominantly the philosophical stance (Hall, 2013), is incorporated in the designing of those studies. Particularly, both the Qualitative and the Quantitative study set out to investigate the process of integrating Blockchain in the FSC, with the former developing the primary concepts and constructs with qualitative findings from interviews and the latter statistically assessing the key relationships between constructs with quantitative data from a survey. Playing to the strength of each method, the author wished to achieve a complete picture of the Blockchain implementation process by extracting rich and in-depth insights from interviews as well as validating the relationships between various constructs and factors following a survey, meeting two purposes of mixed methods research – completeness and developmental (Venkatesh *et al*., 2013).

Further, the two studies are deliberately conducted in sequence, with the leading Qualitative study followed by the Quantitative study. This choice aligned with the exploratory mixed-methods research design suggested by Cresswell and Plano Clark (2012). With this design, the role of the qualitative phase is to establish the initial understanding of the phenomenon (Blockchain implementation in the FSC for this case) and the role of the quantitative phase is to measure, evaluate, and elaborate on the previous results. Together, the two studies formed a coherent mixed-methods research, which attempts to understand the multi-facet of the Blockchain adoption journey in the FSC and develops a model for such a process. Furthermore, the Quantitative study also provides an assessment of Blockchain's impacts on the FSC performance. For this part of the study, SD modelling was utilized. SD is a unique modelling and simulation tool, as it contains both quantitative and qualitative methods to explore and analyze complex systems (Kunc, 2017). Specifically, qualitative data is essential to understand the system under study (key variables, relationships, feedback loops, etc), whereas quantitative data is critical to set up the simulation of the models to uncover the behavior of the said system under interventions (.ibid). The Qualitative study incorporates both qualitative and quantitative inputs in the modelling process.

1.5 Thesis design and structure

1.5.1 Overview of the studies in the thesis

This PhD thesis follows a PhD-by-paper route, thus the core of this thesis is a series of studies conducted by the author to achieve the overarching aim of the thesis. The overall contributions of this thesis, therefore, are structured to be delivered through three separate chapters. Each chapter corresponds to a study and is formatted like an academic journal paper. Figure 1-3 depicts a visual representation of all chapters in this thesis, highlighting the role of each chapter, and more importantly, how Chapters 2, 3, and 4 correspond to and accomplish the three objectives of this thesis (Note: see Section 1.3 for the aim and objectives). Each study employs a different perspective to investigate the phenomenon of interest; nonetheless, together they form a coherent piece of mixed-methods research that contributes to the overall aim of the thesis. The following discussions will highlight the aim, method used, and contribution toward the thesis of each study.

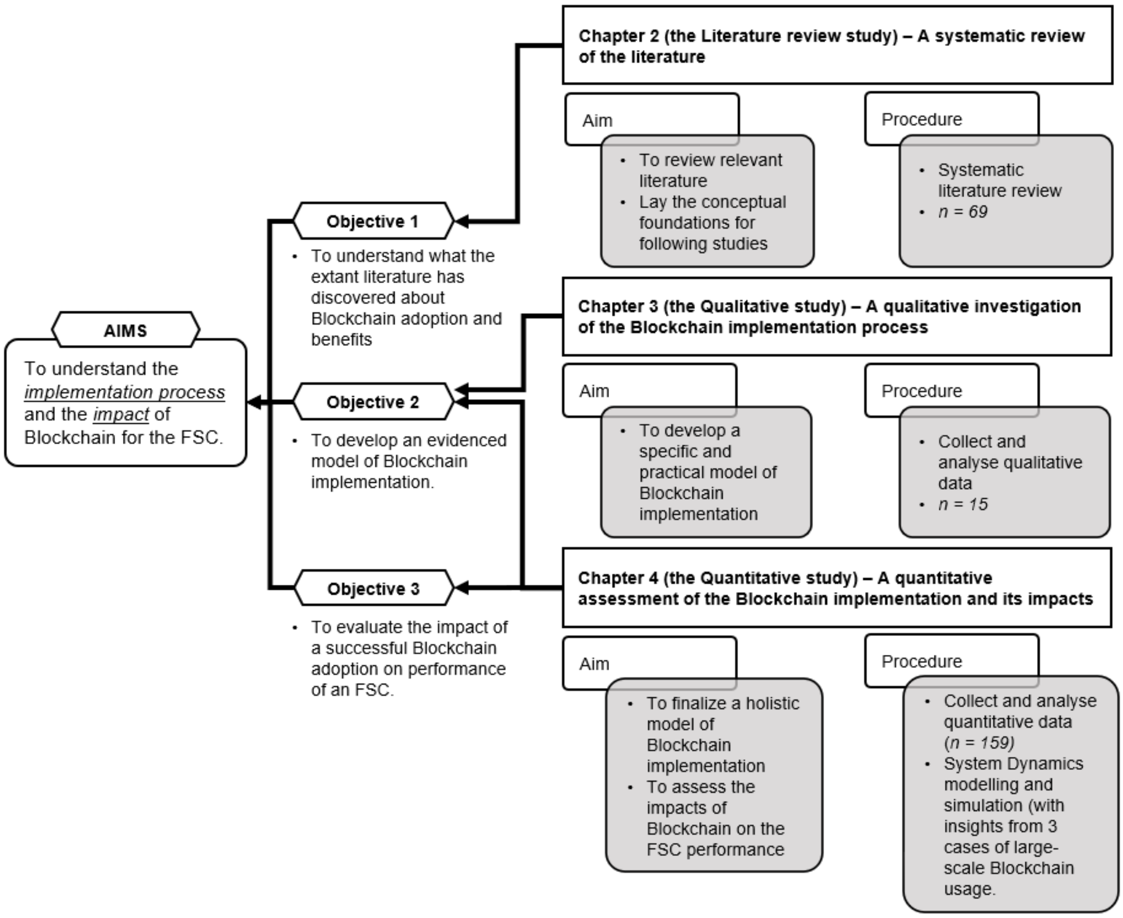

Figure 1-3. Overview of the studies included in this thesis.

Chapter 2 is a Literature review study. This study aims to discover state of the art in the extant literature about the Blockchain technology and the process of integrating Blockchain along with its impact on FSC. As implied by scholars' calls for further investigation regarding Blockchain adoption and impacts in specific SCM settings (Martinez et al., 2019; van Hoek 2019; Wang et al., 2019), the author had a preliminary understanding of the need for this thesis. Nevertheless, it is necessary to validate by holistically examining relevant literature. Further, the Literature review study also provides important theoretical foundations for the following works. To achieve the aim of the Literature review study, a systematic literature review (SLR) method was used to locate quality academic papers and synthesize important insights from them. IA theoretical lenses, concepts, and models were adopted to develop a conceptual framework of Blockchain implementation in the FSC, setting the stage for later studies to build upon. In achieving the overarching research aim of this thesis, the Literature review study (Chapter 2) answers Objective 1, which is to understand the current body of literature concerning the phenomenon of interest (Blockchain in the FSC). In relation to the other studies of this thesis, the Literature review study identified the under-explored areas in the current literature that the following work can address, provided the conceptual foundation, and developed an initial model of Blockchain adoption based on literature insights.

As stated previously, the thesis follows a mixed-methods research design, particularly the exploratory mixed-methods research design. An exploratory design consists of two sequential phases: a qualitative phase followed by a quantitative phase, as outlined by Creswell and Plano Clark (2012). The qualitative phase helps to uncover and shape the instruments for the quantitative analysis. This is done to effectively explore a new research area, of which there is not yet sufficient knowledge to develop effective and relevant measures and instruments for quantitatively analyzing the phenomenon of interest (Creswell and Plano Clark, 2012). This is especially applicable to the context under study, as section 1.2 pointed out a dearth of research dedicated to the implementation process of Blockchain and its impacts on performance in the FSC setting. For this thesis, the exploratory design is particularly represented by the interplay between Chapter 3 (the Qualitative study) and Chapter 4 (the Quantitative study). In the former, the author draws from IA theoretical lenses and interview insights to make sense of the Blockchain implementation in the specific context of FSC. In the latter, the author collected numerical data, in the form of survey responses, to statistically assess the relationships between important constructs of the Blockchain implementation process. The previous findings also led the author to explore the impacts of Blockchain on FSC performance through a simulation study, part of the Quantitative study. With the interplay between the Qualitative and Quantitative studies explained, the outlines of each study are presented next.

The Qualitative study aims to investigate the specific process of adopting Blockchain for organizations in the FSC. The study achieves its aim by collecting qualitative data from semi-structured interviews with experts, who have had experience in deploying Blockchain projects tailored to food products. The Qualitative study (Chapter 3) used the Literature review study's conceptual framework, relevant IA theoretical lenses and models, and qualitative interview findings to construct an evidence-based model for Blockchain implementation in the FSC, including specific phases, activities, and more importantly the contextual influential factors. Toward answering the overarching research question of this thesis, this Qualitative study achieves Objective 2 – developing a model for Blockchain diffusion in the FSC. In the relation to the other studies of this thesis, this study in Chapter 3 serves as the next logical step to leverage the findings in the Literature review study, and effectively set the scene for further assessment in Chapter 4.

The Quantitative study's aim is two-fold. First, this study collects empirical data from a survey to statistically evaluate the relationships between the key constructs of the Blockchain implementation model. These constructs were derived from the findings of the Qualitative study, reflecting the contextual characteristics of Blockchain adoption in the FSC. The Quantitative study, therefore, provided an elaboration on the results of the Qualitative study and unified both qualitative and quantitative insights to finalize the model of Blockchain implementation. Second, the Quantitative study adopted an analytical approach (SD modelling) to capture and assess the impacts of Blockchain on key FSC performance indicators. Overall, this study contributes to both Objective 2 and Objective 3 – to understand the impacts of Blockchain on operational performance – in seeking the answers to the thesis' overarching research question.

1.5.2 Thesis structure

The rest of the thesis is structured as follows: Chapter 2 presents an SLR study about Blockchain for FSC, Chapter 3 provides a qualitative investigation of the Blockchain implementation process in the FSC, Chapter 4 details an empirical and analytical study about Blockchain integration process and the impact of Blockchain on the performance of an FSC, and Chapter 5 concludes the study with discussing the overall findings, stating the contributions and limitations, and providing future research directions.

To elaborate further on the PhD-by-paper aspect, a summary of all the academic outputs of this PhD thesis is provided in Table 1-3.

Table 1-2. All research dissemination of this thesis.

Chapter	Journal papers	Conference Proceedings
2	**Published:** Vu, N., Ghadge, A. and Bourlakis, M., 2021. Blockchain adoption in food supply chains: A review and implementation framework. *Production Planning & Control*, pp.1-18.	Vu, N., Ghadge, A. and Bourlakis, M., 2020. Blockchain implementation in the food supply chain: A systematic literature review, EurOMA 2020 Conference, Warwick, UK.
3	**Published:** Vu, N., Ghadge, A. and Bourlakis, M., 2022. Evidence-driven model for implementing Blockchain in food supply chains. *International Journal of Logistics Research and Applications*, pp.1-21.	Vu, N., Ghadge, A. and Bourlakis, M., 2021. Implementing Blockchain in the food supply chain: An empirical study, Logistics Research Network Conference 2021, Cardiff, UK.
4	**In preparation:** (aim for *International Journal of Production Economics)* A quantitative assessment of the Blockchain implementation process and its impacts.	Vu, N., Ghadge, A. and Bourlakis, M., 2022. Impact of blockchain implementation on food supply chain performance, EurOMA 2022 Conference, Berlin, Germany.
		Vu, N., Ghadge, A. and Bourlakis, M., 2022. An empirical assessment of the determinants of blockchain

	implementation in the food industry, International Symposium on Logistics Conference 2022, Ireland.

Reference to Chapter 1

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2 BLOCKCHAIN ADOPTION IN FOOD SUPPLY CHAINS: A REVIEW AND IMPLEMENTATION FRAMEWORK

Abstract

Blockchain technology has received significant attention from the food industry; however, due to the scarcity of successful Blockchain projects and sector-specific studies, a step-by-step approach for implementing Blockchain in food supply chains (FSCs) is still missing. A systematic literature review of 69 high-quality, peer-reviewed articles is utilized to capture Blockchain adoption drivers and barriers, applications, and implementation stages within FSCs. Current Blockchain issues such as scalability, regulations, privacy, and incentivization are identified as future research opportunities. Following innovation adoption theory, a three-stage conceptual framework for Blockchain implementation in FSCs is developed. The proposed framework is novel and is expected to benefit food chain managers in establishing the suitability of Blockchain for their organization and/or wider supply network. Identified influential factors, case examples, and implementation stages are expected to guide practitioners in developing a roadmap for adopting Blockchain in the food industry

Keywords: Food supply chains; Blockchain; implementation; Innovation adoption; Industry 4.0; systematic literature

2.1 Introduction

Popularized via decentralized transaction networks, Blockchain is emerging as a transformative technology for Supply Chain Management (SCM). Blockchain can be defined as a digitalized, decentralized, and distributed ledger system for storing and sharing information (Iansiti and Lakhani 2017; Nofer et al. 2017; Saberi et al. 2019). Stored data/information on a 'chain of blocks' is immutable, transparent, traceable, and tamper-proof (Nofer et al. 2017; Kumar, Liu, and Shan 2020). SCM is a highly promising field for Blockchain implementation due to several pinch points (Iansiti and Lakhani 2017; Martinez et al. 2019). In particular, Blockchain applications can bring significant improvements in terms of transparency, efficiency, and sustainability (Cole, Stevenson, and Aitken 2019; Saberi et al. 2019). The technology has been experimented for better managing supply chains in several industries, namely food (Kamilaris, Fonts, and PrenafetaBoldu 2019), construction (Wang, Chen, and Zghari-Sales 2021), apparel (Fu, Shu, and Liu 2018), pharmaceuticals (Hackius and Petersen 2017), and is highly regarded as the next significant innovation for SCM by industry practitioners (Capgemini 2018).

Research developments linking Blockchain with SCM are growing at an exponential speed. To date, various dimensions of using Blockchain for SCM have been investigated, ranging from conceptualizing the benefits of the technology (Cole, Stevenson, and Aitken 2019; Saberi et al. 2019); examining successful cases of Blockchain application for SCM (Kshetri 2018; Wang, Chen, and Zghari-Sales 2021), to exploring influential factors concerning the decision of adopting Blockchain (Wong et al. 2019; Wamba, Queiroz, and Trinchera 2020). Due to massive growth in research interests in this field, scholars are attempting to capture the development of Blockchain, following literature review studies. Table 2-1 presents nine literature reviews found in Operation and SCM literature, exploring the potential of Blockchain in SCM.

Except for Cole, Stevenson, and Aitken (2019), all studies chose a systematic literature review (SLR) to synthesize insights from the literature. Further, most studies provide an overview of Blockchain, such as its potential, challenges, usage, etc., within SCM in general (e.g. Cole, Stevenson, and Aitken 2019; Gurtu and Johny 2019; Pournader et al. 2020; Wang, Han, and Beynon-Davies 2019). Several review studies, shown in Table 2-1, have a narrower scope. For example, Queiroz, Telles, and Bonilla (2019) focus on Blockchain integrated supply chain management, while the use of Blockchain in the food industry has drawn considerable attention from academia (e.g. Kamilaris, Fonts, and Prenafeta-Boldu 2019; Zhao et al. 2019; Duan et al. 2020; Feng, Wang, Duan, et al. 2020).

FSCs have been at the forefront of exploring Blockchain since it first emerged as a promising technology for SCM. The food industry has witnessed some of the earliest and most developed 'Blockchain-for-Supply Chains' initiatives (Galvez, Mejuto, and Simal-Gandara 2018; Kshetri 2019; Wang, Han, and Beynon-Davies 2019). According to a report by McKinsey in 2017, many among the very first Blockchain initiatives focus on food products (Alicke et al. 2017). Some notable examples include a Blockchain-based food tracking platform created by IBM and a successful Blockchain pilot by Walmart for tracking its pork supply in China. The momentum for adopting Blockchain in the FSC continues to grow strongly. In 2019, Albertsons joined more than 50 other organizations as a member of IBM's Blockchain-based Food Trust network, alongside many other retail giants such as Walmart and Carrefour (Wolfson 2019).

Table 2-1. Summary of recent reviews on Blockchain for SCM.

Reference	**Aim of the study**
Cole *et al*. (2019)	To examine Blockchain technology and its potential in Operation and Supply Chain Management (OSCM) and to address whether common theories in OSCM can be useful in studying the phenomenon of Blockchain.
Gurtu and Johny (2019)	To review the current literature on Blockchain technology to determine the overall potential of Blockchain for SCM.
Pournader *et al.* (2019)	To review literature about the implementation of Blockchain in the supply chain, logistics, and transport for future applications and research directions.
Queiroz *et al.* (2019)	To determine current applications, the main challenges, and future research directions of the research stream about Blockchain supply chain integration.
Wang *et al.* (2019a)	To examine future influences of Blockchain to supply chain practices and policies.
Kamilaris *et al*. (2019)	To identify the goals, designs, enablers, and barriers of Blockchain initiatives in the food and agriculture industry.
Zhao *et al.* (2019)	To determine applications, main challenges and future directions of Blockchain implementations in food supply chains (FSC).
Duan *et al.* (2020)	To investigate how Blockchain has been used to manage food products, benefits and challenges of the technology, and how it can help address food security.

Feng *et al*. (2020a)	To understand how Blockchain can facilitate a food traceability system for FSC.

Blockchain adoption in the food industry is growing and, thus, providing an excellent opportunity for theoretical and practical contributions to Blockchain-enabled food supply chains. While existing review studies on Blockchain for FSCs (Table 2-1) provide an ideal starting point for researchers, certain aspects have not been fully realized. Specifically, there is a need for exploring the process of implementing Blockchain in the specific FSC setting. Blockchain is a novel technology; nevertheless, the subject of implementing new technological innovation in SCM has been long studied under the perspective of Innovation Adoption (IA) theory (Zhu, Kraemer, and Xu 2006; Martins, Oliveira, and Thomas 2016; Hossain, Quaddus, and Islam 2016). The implementation process is considered an essential facet in studying innovations since such a process is seldom straight-forward and a thorough understanding regarding the integration of new technology/ ideas is key to realizing the wider benefits for businesses (Zhu, Kraemer, and Xu 2006; Damanpour and Schneider 2006; Hossain, Quaddus, and Islam 2016). The importance of this topic, together with the scarcity of successful Blockchain initiatives within the food industry (Kamilaris, Fonts, and Prenafeta-Boldu 2019), led us to explore the following research question: What is the process for implementing Blockchain in FSCs? To address the defined research question, this study presents a review of relevant studies to recommend evidence-based research avenues and provide a conceptual framework for implementing Blockchain in FSCs. This work contributes by strengthening the body of literature interfacing Blockchain and FSCs.

The rest of the paper is structured as follows: Section 2 provides the background to the research, Section 3 presents the methodology of this paper, Section 4 and Section 5 provide the descriptive and thematic analysis, respectively. Section 6 develops a conceptual framework of Blockchain implementation in the FSC based on findings from the data set and established theories. Section 7 concludes this study with future research avenues, discussion and concluding remarks.

2.2 Research background

2.2.1 FSC challenges

FSC-oriented research is compelling since food products possess distinctive characteristics (Ghadge, Er Kara, et al. 2020). A large number of food products are perishable, temperature-sensitive, seasonal, and dependent on nature for production (Akkerman, Farahani, and Grunow 2010; Shukla and Jharkharia 2013; Fredriksson and Liljestrand 2015). Food is an integral aspect of today's societies and economies. On average, a household in the UK allocates 10% of its total spending on home meals and another 7% for catering services, according to the 2018–2019 report from the UK government (Office for National Statistics 2020). The EU acknowledges the food and drink industry as the largest manufacturing sector in this region, with a turnover of 1.2 trillion Euros in 2019 (Food Drink Europe, 2019). For the US, agriculture and its related industries account for 11 percent of total employment and 5.2% of GDP (United States Department of Agriculture 2020). Similar figures are observed in developing countries, and this portrays the criticality of FSC. Therefore, researchers need to 'adapt and develop solutions that fit the specific demand for food products' (Fredriksson and Liljestrand 2015, 16). This study echoes the view and further argues that a dedicated review for implementing Blockchain in FSCs is necessary. Moreover, such a focussed study can provide a meaningful contribution to the research on food supply chain management.

2.2.2 Defining stages and determinants of Blockchain implementation

It is crucial to study the phenomenon of Blockchain under appropriate theoretical lenses (Cole, Stevenson, and Aitken 2019; van Hoek 2019; Saberi et al. 2019), as theories can help to understand different aspects of the phenomenon better. Since this study looks at implementing new technology (i.e. Blockchain) for managing FSCs, use of IA theories is a suitable approach. Blockchain can be categorized as an innovation, as the technology is new to the adopting units and benefits are anticipated from the changes brought by the latest technology

(Damanpour and Schneider 2006). Moreover, theoretical lenses were successfully used in studying the implementation of preceding technological innovations such as RFID (Hossain, Quaddus, and Islam 2016). IA theories and models have also been used to explore various facets of Blockchain adoption recently, such as individual user acceptance (Queiroz and Wamba 2019), defining adoption processes (Hughes et al. 2019) and identifying determinants of Blockchain adoption (Wong et al. 2019; Wamba and Queiroz 2020).

A structured model is often used to capture the implementation process, as the adoption of new technology happens over sequential phases (Hameed, Counsell, and Swift 2012; Pichlak 2016). The dichotomy of stages is found to vary between models. According to Rogers Everett (1995), the adoption of innovation unfolds in five stages: knowledge, persuasion, decision, implementation, and confirmation. Drawing on the technological diffusion perspective, Kwon and Zmud (1987) and Cooper and Zmud (1990) constructed a model for IT implementation comprising six steps: initiation, adoption, adaptation, acceptance, routinization, and infusion. More recent studies tend to suggest a model with a lower number of stages but providing extensive meaning. Hameed, Counsell, and Swift (2012) considered a three-stage model for innovation implementation, including pre- adoption, adoption-decision, and post-adoption; and Pichlak (2016) suggested a process of adoption with initiation, adoption decision, and implementation phases. Though the generalization of concepts and categorization of terms differ in the literature, the essential activities are consistent throughout existing models: (1) Initiation – the organization rationalizes the decision of adopting the innovation, (2) Adoption decision – the organization decides whether and how to implement the innovation, and (3) Implementation – the organization deploys/applies the innovation.

Four main categories of influential attributes towards the implementation process are further determined as: innovation characteristics, organizational characteristics, environmental characteristics, and management characteristics. To outline these attributes, several vital studies were reviewed. Damanpour and Schneider (2006) examined multi-dimensional factors influencing innovation adoption phases focussing on public organization. Zhu, Kraemer, and Xu (2006) assessed the assimilation of e-business for organization and determinants for such processes. Hameed, Counsell, and Swift (2012) developed a conceptual model for adopting IT innovation based on the integration of Diffusion of Innovation and Technology Organization Environment frameworks. Pichlak (2016) combined RBV and various innovation adoption models to develop a conceptual framework for determinants of the innovation adoption process. A more indepth discussion about the four clusters of influential factors is provided in Section 6, where the construction of a final conceptual framework is presented.

In defining the innovation adoption process, and combining them with identified influential attributes, a preliminary conceptual model was proposed as shown in Figure 2-1. With insights generated from a thematic analysis of Blockchain interfacing FSCs studies, this model will be further refined to represent the implementation of Blockchain specifically for FSCs.

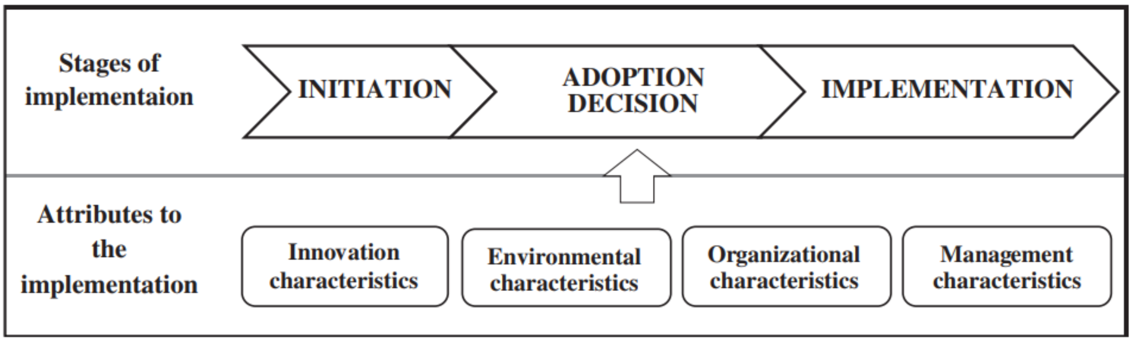

Figure 2-1. Hypothesized stages and determinants of Blockchain implementation.

Two key aspects of this conceptual model are the integrative nature of the model and the theoretical foundation of the specific constructs.

First, the conceptual model does not hinge on a specific theoretical lens but integrates different perspectives to understand the phenomenon under study. Since the adoption of innovation is often multi-faceted and complex, relying on a single theory might not be sufficient to fully understand the process of adoption (Hameed et al., 2012; Wamba and Queiroz, 2020). Therefore, an integrative approach, in which different but complementary theoretical perspectives are combined into one model, is often used. The aim is to provide a better understanding of the phenomenon at hand. This approach is especially common in researching the innovation implementation process, as shown in past literature such as Zhu et al. (2006), Damanpour and Schneider (2006), Hameed et al. (2012), Martins et al. (2016), Wamba and Queiroz (2020, and so on.

Second, when an integrative approach is proposed, it is important to determine what theories and conceptual models are included and how they underpin the key element of the model in construction. Regarding the phases of adoption during the implementation process, findings from previous works were adapted. When examining the relevant literature, a gradual change in the conceptualization of the adoption phases is observed. Early works such as Cooper and Zmud (1990) attempted to define detailed activities during the integration of technology at the organizational level, including initiation, adoption, adaptation, acceptance, routinization, and infusion. Later studies prefer to characterize the implementation process by broader stages, with the premise that activities within one stage can be context-dependent. Hameed et al. (2012) and Pichlak (2016) extensively reviewed and discussed this view, suggesting three main phases of adoption Initiation – Adoption – Implementation. The same perspective was seen in both earlier and later studies of the innovation adoption process (Zhu et al., 2006; Martins et al., 2016; Hossain et al., 2016, Wamba and Queiroz, 2020). The conceptual model in this study concurred with the recent development in theorizing the innovation implementation process, thus adopting three key phases of adoption and anticipating that the granular activities will be dependent on the specific context of adopting Blockchain in the FSC.

Regarding the determinants of the implementation process of Blockchain in the food industry, two prominent theoretical perspectives were used to inform the potential group of determinants. In his popular work about innovation and the rate of adoption, Rogers (1995) proposed a system of 5 categories of variables, that determine the rate of an innovation being adopted in a population. Among these categories, the first one, named “Perceived Attributes of Innovation”, is still prevalent as of today, inspiring many studies in this area. Rogers (1995) theorized that relative advantage, compatibility, complexity, trialability, and observability are important attributes that dictate whether a population (e.g., individuals in an organization, or companies in a certain industry) is willing to adopt an innovation. Relative advantages refer to the degree to which an innovation can potentially put the adopters in a more advantageous position. Compatibility is defined as how an innovation aligns with the current value, need, systems, and other infrastructure of the adopting unit. Complexity describes the degree to which innovation/ technology is difficult to master. Trialability is the possibility of innovation to be learned by doing. Observability refers to how visible the outcome of adopting innovation is to others. While Rogers' (1995) conceptualization of innovation/technology attributes is comprehensive and useful, others suggested that innovation is a multi-faceted process, attributing the success of one to other dimensions. Tornatzky et al. (1990) proposed two dimensions of Organization and Environment, alongside Technology, known as the TOE framework, to capture the adoption of technological innovation. According to those authors, the organization context refers to the resources, characteristics, and structure of the adopting firm. These can include but are not limited to, firm size, resources, culture, centralization, professionalism, etc (Tornatzky, 1990; Pichlak, 2016). The environment implies the larger context surrounding the adopting firm, such as the industry, countries, regulatory environment, etc (Hameed et al., 2012). Finally, drawing on the premise that management is an important resource of a company in adopting a new solution, studies such as Damanpour and Schneider (2006) and Hameed et al. (2012) suggested management as another important facet of implementing innovation. This idea is frequently featured in later models of the adoption process, such as Pichlak (2016), Hossain et al. (2016), and Wamba and Queiroz (2020). Overall, by combining the prominent and established theoretical perspectives in the literature, the conceptual model of this study outlines four main categories of determinants of the Blockchain implementation process in the FSC, including Technology, Organization, Environment, and Management.

2.3 Methodology

This study examines the existing literature using the Systematic Literature Review (SLR) approach to answer the research question. The SLR is recognized as a robust methodology for a critical review of literature in management research (Tranfield, Denyer, and Smart 2003). Compared with the traditional narrative-led approach to the literature review, SLR provides a scientific, replicable, and transparent approach to accumulate studies, summarize existing information and minimize bias (Tranfield, Denyer, and Smart 2003; Denyer and Tranfield 2009). In Operations and SCM, SLR has become an essential review tool for researchers (Durach, Kembro, and Wieland 2017).

Drawing from SLR examples in medical research, Tranfield, Denyer, and Smart (2003) suggested a review protocol with three main stages (planning – conducting – reporting). While some studies followed this structure precisely (e.g. Queiroz, Telles, and Bonilla 2019), other researchers have adapted this to develop improved step-by-step approaches for conducting the SLR (e.g. Seuring and Muller 2008; Ghadge, Dani, and Kalawsky 2012). Nevertheless, the essence of the process remains as selecting relevant studies, synthesizing insights from the dataset, and disseminating the state-of-the-art and future research directions. These fundamental stages are adopted in this study for the literature review on Blockchain implementation in FSCs.

The time horizon of the search was set from the year 2009 to June 2020. Many SLR studies on Blockchain understandably selected 2009 as the starting point for their data search (e.g. Queiroz, Telles, and Bonilla 2019; Wang, Han, and Beynon-Davies 2019) as it marks the launch of Bitcoin, the first proof of Blockchain's practicality (Iansiti and Lakhani 2017; Helo and Hao 2019). The author, after careful consideration, came up with the following search strings to select relevant sources:

```
(Blockchain OR smart contract OR distributed ledger) AND (food OR
agriculture OR perishable OR fresh) AND (supply chain OR value chain OR
demand chain OR logistics OR cold chain) AND (implementation OR
traceability OR transparency OR visibility OR tamper* OR security OR safety
OR integrity)
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Tachizawa and Yew Wong (2014) suggested that a search string should identify all papers suitable for answering the research questions, while also being narrow enough to ensure the relevance of those results. Therefore, this study identified ‘Blockchain’, ‘food supply chain’, ‘implementation’ and ‘benefits’ as keywords and the search strings were defined accordingly. Three reputable databases for academic publications, namely Scopus, EBSCo, and Web of Science (WoS), were selected for the search. Using the search strings, 2218 studies between 2009 and 2020 were identified, as shown in Figure 2-2. WoS returned a noticeably lower number of results as this search engine employs different criteria for full text searching in contrast with Scopus and EBSCo. Given the nascent stage of Blockchain technology and its application in FSCs, full-text searching helped to determine relevant papers to the topic comprehensively.

Selecting studies with high quality and relevance is essential for accurate and meaningful synthesis (Ghadge, Dani, and Kalawsky 2012). Inclusion and exclusion criteria were introduced to screen the initial search results for filtering out the most relevant studies for the data synthesis. Figure 2-2 presents the screening process in the PRISMA diagram. The Preferred Reporting Items for Systematic Reviews and Meta Analysis (PRISMA) approach helps to visualize the selection process followed for SLR (Moher et al. 2009). Since this review’s objective was to deliver academically strong findings, stringent inclusion and exclusion criteria were defined by the author. Papers appearing only in peer-reviewed studies were included. Although conference papers, book chapters, and news articles provide useful insights, such grey sources were excluded. In total, 1650 papers were excluded from the initial result of 2218 papers. The first author scanned the title, abstract, and keywords of the remaining papers to determine their relevancy to this study’s aim. Eighty-four studies were qualified, and these were followed up with full-text evaluation by a pair of author. Papers were deemed eligible if they focus mainly on employing Blockchain for FSCM or address the FSC as one of the main fields for Blockchain applications. This search included academic journals from multi-disciplinary areas to obtain a holistic perspective of the field. The initial search was conducted at the end of 2019. However, to make the review most up to date, 20 papers published from January to June 2020 were included based on a full-text assessment. In the final stage, 69 papers were selected and approved by the author for conducting data synthesis.

Data synthesis was conducted following a descriptive and thematic analysis approach proposed by Tranfield, Denyer, and Smart (2003). The descriptive analysis captures the overall state of the research stream, while the thematic analysis examines, in-depth, the selected literature for specific themes emerging from the reviewed paper (Ghadge, Weiß, et al. 2020).

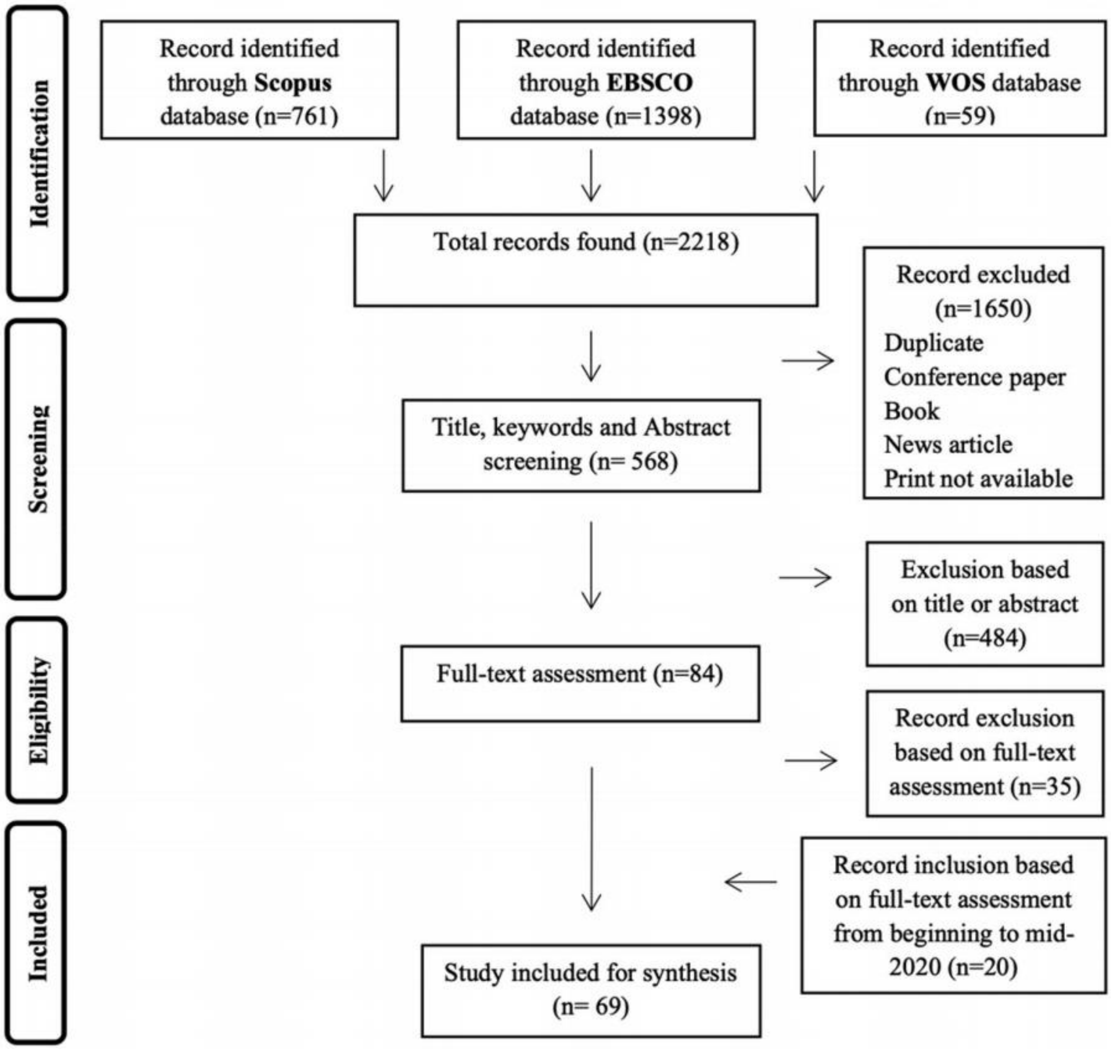

Figure 2-2. PRISMA flow diagram

2.4 Descriptive analysis

This section provides an overview of the research field under study – capturing publication trend, geographical and food product focus, and adopted theories and methods for conducting research. The publication trend indicates a growing interest of researchers on Blockchain interfacing FSCs. Figure 2-3 showcases the distribution of 69 papers by year. It can be observed that peer-reviewed academic papers started to emerge mainly from the year 2018 and, since then, this number is continuously growing. The number of studies in 2020 captured only published work in the first half of the year. There are several exciting studies regarding Blockchain and FSC before 2018 – such as Tian (2016) and Caro et al. (2018), but they were excluded as they are conference papers. Overall, it can be concluded that the research stream about Blockchain implementation in FSCs is in an early stage of development and has started to gain strong momentum since 2018.

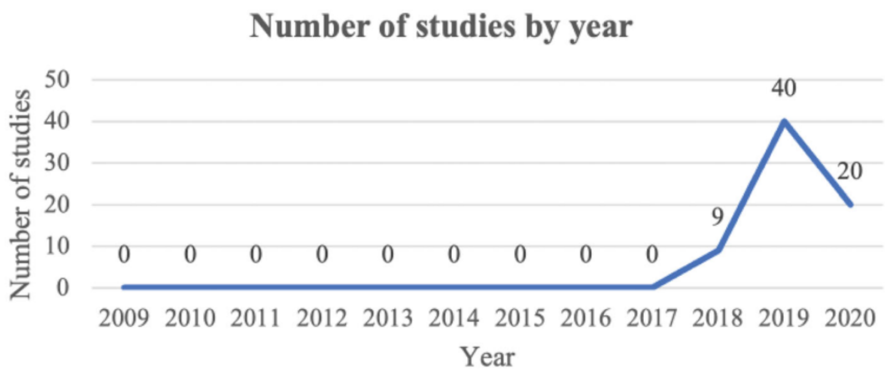

Figure 2-3. Publication by year

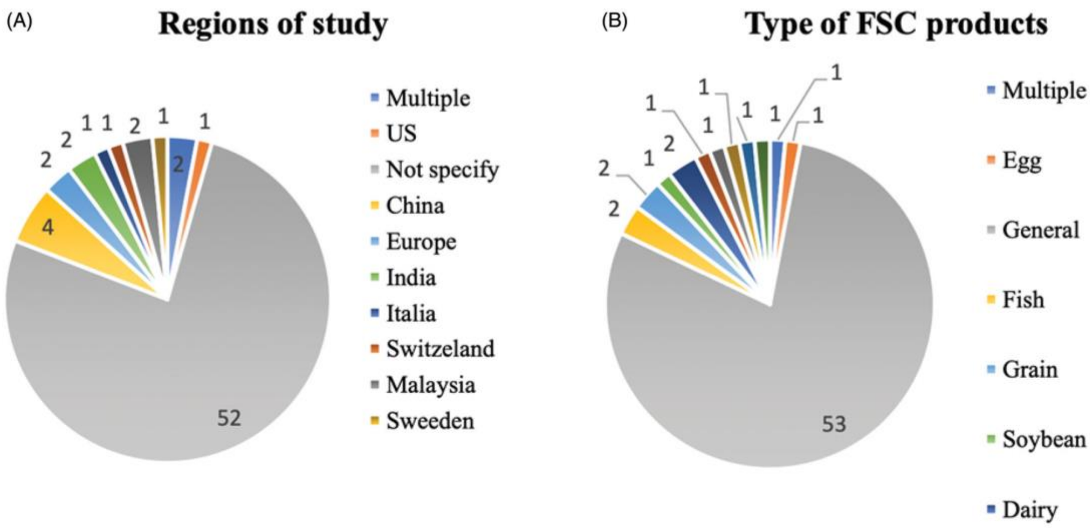

Figure 2-4. FSC regions of studies (A) and products type (B) covered in the data set

Next, the focus by geographic regions and by type of food products are captured in Figure 2-4. It can be observed that the majority of the selected papers investigated the use of Blockchain for the agri-food industry in general, rather than focussing on a specific type of food chain or region. Those papers, which focussed explicitly on a food chain, indicated that the interest in using Blockchain stems from numerous geographical regions and across varied food product types.

Concerning the use of theories, around one-fifth of the papers (22%) use established theories or existing conceptual frameworks to study Blockchain for FSCs. This is an expected observation given the nascent state of research on Blockchain-interfacing supply chains. Table 2-2 presents 15 studies adopting established theories and/or conceptual models, whilst the remaining papers (78%) do not include any theoretical lenses/elements.

Table 2-2. Use of theories and conceptual framework

Use of theories/conceptual frameworks	**References**	**Theories/ conceptual frameworks**
15 papers (22%)	Queiroz and Wamba, 2018	Combination of Network theory and Technology Acceptance Model (TAM).
	Hughes *et al.,* 2019	Diffusion of innovation, specifically the model of innovation decisions process proposed by Rogers (1995).
	Kouhizadeh *et al.,* 2019	ReSOLVE model for the circular economy.
	Roeck *et al.,* 2019	Transaction cost theory.
	van Hoek, 2019	Adaption from Reyes 2016's model of RFID implementation.
	Martinez *et al.,* 2019	Combination of Resource-Based View and Information Processing theory.
	Morkunas *et al.,* 2019	Utilization of the business model framework by Osterwalder and Pigneur.
	Wang *et al.,* 2019b	Sensemaking theory.
	Zelbst *et al., 2019*	General living systems theory.
	Wong *et al.,* 2019	Technology Organization Environment framework.
	Behnke and Janssen, 2020	Adaption from the conceptual framework developed by Aung and Chang in their 2014 research.
	Caldarelli *et al.,* 2020	Combination of Knowledge-based view and Gold *et al*. 2015 model.

	Hew *et al.,* 2020	Combination of Institutional theory and Innovation diffusion theory.
	Sternberg *et al., 2020*	Interorganizational System (IOS) Model.
	Wamba *et al.,* 2020	Technology adoption models, mainly TAM and Unified theory of acceptance and use of technology.

The research approaches/methods which were adopted in the selected papers are summarized in Table 2-3. The choice of research approach/methodology and the proportion of each type reflect the preliminary stage of Blockchain development in the FSC. Most of the effort from scholars has been directed to conceptualize various aspects of Blockchain implementation, experiment with the technology on a small scale, and synthesize up to date understanding about Blockchain. The two most common research approaches found comprise of conceptual (25%) and proof of concept (28%). Conceptual papers analyze the phenomenon of Blockchain using existing knowledge in SCM, while proof of concept papers are pilot stage studies, proposing a Blockchain-based solution for specific FSC problems. Review papers account for 19% of the total number of papers. Lack of large-scale projects and adopters is potentially attributed to lower numbers of empirical studies comparing other kinds of studies. There are eight papers using quantitative methods (12%), ten using a qualitative method (14%), and two using mixed methods of survey and case study (2%).

Table 2-3. Research approaches

Research approach	**Number of studies (%)**	**References**
Conceptual	17 (25%)	Ko *et al.* (2018); Galvez *et al.* (2018); Al-Jaroodi and Mohamed, (2019); Astill *et al.* (2019); Chang *et al.* (2019); Cole *et al.* (2019); Creydt and Fischer (2019); Heinrich *et al.* (2019); Kos and Kloppenburg (2019); Kumar *et al.* (2019); Kshetri (2019); Montecchi *et al.* (2019); Morkunas *et al.* (2019); Pearson *et al.* (2019); Saberi *et al.*(2019); Howson (2020); Zhang *et al.* (2020a)
Proof of concept	19 (28%)	Leng *et al.* (2018); Mao *et al.* (2018a); Mao *et al.* (2018b); Perboli *et al.* (2018); Bumblauskas *et al.* (2019); George *et al.* (2019); Helo and Hao (2019); Lin *et al.* (2019); Mondal *et al.* (2019); Salah *et al.* (2019); Tao *et al.* (2019); Tsang *et al.* (2019); Wang *et al.* (2019c); Casino *et al.* (2020); Feng *et al.* (2020b); Hang *et al.*

		(2020); Prashar *et al.* (2020); Shahid *et al.* (2020); Zhang *et al.*(2020b)
Review	13 (19%)	Antonucci *et al.* (2019); Hughes *et al.* (2019); Juma *et al.* (2019); Kamilaris *et al.* (2019); Pournader *et al.* (2019); Wamba *et al.* (2019); Wang *et al.* (2019a); Zhao *et al.* (2019); Chen *et al.* (2020); Feng *et al.* (2020a); Lin et al. (2020); Gonczol *et al.* (2020); Hastig and Sodhi (2020)
Quantitative	8 (12%)	Queiroz and Wamba, (2018); Azzi *et al.* (2019); Kamble *et al.* (2019); Sander *et al.* (2018); Wong *et al.* (2019); Zelbst *et al.* (2019); Hew *et al.* (2020); Wamba *et al.* (2020)
Mixed methods	2 (2%)	Martinez *et al.* (2019); van Hoek (2019)
Qualitative	10 (14%)	Wang *et al.* (2019b); Kshetri (2018); Chong *et al.* (2019); Roeck *et al.* (2019); Behnke and Janssen (2020); Caldarelli *et al.* (2020); Sternberg *et al.* (2020); Shin *et al.* (2020); Rogerson and Parry (2020); Kouhizadeh *et al.* (2019);

2.5 Thematic analysis

Thematic analysis can provide a comprehensive and interpretative literature examination (Ghadge, Weiß et al. 2020). There are two approaches to thematic analysis in social studies (Terry et al. 2017). One is the deductive approach, which builds predetermined themes based on existing theories, then uses them as guidelines in the coding process. This approach echoes the standard scientific method, moving from theory to hypothesis (identifying themes) then testing the hypothesis (coding). The other is an inductive approach, which aims to build themes throughout the examination of the available information. Braun and Clarke (2012) suggested starting with coding the contents and then developing and finalizing themes during and after the coding process.

This study employed a mixed approach to examine the literature. First, the researchers outlined potential themes based on concepts frequently found in the IA literature regarding the process of ingraining new technology (Hameed, Counsell, and Swift 2012). The initial themes then served as guidelines for the coding process. With support and guidance from the other two researchers, the first author thoroughly read each selected paper and recorded insights associated with Blockchain implementation (activities and influential factors). Subsequently, the key findings were gathered in a group with similar underpinning themes. Findings were circulated and agreed upon among all author. An iterative process was followed to best represent the body of literature on Blockchain and the FSC. Figure 2-5 presents four broad themes utilized for conducting the thematic analysis.

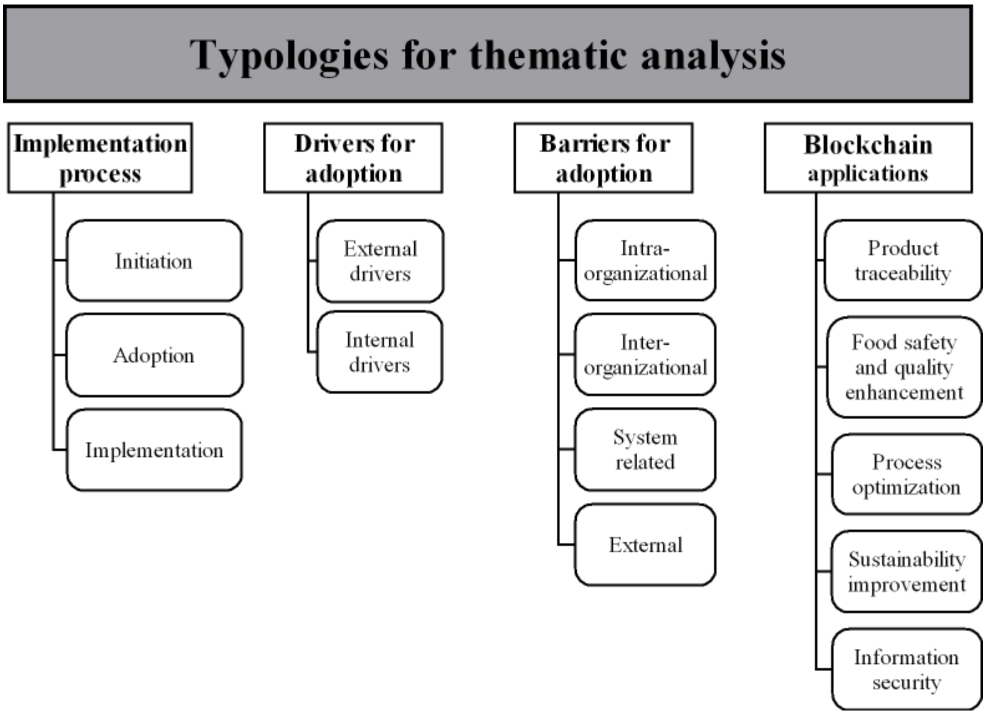

Figure 2-5. Themes emerging from selected papers.

2.5.1 The implementation process

As indicated by the literature regarding the adoption of innovation (Zhu, Kraemer, and Xu 2006, Hameed, Counsell, and Swift 2012; Pichlak 2016; Sternberg, Hofmann, and Roeck 2021), a new technological innovation typically goes through the phases of imitation, adoption decision, and implementation to be ingrained fully into organizations. Literature about Blockchain for FSCM has reported similar activities suggested by IA literature; however, it is apparent that the emphasis is placed on only specific activities. Among the selected studies, the topic of adopting Blockchain can be seen as either sole focus (e.g. Queiroz and Wamba 2019; van Hoek 2019; Wong et al. 2019) or part of the discussion (e.g. Bumblauskas et al. 2020; Caldarelli, Rossignoli, and Zardini 2020; Sternberg, Hofmann, and Roeck 2021). Drawing from IA literature, three broad phases, initiation – adoption – implementation, were suggested for the implementation of Blockchain (Cole, Stevenson, and Aitken 2019; van Hoek 2019; Sternberg, Hofmann, and Roeck 2021). In particular, during the initiation stage, a firm can realize a need, acquire knowledge about the technology, and propose a suitable solution fitting with the firm's current situation. An example is a case study conducted by Caldarelli, Rossignoli, and Zardini (2020), in which an Italian cheese producer opted for Blockchain due to the desire to reach final consumers and reduce the risk of counterfeit products. Subsequently, the company took the time to learn about the technology and analyzed their current situation to outline the most suitable Blockchain solution (being run by a consortium, using third-party software, etc.). For the adoption phase, extant literature mainly focussed on determining influential factors which constituted the decision to adopt/use Blockchain, such as relative advantages of the technology, cost of adoption, pressure from competitors, etc. (Queiroz and Wamba 2019; Kamble, Gunasekaran, and Sharma 2020; Wong et al. 2019). A more detailed discussion about these factors can be found in the later sections. Lastly, piloting Blockchain is seen as the standard choice for organizations before rolling out on a mass scale (Cole, Stevenson, and Aitken 2019; van Hoek 2019; Bumblauskas et al. 2020). However, since most Blockchain for FSC projects are pending for large-scale deployment or on hold after the pilot (Kamilaris, Fonts, and Prenafeta-Boldu 2019; Zhao et al. 2019), activities beyond this step have not been established.

While literature about Blockchain for FSCs has identified several activities during the implementation process, others might still be in the dark. For instance, during the adoption phase, IA researchers have determined that companies also take the step of allocating necessary resources for the implementation, in addition to the adoption decision (Hameed, Counsell, and Swift 2012, Pichlak 2016). Similarly, the implementation phase does not stop at large-scale deployment of the technology, but the organization needs to take further actions to integrate it into the existing infrastructure, such as training or routinizing (Martins, Oliveira, and Thomas 2016) and, perhaps, continuing to extend the scope of the project (Hossain, Quaddus, and Islam 2016). The lack of these recognised activities could be attributed to the novelty of both Blockchain use for FSCs and the infancy stage of the corresponding stream of research, further motivating researchers to explore this unchartered territory.

2.5.2 Drivers for adoption

This section presents the drivers for Blockchain implementation in the FSC. Drivers found in the selected literature can be broadly grouped into internal and external drivers. The former are motivations emanating from within an organization, while the latter are factors coming from outside an organization. These motivational drivers originate primarily from the challenges faced by the FSC and explore whether Blockchain can provide potential solutions.

2.5.2.1 Internal drivers

Reviewed papers reveal that businesses are most interested in the Blockchain's ability to enhance food traceability, transparency, and efficiency. Other motivations found include combating food fraud and cost-saving.

2.5.2.1.1 Enhance food traceability

Food traceability is the ability to track food products throughout multiple processes and entities in the FSC. Traceability in the current agricultural-food chain is difficult to execute since it is complex and globalized, with multiple tiers of suppliers and buyers (Mao, Hao, et al. 2018; Azzi, Chamoun, and Sokhn 2019). Moreover, current practices of centralizing tracking information cause severe data fragmentation and information asymmetry in the FSC (Salah et al. 2019; Tsang et al. 2019). With its distributed and tamper-proof ledger design, Blockchain can guarantee every party in the FSC to have access to authentic information at any given time. Therefore, businesses expect to be able to track food in real-time (Kos and Kloppenburg 2019) with more accuracy and effectiveness than conventional centralized systems (Al-Jaroodi and Mohamed 2019; Pearson et al. 2019). Businesses further anticipate Blockchain to accelerate the speed of the tracking process significantly, as Walmart's Blockchain pilot saw a significant amount of time reduced for tracing mangoes and pork (George et al. 2019; Kamilaris, Fonts, and Prenafeta-Boldu 2019; Wang, Singgih, et al. 2019).

2.5.2.1.2 Enhance food chain transparency

Transparency can be defined as the ability to see from one end of the supply chain to another (Zelbst et al. 2019). Lack of transparency can result in quality and safety issues in FSCM. For instance, an E. coli outbreak (2015) in the US caused not only tremendous damage to people and businesses but also took a substantial amount of time to resolve due to the lack of visibility in the supply chain (Kshetri 2019; George et al. 2019). Blockchain can broadcast information of products' movement and custody along the chain to every participant in real-time (Kumar, Liu, and Shan 2020; Mondal et al. 2019), enabling FSCs to be more transparent. This is a meaningful improvement in managing food quality and safety, especially for product lines in which different grades and types of food can be easily mixed, such as processed meat (Pearson et al. 2019) or soybean (Salah et al. 2019). Halal food is another example where increased transparency is hugely beneficial (Hew et al. 2020). Furthermore, businesses can rely on Blockchain to obtain reliable information about food provenance and communicate such information to consumers to gain a competitive edge over others in the market (Helo and Hao 2019; Montecchi, Plangger, and Etter 2019; Caldarelli, Rossignoli, and Zardini 2020).

2.5.2.1.3 Increase efficiency

Organizations expect Blockchain to increase the efficiency of critical activities in FSCM. Blockchain could improve the process of responding to food safety and quality outbreaks, which is frequently mentioned in the literature as one of the biggest challenges of FSCM (Astill et al. 2019; Kumar, Liu, and Shan 2020; van Hoek 2019). Transparent and immutable records of transactions and activity stored on Blockchain can help firms quickly locate and separate contamination areas (Creydt and Fischer 2019; Gonczol et al. 2020), thus avoiding the necessity to shut down the entire supply line. Other logistical processes can also be optimized with the help of Blockchain. For instance, businesses can obtain comprehensive information regarding food products' shelf life to manage inventory and plan transportation accordingly, increasing profit and reducing waste (Astill et al. 2019; Roeck, Sternberg, and Hofmann 2020). It is further suggested that trustworthy information provided by Blockchain can speed up the claims-processing system in agriculture and payment process between FSC entities (Kamilaris, Fonts, and Prenafeta-Boldu 2019; Kumar, Liu, and Shan 2020; Hang, Ullah, and Kim 2020).

2.5.2.1.4 Combat food fraud

Counterfeit food products are a serious problem in modern food chains. Malicious parties can take advantage of the complex and fragmented food supply line to substitute food and ingredients with those of lower quality (Creydt and Fischer 2019; Hang, Ullah, and Kim 2020). As product movements are documented, verified, and protected with Blockchain, firms can prevent false products from mixing in and reaching consumers (Galvez, Mejuto, and Simal-Gandara 2018; Caldarelli, Rossignoli, and Zardini 2020). Moreover, Blockchain can accelerate the process of auditing and settling disputes since audit trails of every activity are recorded and protected in the chain (Chang, Iakovou, and Shi 2020; Kamble, Gunasekaran, and Sharma 2020), thus discouraging the unethical practice of violating food integrity.

2.5.2.1.5 Reduce cost

Blockchain can help companies to reduce cost. The cost of implementing a Blockchain-based system for a group is possibly less than an individual organization investing in a separate solution (Roeck, Sternberg, and Hofmann 2020). Blockchain can potentially remove the middle entities in a certain part of FSCs, lowering the over-cost of goods sold (Wong et al. 2019; Chen et al. 2020). A smart contract, a computer program with the ability to self-execute based on predetermined conditions, can be run on Blockchain to reduce further expense (Creydt and Fischer 2019; Kumar, Liu, and Shan 2020). For example, the smart contract can authorize payment automatically to suppliers once buyers provide proof of delivery and confirmation of the condition of goods, minimising human involvement to save time and effort.

2.5.2.2 External drivers

External drivers arise outside the company's environment and motivate firms to adopt Blockchain for better management of food The examined literature specifies pressure from consumers, competitors, and regulatory bodies within the FSC as external drivers.

2.5.2.2.1 Pressure from consumers

Consumers are increasingly concerned about the quality and safety of food products due to a series of violations in recent years (e.g. the horsemeat scandal in the EU; infant milk incident in China; salmonella and E. coli outbreak in the US) (Sander, Semeijn, and Mahr 2018; Astill et al. 2019). Frequent problems of counterfeit food (Hang, Ullah, and Kim 2020) and mislabelling (Astill et al. 2019; Kamilaris, Fonts, and Prenafeta-Boldu 2019) also broaden this concern. Furthermore, consumers are becoming highly aware of the environmental and social impacts associated with FSC by-products (Heinrich et al. 2019; Kouhizadeh, Zhu, and Sarkis 2020; Wang, Han, and Beynon-Davies 2019). Thus, organizations view Blockchain as a tool to cope with recent changes in consumers' preferences. Using Blockchain, trustworthy firms in FSCs can provide reliable information about product provenance and assure consumers of their sustainable practices.

2.5.2.2.2 Pressure from buyers/suppliers and competitors

With a growing focus on the use of modern technology in the digital era, several competitors indirectly drive the need for adopting Blockchain. For example, Carrefour (a major French grocery retailer) launched a Blockchain project to monitor product lines such as poultry, tomato, honey, etc., anticipating that traceable food products would give them a competitive edge over other retailers (Chang, Iakovou, and Shi 2020). Moreover, the leading company in adopting Blockchain can, in turn, pressure other entities in the FSC to adopt the technology. For instance, following successful pilots, Walmart now mandates farmers and suppliers to join its growing Blockchain system (Kshetri 2018; Chang, Iakovou, and Shi 2020). Global suppliers can exert similar pressures to streamline industries for Blockchain use. Since the benefit of using Blockchain is multiplied with a larger number of users (Chen et al. 2020), pioneering firms cannot neglect the participation of smaller organizations, and often urge them to join the Blockchain network (Cole, Stevenson, and Aitken 2019; Wang, Han, and Beynon-Davies 2019).

2.5.2.2.3 Pressure from regulations

FSCs have always been under strict scrutiny from regulatory bodies on multiple aspects. For instance, Canada enforces the use of barcodes and tags to identify the initial herd of animals, and Australia uses a national scale system to track animals from birth to slaughter (Wang, Li, et al. 2019). Furthermore, fishing companies are now required to report annually about slavery and human trafficking in the US and UK (Howson 2020). Under the pressure of regulations becoming stricter on multiple fronts, firms in the food industry are pressured to explore Blockchain for better compliance with the requirements (Casino et al. 2020), as the technology can help track a product through multiple stages and provide reliable records of sustainable practices.

2.5.3 Barriers to adoption

In this theme, barriers to adopting and/or implementing Blockchain in FSCs are discussed. Saberi et al. (2019) and Cole, Stevenson, and Aitken (2019) classify barriers to Blockchain adoption within SCM into four main categories: intra-organizational, inter-organizational, system-related, and external barriers. Adopting this classification, barriers for implementing Blockchain in FSC are assessed

2.5.3.1 Intra-organizational barriers

Intra-organizational barriers are reasons derived from within an organization, making managers reluctant to adopt Blockchain. Four intra-organizational barriers are identified namely, high implementation cost, lack of knowledge and expertise, transparency versus privacy dilemma and uncertainty about Blockchain suitability.

2.5.3.1.1 High implementation cost

Investing in Blockchain can be expensive, and firms are concerned that the benefits of technology might not outplay high cost (Wang, Singgih, et al. 2019; Zhao et al. 2019). The complexity of Blockchain could require a considerable amount of time and resource from firms to master (Wong et al. 2019); meanwhile, the cost of hiring Blockchain specialists can be exceptionally high due to large demand (Kshetri 2019). Moreover, firms must often invest in additional devices such as RFID or sensors for a comprehensive solution (Chen et al. 2020; Zhang et al. 2020a). Pioneers in exploring Blockchain include large enterprises such as Walmart or Carrefour since they are financially capable of investing in costly projects with an expectation of rewards in the long term (Cole, Stevenson, and Aitken 2019; Wang, Han, and Beynon-Davies 2019). For others, it might be difficult to justify such an investment. In the case of small and medium farmers or companies with low margins, a sudden spike in cost due to implementing Blockchain is a major concern and could hinder the chance of adoption (Kamilaris, Fonts, and Prenafeta-Boldu 2019; Zhao et al. 2019).

2.5.3.1.2 Lack of knowledge and expertise

Lack of knowledge and expertise about Blockchain technology is a concern for several organizations. Implementing Blockchain is a complex and lengthy process, requiring firms to have a certain level of knowledge, infrastructure, and technological capability (Chang, Iakovou, and Shi 2020; Helo and Hao 2019; Wong et al. 2019). For FSCs, small to medium farmers and companies make up a relatively large portion of the network (Leng et al. 2018; Kshetri 2019; Zhao et al. 2019), and they may not have sufficient technological understanding and expertise to engage in Blockchain implementation. Moreover, a lack of understanding about Blockchain from top managers can postpone implementation for the firm (Zhao et al. 2019; Chen et al. 2020). van Hoek (2019) further concludes from interviews with managers that the difficult part for many companies is not the technology but, rather, how to obtain the right experts to start the Blockchain project.

2.5.3.1.3 Transparency versus privacy dilemma

Blockchain provides transparency by allowing each participant to track, trace, and view all transactions stored in the chain. Companies can see activities and product movements further upstream or downstream in the context of the supply chain. Increased visibility brings inherent benefit such as end-toend traceability; however, companies also face the risk of leaking private information (Lin et al. 2019; Chen et al. 2020). The trade-off between transparency and privacy could make organizations hesitate in investing in Blockchain. For instance, Sander, Semeijn, and Mahr (2018) found that large meat providers, who compete on a cost base, are reluctant to share their information about sources. Despite technical solutions such as encryption or masking identity, basic information, e.g. product type, price, time, location can still be revealed (Zhao et al. 2019). This is less of an issue for permissioned Blockchain networks since access to information can be controlled and authorized (Kumar, Liu, and Shan 2020; Wang, Han, and Beynon-Davies 2019); nonetheless doing so would compromise the visibility of the FSC.

2.5.3.1.4 Blockchain suitability

An inhibitor of Blockchain adoption is that technology might not be suitable for every organization or every kind of product. Companies may implement Blockchain due to the hype around it or the fear of competition (missing out) rather than the actual need (van Hoek 2019; Wang, Han, and Beynon-Davies 2019). Kumar, Liu, and Shan (2020) argue that if conventional solutions still prevail, investing in Blockchain will not be necessary. Kshetri (2019) further suggests that implementing Blockchain to manage high-value food products, for example high-end Australian beef is more realistic as it can potentially yield better returns. Return on investment is often critical to the decision of implementing technology such as Blockchain (Kouhizadeh, Zhu, and Sarkis 2020; Saberi et al.

2019); thus, the suitability of the technology can greatly dictate, and in some instances postpone, such decisions.

2.5.3.2 Inter-organizational barriers

There are barriers at an inter-organizational level that obstruct the implementation of Blockchain. The literature emphasizes supply chain readiness, inaccurate inputs, and variations of companies' standards as inter-organizational barriers.

2.5.3.2.1 Supply chain readiness

The Blockchain's ability to facilitate end-to-end traceability and increase transparency would be greatly undermined if only a small number of nodes in the FSC can join the network (Perboli, Musso, and Rosano 2018; Tsang et al. 2019). Although large enterprises can initiate Blockchain projects, smaller firms' participation is required for fruitful results (Wang, Han, and Beynon-Davies 2019; Chen et al. 2020). However, a large number of nodes in the food chain relate to farmers or small and mediumsized firms with limited technological expertise and financial resources (Leng et al. 2018; Kshetri 2019; Hang, Ullah, and Kim 2020). They are not likely to have the adequate capability to adopt Blockchain. Practitioners, indeed, voice concern that while a single pilot might be plausible, implementing Blockchain on a supply chain scale is a great challenge (van Hoek 2019). As a result, firms could hesitate to invest in Blockchain if the majority within the FSC are not yet capable of adopting the technology.

2.5.3.2.2 Smart contract designing

Blockchain assures that no changes can be made once the information is verified and stored. However, manipulations or mistakes can still introduce incorrect data into the system, reducing the system's overall reliability and making it difficult to fix (Kamble, Gunasekaran, and Sharma 2020; Tsang et al. 2019). Sternberg, Hofmann, and Roeck (2021) found in a Blockchain pilot – ReLog – that fake red wine can still enter the system because Blockchain can only guarantee digital trust but not the physical monitoring of products. IT experts in organizations have stressed that even with automatic data capture using sensors, the integrity of input information cannot be fully guaranteed (Wang, Singgih et al. 2019; Creydt and Fischer 2019). Kumar, Liu, and Shan (2020) further pointed out that malicious entities can band together and falsely validate inputs into Blockchain in a permissioned network – the preferred choice for business. Subsequently, inaccurate inputs due to various reasons can compromise the ability of Blockchain to facilitate trust and transparency, hindering the motivation to adopt the technology from organizations.

2.5.3.2.3 Variations in standards

Since companies adhere to different policies and use different information systems, there is a lack of standards when it comes to the traceability of information and data format (Galvez, Mejuto, and SimalGandara 2018; Behnke and Janssen 2020). For example, food producers or processors from the US are required by law to always have information 'one step forward one step back' available (Bumblauskas et al. 2020); this might not be the case for firms in other regions of the world. Thus, it can be challenging to introduce standard Blockchain at the SCM/FSC level since there is no existing consensus on what information must be included. Moreover, early adopters tend to employ different Blockchain solutions; therefore, it is possible that one supplier/retailer might have to comply with many Blockchain systems at once (Pearson et al. 2019). This scenario can impose more cost and confusion to organizations, creating a non-welcoming attitude towards technology.

2.5.3.3 System-related barriers

This section addresses the Blockchain technology limits for FSCM and the challenges in designing an effective Blockchain system for the FSC.

2.5.3.3.1 Scalability

Scalability is a vital issue when using Blockchain for FSCM. To fully understand the nature of this problem, we need to review the core principle of technology. Blockchain is referred to as distributed ledger technology because each network participant has an identical version of the ledger (Kumar, Liu, and Shan 2020). When a change happens, such as adding a new block, the system must update the ledger at every node to ensure a single version of truth among all entities. When the network scales up with more members and data, this update process is consequently slower, and latency becomes a more significant issue. The FSC has many actors involved from the point of production to the point of consumption (Pearson et al. 2019, Zhang et al. 2020b), and the amount of information generated is extremely large (Lin et al. 2019). Even though permissioned can process much more than public Blockchain – up to 3500 transactions per second for Hyperledger compared to 30 per second for Ethereum (Perboli, Musso, and Rosano 2018; Chang, Iakovou, and Shi 2020) – it is still not sufficient to handle the amount of data typically generated from FSC activities (Hang, Ullah, and Kim 2020). Consequently, organizations find that scaling Blockchain implementation beyond the pilot stage is very difficult (van Hoek 2019; Wang, Singgih et al. 2019).

2.5.3.3.2 Smart contract designing

An essential feature of the Blockchain system is the smart contract, which is fundamentally a computer program with the ability to self-execute based on predetermined conditions (Tao et al. 2019). A smart contract is stored in Blockchain and has access to data in the chain, increasing its validity and reliability. However, designing smart contracts for complex business logic remains a great challenge, and companies are somewhat hesitant to believe that all activities can be fully captured via smart contracts (Cole, Stevenson, and Aitken 2019; Kumar, Liu, and Shan 2020).

2.5.3.4 External barriers

External barriers refer to challenges originating from external stakeholders such as institutions, or the government, that are not directly benefitted from FSC activities (Saberi et al. 2019). In a complex supply chain such as food, participants may be in different regions; thus, they are placed under different restrictions and regulations (Sander, Semeijn, and Mahr 2018; Howson 2020). The question then arises – What laws the Blockchain system must choose to build its policy? Furthermore, regulations from different countries may not align, e.g. a smart contract is recognized under US contract law, but it is not under other jurisdictions

(Kumar, Liu, and Shan 2020; Chen et al. 2020). This could potentially be a problem in the case of a dispute. Overall, the lack of a unified regulation frame for Blockchain can make implementation less plausible.

2.5.4 Applications of Blockchain in FSCM

This theme presents how organizations in the FSC can utilize Blockchain. Drawing from actual use cases of Blockchain in the food industry and solutions proposed by researchers, it is determined that the use of Blockchain includes product traceability, enhancing food safety and quality, process optimization, sustainability improvement, and information security.

2.5.4.1 Product traceability

From a conceptual perspective, Blockchain technology, which provides comprehensive and real-time information about operations, matches the pre-requisite of a fragmented supply chain. Therefore, Blockchain in FSCs initiatives heavily prioritizes end-to-end product traceability. Walmart has cooperated with IBM since 2017 to pilot a Blockchain-based system to track mangoes and pork (Hughes et al. 2019; George et al. 2019), IBM introduced a Food Trust platform based on Blockchain (Chang, Iakovou, and Shi 2020; Pournader et al. 2020), and Carrefour launched the first Blockchain project in the EU for tracking its poultry products (Chang, Iakovou, and Shi 2020). Moreover, there are third-party Blockchain solutions that are tailored to food traceability. Notable examples include Provenance tracking fish in Indonesia (Kshetri 2018; Cole, Stevenson, and Aitken 2019), OpenSC tracking seafood from Australian waters (Howson 2020), and ChainNova tracking rice in China (Chong et al. 2019). Nevertheless, the majority of Blockchain projects for FSCM remain either pilots or small-scale implementation.

Additionally, a large amount of academic research also aims to facilitate end-to-end traceability for food products. Wang, Li, et al. (2019) and Salah et al. (2019) developed applications using Blockchain and smart contracts for food traceability; Lin et al. (2019) integrated Blockchain with an existing food traceability system (EPCIS) for an improved solution. Perboli, Musso, and

Rosano (2018) applied a fivestep model (GUEST) to design a Blockchain application for a European fresh food chain. Combining Blockchain with information-capturing technologies, e.g. RFID or sensors, Mondal et al. (2019) designed a generic solution for tracking food, and George et al. (2019) designed one specifically for food service businesses. The literature also frequently refers to BigchainDB proposed by researcher Tian, a real-time food tracking system based on Blockchain (Azzi, Chamoun, and Sokhn 2019; Juma, Shaalan, and Kamel 2019; Wang, Li, et al. 2019).

2.5.4.2 Food safety and quality enhancement

Food quality and safety are critical factors to a business's competitiveness (George et al., 2019; Heinrich et al. 2019; Tsang et al. 2019). Food recalls/incidents have placed tremendous pressure on the FSC to improve quality and safety monitoring (Zhao et al. 2019). Numerous Blockchain projects set out to specifically target the current quality and safety issues in the FSC. Notable examples are Alibaba's initiative (Kshetri 2018), the Food Trust Group by IBM and Walmart (Mao, Hao, et al. 2018), and collaboration between the Chinese retailer JD, Walmart, IBM, and Tsinghua University (Antonucci et al. 2019; Chen et al. 2020). Moreover, expensive food products are often the victim of food fraud, causing severe harm to legitimate businesses (Kshetri 2019). Thus, organizations can share traceability information on Blockchain with consumers to ensure they purchase authentic products. Examples of such initiatives include ChainNova for high-value rice from a specific region of China (Chong et al. 2019), San Rocco Dairy applying Blockchain for its Italian dairy products (Caldarelli, Rossignoli, and Zardini 2020), and Ireland Craft Beers using Blockchain for the authenticity of artizan beer (Wamba et al. 2020).

2.5.4.3 Process optimization

Blockchain could increase the efficiency of various activities in FSCM in terms of speed and accuracy. For instance, Blockchain helped Walmart reduce the tracking time from days to minutes in their most recent pilot (Astill et al. 2019; Wong et al. 2019). Mao, Wang, et al. (2018) and Tao et al. (2019) designed

Blockchain-based systems to supervise FSC actors' credibility. Upon testing, Blockchain effectively accelerated the process of validating credibility while it also increased the trustworthiness of the results. Casino et al. (2020) used a pilot case of local private Blockchain for dairy products to demonstrate how the smart contract can lubricate the handling of traceability.

2.5.4.4 Sustainability improvement

Blockchain can be used to tackle various sustainability issues in FSCM. Through Blockchain pilots, Walmart gained more comprehensive data of products' shelf-life and used such data to target the food waste issue via optimizing operations (Helo and Hao 2019). Organizations can also identify spoilage with increased precision, leading to less food going to landfill (Mao, Wang, et al. 2018, Wang, Han, and Beynon-Davies 2019). Resource usage in agriculture production can be made transparent using Blockchain, thus improving natural resources management (Kamilaris, Fonts, and PrenafetaBoldu 2019; Zhao et al. 2019). Blockchain can be further used to address social concerns. Coca-Cola has experimented with Blockchain to address forced labour in the sugarcane sector (Kamilaris, Fonts, and Prenafeta-Boldu 2019). Many Blockchain initiatives also aim to monitor better animal welfare, such as Hendrix Genetics (Kamilaris, Fonts, and Prenafeta-Boldu 2019) and Carrefour (Chang, Iakovou, and Shi 2020; Feng, Wang, Duan, et al. 2020).

2.5.4.5 Information security

Blockchain requires validation for each transaction and ensures no changes can be made after the information is stored, making falsification of data extremely difficult (Queiroz and Wamba 2019; Wang, Singgih, et al. 2019). Further, as a distributed ledger technology, Blockchain eliminates the single-point-of-failure existing in the conventional centralised system (Chang, Iakovou, and Shi 2020). Thus, the technology can be effectively used to ensure information security for FSCM (Salah et al. 2019; Zhao et al. 2019). A number of proposed proof-concepts also demonstrate this use of Blockchain; for instance, Zhang et al. (2020b) and Hang, Ullah, and Kim (2020) designed Blockchain applications to strengthen information security in the rice supply chain and fish farms respectively.

2.6 Towards a framework for Blockchain implementation

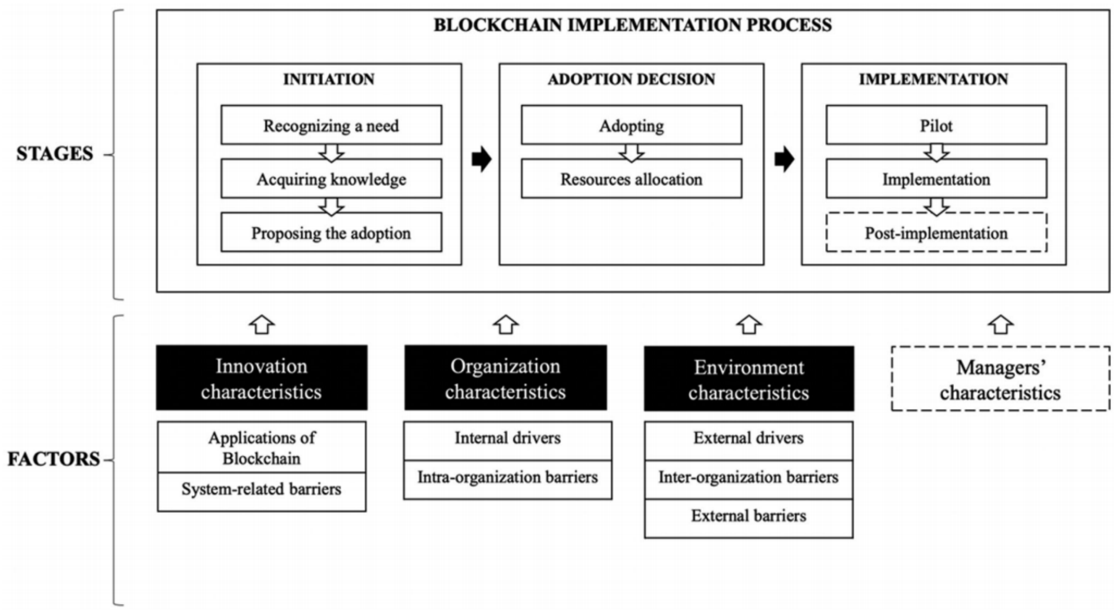

Figure 2-6. A conceptual stage model for Blockchain implementation in FSC.

The above developments of Blockchain interfacing FSCs highlight a lack of empirical research and successful largescale implementation examples in the food industry. Moreover, there are limited studies about executing Blockchain and the best practices for implementing it (van Hoek 2019; Saberi et al. 2019; Zhao et al. 2019). This aspect is crucial since understanding how innovation is ingrained into an organization is the key to materialising business benefits (Zhu, Kraemer, and Xu 2006). To address this established gap, insights synthesised on Blockchain-interfacing food chains literature (Section 5) are incorporated with the preliminary conceptual model (Figure 2-1) to develop a conceptual framework (capturing phases and influential factors) for implementing Blockchain in FSCs. The final integrated conceptual framework for Blockchain implementation in FSCs is presented in Figure 2-6.

As defined in the preliminary model construction (see Section 2.2), implementing Blockchain can happen through three main phases: initiation, adoption decision, and implementation. Eight activities were identified from the innovation adoption literature. First, an organization recognises a need for innovation, obtains knowledge of it, and proposes a plan of implementation (Hameed, Counsell, and Swift 2012; Pichlak 2016). Second, organizations must decide whether to adopt the innovation (Zhu, Kraemer, and Xu 2006; Martins, Oliveira, and Thomas 2016) and, if they choose to do so, they will allocate resources for adoption (Hameed, Counsell, and Swift 2012; Pichlak 2016). Third, the innovation is deployed, and the adopter must take the necessary steps to fully infuse it at an organizational and individual user level. Typical activities at this phase include developing the solution, implementing it at a large scale, training end-users, and routinizing the new technology (Cooper and Zmud 1990; Hameed, Counsell, and Swift 2012; Pichlak 2016). For adopting Blockchain in the food industry, five specific activities were echoed in the relevant literature. Companies first recognize a need for Blockchain to better track food products (Bumblauskas et al. 2020; Sternberg, Hofmann, and Roeck 2021) or ensure food authenticity (Kouhizadeh, Zhu, and Sarkis 2020), then engage in learning more about the technology (Caldarelli, Rossignoli, and Zardini 2020), and outline a pertinent solution (Chong et al. 2019; Caldarelli, Rossignoli, and Zardini 2020). Subsequently, the adoption decision is made after considering various factors (Kamble, Gunasekaran, and Sharma 2020; Wong et al. 2019). Further, a pilot is commonly carried out before full implementation (van Hoek 2019). The extant literature currently provides little insights about post-implementation activities, possibly due to the scarcity of successful large scale Blockchain projects for FSCM (Kamilaris, Fonts, and Prenafeta-Boldu 2019). This study predicts that further development of this stage will require major advancement of Blockchain in FSCs. Nonetheless, based on the IA literature, several activities can be hypothetically suggested, such as: training, routinizing, and extending the use of the technology (Cooper and Zmud 1990; Martins, Oliveira, and Thomas 2016; Hossain, Quaddus, and Islam 12 2016). Both actual activities recorded from literature and hypothetical were presented in Figure 2-6, with the latter in dotted boxes.

Furthermore, studies about Blockchain for FSCM unveiled interesting, influential factors to said process. Damanpour and Schneider (2006) argued that the process of incorporating innovation into an organization is not only multi-phased but also multi-dimensional, thus encouraging researchers to look at not only the stages of dissimilation but also influential factors and their effects. In this case, the determinants of the Blockchain implementation process can be drawn from insights synthesized from studies about Blockchain for FSCM, constituting the second important aspect of the conceptual framework.

As described in the preliminary model (Figure 2-1), four categories of determinants to the implementation process include innovation characteristics, organizational characteristics, environmental characteristics, and management characteristics. Insights drawn from the literature about Blockchain for FSCM were mapped and grouped under pertinent groups of attributes. For instance, innovation characteristics refer to the attributes of the innovation in consideration, which can affect the adoption decision and how the adoption process unfolds (Hameed, Counsell, and Swift 2012; Pichlak 2016). For this case, the cluster includes the applications of Blockchain, which outlines the use and potential of Blockchain, together with the system-related barriers, which identifies the constraints of the technology. For example, organizations need to determine the specific aim of the Blockchain project, e.g. for product traceability and understand the current technical limitations/challenges of Blockchain, before evaluating the feasibility of its implementation.

Subsequently, organizational characteristics are certain attributes of the adopter that can influence the adoption process (Damanpour and Schneider 2006; Hameed, Counsell, and Swift 2012). Intra-organization drivers, which are the improvements anticipated by organizations from using Blockchain, and several intra-organizational barriers, such as lack of capability or fear of losing privacy, can be considered as characteristics of an organization. Those factors can potentially impact different stages of implementation, as found in prior studies examining different technological innovation (Hossain, Quaddus, and Islam 2016; Martins, Oliveira, and Thomas 2016; Pichlak 2016). For instance, a barrier such as lack of IT capability is found to have an impact during the initiation and adoption phases (Martins, Oliveira, and Thomas 2016).

Further, the environment characteristics include factors originating from the surroundings of an organization, such as industry or market (Damanpour and Schneider 2006; Pichlak 2016). In the particular situation of using Blockchain for FSCM, it can be seen that inter-organization barriers, external barriers and external drivers belong to this category. Similar attribution can also be found in extant IA literature, in a conceptual model such as Hameed, Counsell, and Swift (2012) or empirical model such as Martins, Oliveira, and Thomas (2016) and Hossain, Quaddus, and Islam (2016).

Management characteristics are theorised to play an important role in the whole process of adopting innovation at an organizational level (Damanpour and Schneider 2006; Hameed, Counsell, and Swift 2012; Pichlak 2016). This attribute is highlighted in the literature on Blockchain for the FSCs. Saberi et al. (2019) considered the lack of top management support as a barrier to Blockchain. The involvement and commitment of managers can not only accelerate the project (van Hoek 2019) but also motivate other stakeholders to embrace this technology (Hastig and Sodhi 2020). Surprisingly, the discussion regarding the impact of top managers on adopting Blockchain for FSCM has not been articulated strongly among the selected papers in this SLR. Overall, these are important aspects providing the reason to keep them in the final conceptual framework. Future work can explore them further following an empirical study.

Finally, the novelty of the conceptual framework depicted in Figure 2-6 is discussed. As presented in Section 2.2.2, the IA body of literature is well established, and various IA theories and models were developed in the past to examine the adoption decision and process of new technologies or innovations to organizations. The conceptual framework in this research provided an elaboration on those established theoretical foundations. While previous works such as Pichlak (2016) or Hameed *et al.* (2012) contribute valuable models for guiding the process of innovation adoption, they addressed a generic scenario of integrating new technology at the organisational level. Other works such as Zhu *et al.* (2006), Martins *et al.* (2016), and Hossain *et al.* (2016) are more specific, directing their efforts to examine particular innovative technologies. This PhD work is among the first to elaborate and adapt the concept of the implementation model to explicitly explain the adoption journey of Blockchain in the specific settings of FSC. Therefore, it considered activities, stages, and determinants that are distinctive to the phenomenon of interest. Nuanced differences can be found when comparing the conceptual model of this study (Figure 2-6) and previous models. Particularly, a successful implementation is determined to be when Blockchain is diffused in the adopting organisation and its partners, instead of when individuals in a company regularly use the technology as suggested by Pichlak (2016) or Martins *et al.* (2016). Thus, the activities within the Implementation stage were found to be different in the case of Blockchain implementation in the FSC. Further, the determinants of the adoption process are deduced from FSC-related insights found in the literature, implying that these factors are relevant in the FSC context. Overall, the conceptual model (Figure 2-6) provided an attempt at elaborating established IA theories and models to better understand and explain the specific phenomenon of implementing Blockchain in the FSC setting.

2.7 Conclusion and future research agenda

2.7.1 Future research avenues

Based on the synthesis of the study, six recommendations on future research directions of Blockchain implementation in FSCs are identified:

2.7.1.1 Need for empirical work exploring the implementation process of Blockchain in FSCs

The extant literature has shed some light on the process of implementing Blockchain for organizations in FSCs, such as the constitution of adoption decisions (Wong et al. 2019) or how firms engage in Blockchain projects (Caldarelli, Rossignoli, and Zardini 2020). Nevertheless, further exploration is needed. As demonstrated in this study, IA literature can sufficiently outline the framework for implementing Blockchain in FSCs. However, in-depth insights from the agriculture and food industry are needed to develop robust and tailored frameworks for Blockchain-for-FSCs implementation to achieve desired results.

2.7.1.2 Investigating scalability issues in the context of Blockchain implementation at the SC network level

Until now, successful Blockchain initiatives for food chains include pilots and small-scale projects (Cole, Stevenson, and Aitken 2019, Hughes et al. 2019; Kamilaris, Fonts, and Prenafeta-Boldu 2019). Thus, Blockchain implementation at the supply chain network level is a promising area for researchers. Scalability is a significant inhibitor of Blockchain implementation (Kumar, Liu, and Shan 2020). Therefore, examining the impact of this issue and how to effectively tackle it can establish grounds for adopting Blockchain at the inter-organizational level.

2.7.1.3 Overcoming the fundamental challenges to Blockchain adoption

Particularly how to balance the trade-off between transparency and privacy, and how to overcome the problem of oracle – a gateway between Blockchain and the physical world (Caldarelli, Rossignoli, and Zardini 2020). Both challenges were stressed as main concerns when adopting Blockchain for FSCM (Zhao et al. 2019; Caldarelli, Rossignoli, and Zardini 2020). For the former, a case study can observe how the transparency and privacy dilemma is addressed in an established Blockchain system. For the latter, even though inaccurate inputs are a major concern with Blockchain (Tsang et al. 2019; Sternberg, Hofmann, and Roeck 2021), modest effort has been put into exploring how to guarantee that an oracle can convey the correct information to Blockchain. Further work in this area can strengthen the validity of Blockchain use in FSCs.

2.7.1.4 Capturing the aspects of incentivization

Incentivizing is an important mechanism for the permissioned Blockchain network as, when done correctly, it encourages willingness and responsibility in sharing data (Cole, Stevenson, and Aitken 2019; Pearson et al. 2019). Nevertheless, there has not been an ideal approach to incentivization. For public Blockchain, participants are encouraged by financial reward when validating the data (mining)

(Nofer et al. 2017). For permissioned Blockchain, the incentive for providing information and endorsing transactions is not as clear. Hence, future research can investigate designing an effective method of incentivization.

2.7.1.5 Using Blockchain to strengthen sustainability in the FSC

While several projects feature sustainability as a key objective, most Blockchain applications focus on bringing operational benefits to FSCM. Nonetheless, the technology can enhance sustainability in the food chain (Saberi et al., 2019; Kouhizadeh, Zhu, and Sarkis 2020); thus, future works can further explore how Blockchain can be used for sustainable development. For example, in-depth case studies can explore how Blockchain can be utilised to monitor waste or to ensure a fair share to the upstream farmers.

2.7.1.6 Regulations for governing Blockchain networks

The decentralization characteristic of Blockchain can bring certain advantages in terms of trustworthiness and transparency; however, it can be a limitation for the business use case, where overall control must be retained (Pearson et al. 2019; Hughes et al. 2019). The current body of literature about Blockchain and FSCM has offered a limited discussion on this subject. Several governance forms were mentioned, such as by participants of the network (Perboli, Musso, and Rosano 2018), by smart contracts (Chong et al. 2019; Salah et al. 2019), or the consortium that initiated the Blockchain project (Caldarelli, Rossignoli, and Zardini 2020). However, they are briefly examined, and in-depth analysis of each form is lacking. Further inquiries are needed to shed light on this important aspect.

2.7.2 Discussion and concluding remarks

While attempting to address the defined research question – What is the process for implementing Blockchain in FSCs? The study synthesized four major themes: implementation process, drivers and barriers to adopting Blockchain, and current uses of Blockchain within the FSC context. It was found that organizations typically go through the process of initiation – adoption – implementation to assimilate the technology. Further, increasing transparency and efficiency were identified as two key internal drivers for Blockchain, whereas pressure from consumers, competitors and regulatory bodies were critical external drivers. The main barriers to adoption included the privacy versus transparency dilemma, high implementation cost, the supply chain's readiness for Blockchain, and the scalability of Blockchain technology. Facilitating end-to-end traceability and strengthening food safety and quality were found as the most prominent use of Blockchain. The study makes a novel contribution to the field of supply chains in general and FSCs in particular. The study provides academically strong findings regarding the overall state of Blockchain implementation for the food supply chain and a conceptual model for implementation. Descriptive analysis of selected papers shows that this research stream is still in its infancy; nonetheless, the growth has been impressive and is expected to advance faster in the near future.

The study suggests IA theories as a legitimate approach to understanding and guiding the implementation of Blockchain. A novel, conceptual framework for implementing Blockchain in FSCs was developed using the lenses of IA theories. Therefore, this framework can be used as a reference by academics and practitioners in examining Blockchain use in the food industry.

Some implications for companies and regulatory bodies can be drawn from this study. First, managers gain an overview of the Blockchain development in the FSC and fundamental understandings about the implementation activities, potential, and challenges of a Blockchain application. Moreover, although conceptual, the framework can help managers plan their implementation process, utilizing the insights provided. For policymakers, it is possible to help leverage the use of Blockchain in the FSC by eliminating regulatory inhibitors, such as the lack of legal frameworks in recognizing smart contracts and, consequently, companies can adhere better to other regulations such as food traceability and food safety.

There are a few limitations to this study. A limited number of papers were used to derive insights. Future empirical work can advance the conceptual framework by testing it in an industry setting. The review was limited to the FSC context, thus generalizing the study's results to other SCM areas may be constrained. Although the keywords for the data search were carefully formulated, there is a possibility that several relevant studies may have been overlooked. Even though the 'grey literature' such as conference papers or book chapters were excluded to make our review procedure replicable and rigorous, we acknowledge that certain insights about the subject can be gained from examining such a stream of research. Nevertheless, this SLR provides evidence-based future avenues and contributes by providing a novel conceptual framework for implementing Blockchain in FSCs.

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3 EVIDENCE-DRIVEN MODEL FOR IMPLEMENTING BLOCKCHAIN IN FOOD SUPPLY CHAINS

Abstract

Blockchain technology has been identified as a possible solution to address critical challenges faced by the food sector. Building on the potential of Blockchain within Food Supply Chains (FSC), this study aims to develop an evidence-based implementation model for Blockchain in the food industry. Innovation Adoption and other prominent theories are integrated to first develop a conceptual framework, which is later validated following an analysis of the qualitative data. Fifteen semistructured expert interviews are used to develop an evidence-driven, applied model for implementing Blockchain; providing detailed insights into typical stages, associated activities, and contextual determinants needed for successful integration. An empirically validated implementation model advances the extant academic literature and further provides a detailed roadmap for food practitioners, while initiating Blockchain projects with their firms and/or supply chains.

Keywords: Blockchain; implementation framework; innovation adoption; food supply chain.

3.1 Introduction

Food is an important aspect of our society and economy. On average, 17% of a UK household income is spent on food (Office for National Statistics 2020), and the EU recognised the food and drink industry as one of the largest sectors with a turnover of more than 1 trillion Euro in 2019 (Food Drink Europe 2019). However, the modern agriculture and food industry has been facing persistent challenges in managing food safety, quality, and sustainability due to increasingly globalised, complex, and fragmented supply lines (Akkerman, Farahani, and Grunow 2010; Routroy and Behera 2017). Subsequently, the food industry has heavily invested in information systems and modern technology for better management of food products (Routroy and Behera 2017; Kamble, Gunasekaran, and Gawankar 2020). Blockchain technology has recently emerged as a unique technology that can solve critical issues identified in food supply chains (Zhao et al. 2019; Tan, Gligor, and Ngah 2020). A notable example is Carrefour, a European food retailer, which initiated Blockchain for its poultry products in 2018, anticipating full traceability of this product line in 2022 (Carrefour 2020). Similarly, Nestlé and IBM are attempting to monitor the sustainability of their coffee, milk, and palm oil (Nestlé Global 2020). Furthermore, Walmart successfully piloted Blockchain for tracking mangoes and pork and is moving toward fully integrating Blockchain into their operations (Hyperledger 2019).

When examining transformative technologies (such as Blockchain), one of the most critical aspects is to understand the implementation at the organisational level. For instance, the adoption of ERP has long been examined in the literature (see highly cited works such as Liang et al. (2007) or Schniederjans and Yadav (2013)) and is well understood among practitioners with numerous integration guidelines provided by reputable service providers (e.g. SAP 2022) and consulting companies (e.g. Deloitte 2022). RFID is another transformative technology that has received considerable attention from researchers (Kim and Garrison 2010; Hossain, Quaddus, and Islam 2016). The food industry has been at the forefront of exploring Blockchain since it is first considered for Supply Chain

Management (SCM), and the technology has subsequently gained substantial momentum with numerous ongoing initiatives. Therefore, a specific study that examines the implementation process of Blockchain in FSC, with supporting empirical evidence, has tremendous opportunities to contribute to both literature and practice.

Some early attempts at investigating the adoption of Blockchain in the wider SCM domain are evident in the extant literature. However, most studies examine the decision to adopt Blockchain and the different factors leading to such a decision (Kamble, Gunasekaran, and Arha 2019; Queiroz et al. 2020; Wong et al. 2020; Falcone, Steelman, and Aloysius 2021). Understanding how an organisation decides to adopt Blockchain is valuable, yet there is a lack of clarity on the Blockchain adoption process within organisations. The life cycle of technology innovation does not stop after the adoption decision (Wamba and Queiroz 2022). A comprehensive understanding of the technology implementation process can lead to successful integration, creating business value (Zhu et al. 2006; Pichlak 2016). A limited number of studies explore this endeavour; however, most of them are conceptual (Hughes et al. 2019) or lack a strong theoretical foundation (van Hoek 2019). Therefore, it can be seen that the current body of literature remains short of holistic approaches to examining the implementation process of Blockchain at the organisational/SC level. Furthermore, scholars continue to advocate for in-depth inquiries about the adoption process of Blockchain in specific types of industries, to address sector-specific challenges, and to justify the value of Blockchain for improving supply chain performance (van Hoek 2019; Wamba and Queiroz 2022). Considering the critical challenges faced by FSC and the potential growth of Blockchain in this particular domain, it can be further inferred that the literature currently lacks empirical studies exploring the Blockchain adoption journey in the FSC.

To minimise this evident gap, this study aims to answer the following research questions (RQ):

RQ1: How do organizations in the FSC implement Blockchain technology?
RQ2: What are the main determinants of the implementation process of Blockchain in the context of FSC?

while attempting to find answers to the above questions, this study develops an evidence-based model for Blockchain implementation in the FSC, providing detailed insights into adoption stages, associated activities, and contextual determinants needed for successful adoption. First, a conceptual framework for Blockchain implementation in the FSC setting is proposed, utilising prominent theories and established frameworks in the Innovation Adoption (IA). The IA perspective is a suitable foundation to study the adoption of Blockchain, as it has been used successfully to examine similar processes of other technologies (Hameed, Counsell, and Swift 2012; Martins, Oliveira, and Thomas 2016) as well as of Blockchain in other management fields (Kamble, Gunasekaran, and Arha 2019; Queiroz et al. 2020). Further, the conceptual framework also inherits the key findings in prior work by the author (Vu, Ghadge, and Bourlakis 2021) to ensure its relevance when applied to the specific context of FSC. Then, qualitative data (from interviews) is gathered to validate and improve the conceptual framework, resulting in a practical model for implementing Blockchain in the FSC. The contributions of this study thus are two-fold. First, practitioners can draw valuable insights and lessons from early Blockchain adopters in the FSC and further use the implementation model developed in this study as a useful reference for their Blockchain projects. Second, this study also contributes to the Blockchain for SCM literature, as it combines contextual empirical evidence (from in-depth interviews) with a theoretical understanding of implementing technological innovation to develop a specific model of Blockchain implementation for organisations in the FSC.

The rest of this study is structured as follows: Section 2 provides the background for this research; Section 3 discusses the methodology and the data collection process; Section 4 presents the findings from the data; Section 5 highlights the final implementation model and the implications of the study.

Finally, conclusions, limitations, and future research endeavours are presented in Section 6.

3.2 Background to the research

3.2.1 Blockchain in the FSC

The FSC can be broadly defined as a collection of activities from the first point of production (e.g. production of crops, livestock, etc.) to the final point of consumption and/or disposal (Dossa et al. 2020). Food products possess distinct characteristics such as perishability, seasonality, and dependence on climate, and suffer from persistent issues such as high price volatility, security, and serious wastage (Barbosa 2021); thus, they pose unique challenges regarding production, transporting, storing, monitoring quality and safety, and material recycling (Fredriksson and Liljestrand 2015; Barbosa 2021). Furthermore, product traceability and transparency are significant issues for FSC management (FSCM) due to multiple food-related scandals/recalls in the past, and the fact that food supply chains are increasingly globalised and complex nowadays (Routroy and Behera 2017; Kamble, Gunasekaran, and Gawankar 2020).

To overcome the critical challenges of managing food products, Blockchain has been seen as a potential remedy (Kamilaris, Fonts, and Prenafeta-Boldú 2019; Zhao et al. 2019). At the core, Blockchain can be understood as a distributed ledger technology. The name of the technology stemmed from the unique mechanism, by which information gets stored and distributed. Transactions and/ or information are first bundled into a block, then validated by the majority of participants of the Blockchain network, and, finally, the new block of information is linked to the previously created block by a unique hash number, creating a chain of blocks (Belotti et al. 2019; Kumar, Liu, and Shan 2020). Further, Blockchain is append-only, meaning recorded information cannot be changed, and additional blocks must be created to store new data. Blockchain is decentralised, meaning there is no overseeing party of the ledger; rather, every network member holds an authentic copy of the ledger. These characteristics make Blockchain an effective means of storing and sharing tamper-proof information with high security, integrity, and real-time accessibility (Wamba and Queiroz 2022). Consequently, Blockchain can improve FSCM by facilitating reliable information sharing, increasing trust and accountability of records, and extending the visibility of the supply chain (Tan, Gligor, and Ngah 2020). Thus in FSC, Blockchain has been prominently used to enhance the traceability process, improve the management of food inventory, and communicate information about food provenance and integrity to end consumers (Kamilaris, Fonts, and Prenafeta-Boldú 2019).

3.2.2 Conceptual framework for Blockchain implementation

This study proposes to examine the integration of Blockchain in FSCs under the theoretical lenses of IA. Broadly, there are two dominant perspectives in IA research: innovation variance research and dichotomy of innovation process research (Hameed, Counsell, and Swift 2012). Innovation variance research focuses on examining the influence of relevant factors on the adoption decision of, and/or the intention to use an innovation. Some popular theories and perspectives for the first stream include the Technology-Organization-Environment (TOE) framework (Tornatzky, Fleischer, and Chakrabarti 1990), Technology Acceptance Model (TAM) (Davis 1989), and Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al. 2003) and its later extension UTAUT2 (Venkatesh, Thong, and Xu 2012). The factor approach has been widely employed to study Blockchain adoption in the domain of SCM. Some representative examples include – Kamble, Gunasekaran, and Arha (2019) examined Blockchain adoption for SCM in India using a combination of TAM and other theories such as the theory of planned behaviour; Queiroz et al. (2020) studied the same topic, but in a generic SCM setting under the lens of UTAUT, and Wong et al. (2020) employed TOE to develop a model exploring Blockchain adoption among Malaysian SMEs.

In contrast, the process approach does not view the adoption of new technological innovation as a one-off decision of whether or not to use said technology, but rather as a series of sequential stages through which technology is examined, adopted, and finally integrated into an organisation (Hameed, Counsell, and Swift 2012; Pichlak 2016). Since this study aims to develop a framework for the Blockchain implementation process in FSC organisations, it is more aligned with the innovation process stream of research. Compared to the innovation variance perspective, the process approach has been overlooked in the context of adopting Blockchain for SCM and especially FSCM. To the author' best knowledge at the time of writing this study, there has been only one study by Wamba and Queiroz (2022), examining the Blockchain implementation process in the generic SCM setting.

To achieve the objective of the study, a conceptual framework of Blockchain implementation for organisations in FSC is first introduced and later validated and improved with the insights from the empirical data. To develop the conceptual framework, two key aspects need to be determined: the stages of integrating Blockchain and the potential determinants. To this end, prominent theories and established models of IA are utilised to define those aspects. Thus, it can be seen that this study does not hinge on a single theory or perspective but adopts an integrative approach in formulating the conceptual framework. The premise is that relying on a single theoretical perspective may not be sufficient to provide a comprehensive understanding of complex technology adoption (Hameed, Counsell, and Swift 2012; Wamba and Queiroz 2022). Thus, to better comprehend the phenomenon, integrating different theoretical perspectives into one model – an integrative model approach – is often used to provide more explanatory power to the topic under research (Martins, Oliveira, and Thomas 2016; Kamble, Gunasekaran, and Gawankar 2020; Wamba and Queiroz 2022).

Extant literature proposed a variety of phases for adopting innovation; for instance: initiation, adoption, and routinisation (Zhu et al. 2006); initiation, adoption decision, and implementation (Hameed, Counsell, and Swift 2012; Pichlak 2016); intention to adopt, adoption, and routinisation (Martins, Oliveira, and Thomas 2016; Wamba and Queiroz 2022); initiation, adoption, routinisation, and extension (Hossain, Quaddus, and Islam 2016); and initiation, adoption, and assimilation (Nam, Lee, and Lee 2019). Overall, although the generalisation of concepts and the used terminologies differ, the essential process and associated activities for the adoption of new technology are consistent throughout existing models, and can be grouped into three general phases: (1) **Initiation** – the organisation explores various aspects of the innovation in consideration, (2) **Adoption decision** – the organisation decides whether and how to implement the innovation, and (3) **Implementation** – the organisation deploys large scale implementation and integrates the innovation into its structure.

Besides the phases by which an innovation is integrated into an organisation, broad categories of determinants to the implementation process are identified based on prominent theories and models from extant IA literature. These determinants can influence the propensity to adopt new technology (Zhu et al. 2006), as well as the success and adequacy of each implementation stage (Hameed, Counsell, and Swift 2012; Pichlak 2016). As observed from the literature, the influential factors to the implementation process of technology can be broadly categorised into four dimensions: technology, organisation, environment, and management. Diffusion of Innovation (DoI), proposed by Rogers (2003), suggested that certain characteristics of new technology, namely relative advantage, complexity, compatibility, trialability, and observability, can influence its adoption. Technology is also a core element in the TOE framework developed by Tornatzky, Fleischer, and Chakrabarti (1990). The other two categories in this framework are organisation characteristics (e.g. size, structure, resources, etc.) and environment characteristics (e.g. market, industry, country, etc.). Management is another important cluster of determinants, as managers possess critical roles in championing and realising the implementation of new technologies and, therefore, should be examined thoroughly (Hameed, Counsell, and Swift 2012; Pichlak 2016). These four main categories of determinants thus feature in a great number of integrative models for the implementation of technologies such as RFID (Hossain, Quaddus, and Islam 2016), IT technology (Hameed, Counsell, and Swift 2012), software as a service (Martins, Oliveira, and Thomas 2016), or business analytics software (Nam, Lee, and Lee 2019).

Drawing from related IA theories and models discussed previously, a conceptual framework (presented in Figure 3A-1) is introduced. Moreover, the framework proposed in this study greatly resonates and is inspired by an earlier conceptual work by Vu, Ghadge, and Bourlakis (2021). In the prior study, insights from studies exploring Blockchain usage and adoption in FSCM were synthesised and combined with IA literature to develop a theoretical framework for integrating the technology at the organisational level in the FSC setting. Thus readers can refer to Vu, Ghadge, and Bourlakis (2021) to see the relevance of the conceptual framework in the context of Blockchain adoption in FSC.

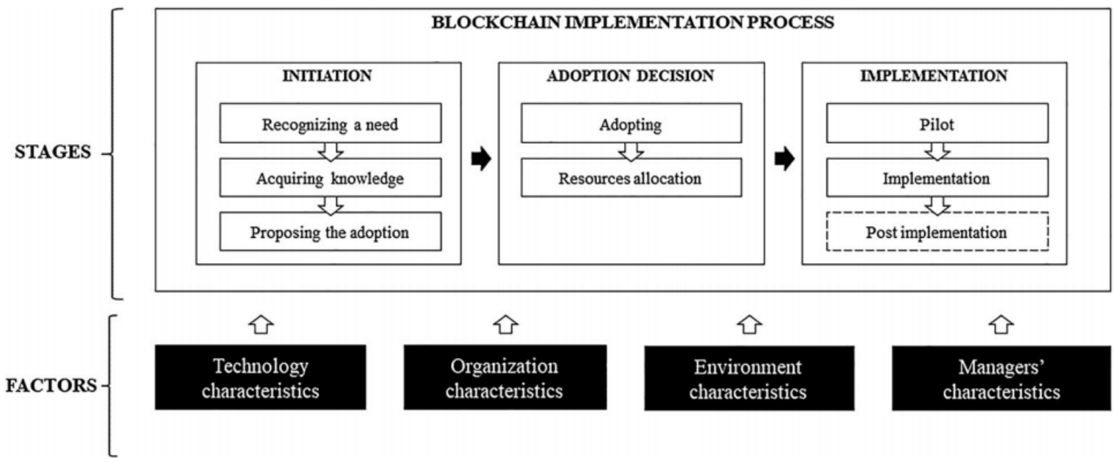

Figure 3-1. A conceptual framework for implementing Blockchain in FSC (Adapted from Vu, Ghadge, and Bourlakis 2021).

3.3 Methodology

A qualitative methodology is applied for this study. It is observed that quantitative research is dominantly used in IA literature to study the implementation of various technologies such as RFID (Hossain, Quaddus, and Islam 2016), software as a service (Martins, Oliveira, and Thomas 2016), e-business (Zhu et al. 2006), or Blockchain for SCM in general (Wamba and Queiroz 2022; Wong et al. 2020). Nevertheless, the author opted for a qualitative approach because the body of research regarding the Blockchain phenomenon, especially in a specific setting such as the FSC, is still regarded as in early development (Cole, Stevenson, and Aitken 2019; Zhao et al. 2019). Thus drawing a definite conclusion about the phases of implementation and pertinent factors to such a process can be difficult. Moreover, for studying novel technology, qualitative research is a preferred method to gain in-depth insights into the phenomenon and to provide valuable foundations for further quantitative studies in the future as the body of literature also progresses over time (Wang et al. 2019; Lohmer and Lasch 2020). Therefore, it is argued that a qualitative approach is suitable for this instance, given the current development of Blockchain for FSCs.

3.3.1 Data collection

The first step in the data collection process is to find potential candidates for the interviews. The author utilized various sources, such as industry news and reports, to compile a list of Blockchain adoption projects in the food industry. To obtain comprehensive insights into the Blockchain implementation process, this list contains projects with various degrees of success. Companies that just announce their engagement with Blockchain, are in the process of deploying the technology, complete Blockchain pilots, or adopt it fully, are all included in the list and at the end fourty seven companies were found. After determining the companies, the author identified individuals who are directly involved in those companies' respective Blockchain projects. Most of the time, the contacts of these individuals can be found in news related to the Blockchain initiatives. In some instances, the author contacted the company and was directed to personnel working on Blockchain adoption. Through this process, it was assured that the potential candidates have sufficient knowledge and experience in implementing Blockchain in the FSC setting, as not only all the identified companies were carrying out Blockchain implementation projects but the contacted individuals were directly involved in those projects.

Next, letters of invitation were sent, via either conventional email or LinkedIn mail. Out of the 47 companies, representatives from 15 companies agreed to participate in the research (31% rate of response). 15 semi-structured expert interviews (with an average time of one hour each) were conducted from March 2021 to July 2021. Table 3A-1 provides an overview of those participants (P). To generalise our findings to a broad range of organisations in the FSC, the author invited participants from different nodes of the FSC (e.g., raw food producer, distributor, manufacturer) with diverse expertise. Further, all identified interviewees have worked on Blockchain projects in food industries from various parts of the globe (e.g. Australia, UK, US, EU, India, South America, East Asia, and Africa).

Before engaging with the interviewees, an interview protocol was designed what is it. The conceptual model of Blockchain implementation (results of the Literature review study) was extensively used to guide the design of the protocol. The interview questions can be broadly divided into two primary sections. The first one focuses on discovering the step-by-step process of integrating Blockchain, and the second one explores the important influential factors of Blockchain adoption from the interviewees' perspectives. These questions are consistent with the implementation model, as the two key facets of this model are the implementation process and the contextual determinants of such a process. Thus, participants' answers were anticipated to be specific and pertinent for enhancing the implementation model at later stages. Further, the author continued to revise the protocol after each of the first three interviews to improve clarity, language, and the relevance of questions. The majority of the changes were primarily based on selecting the best choice of wording to communicate as succinctly as possible the idea to the interviewees. For example, the author changed the word "determinant" in an earlier version of the questions to "influential factors". Overall, the changes were minor; thus valuable insights were gained in the first three interviews and included in the analysis. Later, the protocol remained consistent throughout the rest of the interviews (See Appendix 1 for the interview protocol). Moreover, consent to record interviews was collected both verbally and in writing. One participant did not want to record the session, thus the interviewer took notes of answers and confirmed with them afterwards.

Table 3-1. Descriptions of the interviewees.

Position	Details about the companies	Experience	Country/	Interview duration

				Location	
P1	Quality manager	Fruit producer with 7 large facilities, a leading grower in the country.	15+ years	Australia	90 mins
P2	Business development manager	A blockchain service provider with experience in implementing Blockchain for a wide range of actors in the food chain (cooperatives, producers, importers, retailers).	5+ years	Switzerland	60 mins
P3	Sales Executive	Seafood producer	10+ years	Ecuador	45 mins
P4	General manager	Blockchain service provider, with experience in implementing Blockchain for large and medium-sized organizations in the food chain.	5+ years	EU company	60 mins
P5	CEO	A blockchain service provider, with experience in implementing Blockchain for a large pig producer in East Asia.	20+ years	UK	70 mins
P6	Founder & CEO	A blockchain service provider with experience in piloting Blockchain for a medium-size seafood producer in Northern EU.	20+ years in technology adoption, 4+ years in the food industry	Norway	60 mins
P7	Project manager	Food regulator with direct experience of experimenting with Blockchain for meat and wine products in the UK.	5+ years	UK	60 mins
P8	Project manager	Blockchain service provider, with experience in	2+ years	EU company	60 mins

		implementing Blockchain for a small distillery in the EU.			
P9	Founder & CEO	Seafood reseller, medium-size company in the US.	10+ years	US	60 mins
P10	Founder & CEO	Blockchain service provider	5+ years	Australia	60 mins
P11	Senior Consultant	Consulting service	10+ years	UK	60 mins
P12	Director of emerging technology	Blockchain and software service, with experience of pilot Blockchain for tea producers in South America.	10+ years	India	60 mins
P13	Founder & CEO	Processed food manufacturer, a medium-size company in India.	4+ years	India	60 mins
P14	Founder & CEO	Service provider, with experience in working with small and medium livestock farms in Africa.	15+ years	Africa	30 mins
P15	CEO	Olive oil producer, a large sized company in the EU.	10 + years	Italy	Three members of the company joined the interview at once for 70 mins
	Blockchain project lead		10 + years		
	Marketing director		5+ years		

3.3.2 Data analysis

Each interview was conducted virtually using Zoom, and then auto transcribed by the platform. The first author, after each interview, validated the auto transcription with the recorded audio to correct any mistakes, while also outlining initial observations of answers from participants. Data saturation was reached after the fifteenth interview as the interviewer perceived no new information. Compared to other qualitative studies that also examine the use of Blockchain for SCM, such as Lohmer and Lasch (2020) with 10 interviews or Kurpjuweit et al. (2019) with 12 interviews, the number of interviews included in this study is found to be sufficient.

After all interviews were concluded, 237 pages of transcriptions were generated. Coding is the method of choice for analyzing qualitative data. NVivo 12 software was used to aid the process. First, all the corrected transcripts and notes taken during the interviews were uploaded to the software. The transcripts are the primary coding material, while the notes serve as components for building a coding diary for the author. Nvivo allows users to engage in an intuitive coding process, as relevant texts can be highlighted and assigned a specific code, each code can be enriched by congruent perspectives/ insights found in multiple interviews, and finally, codes can be arranged, grouped, or disaggregated to form higher orders and themes in the Nvivo interface. The coding diary is developed, updated, and kept also in the software, allowing the author to continuously reflect on the process and keep the coding consistent.

Two cycles of coding were performed, namely concept coding and axial coding. Concept coding can be used to effectively capture the broader idea beyond the tangible responses, and axial coding is a suitable follow-up approach as it links separate data from the first coding cycle to categories, links sub-categories with more conceptual ones, and defines the relationship between categories (Saldaña 2021). Literature on innovation adoption was utilised during the coding process, as the author went back and forth between extant literature and qualitative data to improve on the concepts used for capturing the meaning of datum, establish the relationships between different concepts, and cluster concepts under a more abstract theme and/or dimension. Table 3A-2 illustrates how the specific concept of the organisation's innovativeness; part of the organisation dimension was induced from the qualitative data. For the complete development of the first-order concepts and their illustrative codes, second-order themes, and aggregated dimensions, see Appendix 2.

Table 3-2. Example of coding for developing concepts and themes

Illustrative quotes	**First-order concept**	**Second-order theme**	**Aggregated dimension**
We've got a very strong R&D investment program because innovation and improvement are critical to our future development. A value of our company is recognizing the importance of investing in innovation – P1.	Strong R&D investment and infrastructure	Innovativeness	Organization
We are always at the forefront of innovation; we always want to be at the top of the heap. We don't want to be at the bottom of the heap – P3.	Actively seeking new ideas		
From the start, [the adopting company] was really thrilled about Blockchain… they've already heard about at least Bitcoin or Blockchain technology before, they're also very keen on experimenting with a new idea – P8.	Encouraging trial of new ideas		

In the first round of coding, a concept was used to capture the overall meaning of a datum, which is typically a statement from an interviewee during the interview. In the example showed in Table 3-2, P1 shared that "*We've got a very strong R&D investment program because innovation and improvement are critical to our future development. A value of our company is recognizing the importance of investing in innovation".* Subsequently, the concept of "Strong R&D" (investment and infrastructure) is used to represent the insight from this statement. Under the same vein, similar statements and perspectives, that indicate a strong R&D investment and culture of the adopting firms, were classified under the same first-order concept. At the end of the concept coding activity, a list of codes was obtained from the empirical data. These codes can be broadly classified into two main areas. One is about the activities that took place during the implementation process of Blockchain in the FSC, and the other lists all the influential factors that participants viewed as critical to the adoption process.

The second round of coding refined the results from the first round by grouping similar concepts under a more abstract category. Going back to the example provided in Table 3-2, strong R&D investment and infrastructure, seeking new ideas, and trial of new ideas underpin a common theme that describes a company's tendency to explore and innovate. Literature was used to aid the process of finding a suitable label for the broader theme. In this case, Salavou (2004) and Moo et al., (2012) defined innovativeness as the willingness of a firm to experiment with new ideas and/or the outputs of new products and services provided by a firm. Therefore, "Innovativeness" was used to capture the underpinning theme of three first-order concepts in this case. A similar process was repeated across the list of first-order concepts. The result of this activity is a list of themes, which represent either a phase during the implementation process (e.g., initiation) or a category of determinant (e.g., innovativeness, relative advantages). Finally, based on the conceptual framework, which is discussed previously in this study, the themes are classified into specific dimensions. The key dimensions of the implementation models include process, technology characteristics, organization characteristics, environment characteristics, and management characteristics. The former captures the activities and phases of Blockchain adoption in the FSC, while the latter four apprehend the types of determinants of the implementation process. Further, the second-order concepts in each of the themes will represent the constructs of the final implementation models.

3.4 Findings

Insights provided by experts were found to be largely aligned with existing literature regarding the implementation of Blockchain. At a broad level, the journey of Blockchain adoption at different organisations in the food supply chain often unfolds over three broad phases of the implementation process: Initiation, Adoption, Implementation; and four groups of determinants – Technology, Organisation, Environment, and Management are found to be relevant to the process. However, at a more granular level, the data revealed interesting findings that helped improve and validate the conceptual framework, particularly with identifying the detailed list of core activities during the Blockchain project, the sequences of these activities, and additional insights associated with the implementation process. Interestingly, since the experts come from various backgrounds (food producers, food processors, food distributors, and food specific Blockchain service providers), they offered diverse perspectives on their adoption journeys. Furthermore, two of the 15 companies have successfully integrated the Blockchain solution into their businesses; thus, their views strengthen the comprehensiveness of the findings, especially when fruitful adoption of Blockchain in the food industry is relatively scarce.

3.4.1 Establishing the process of Blockchain adoption

Based on the insights generated through interviews with experts, the process of adopting Blockchain can generally be established with three main phases: Initiation, Adoption, and Implementation. This is consistent with the conceptual framework. Figure 3A-2 summarises the phases and particular activities during Blockchain implementation in the FSC.

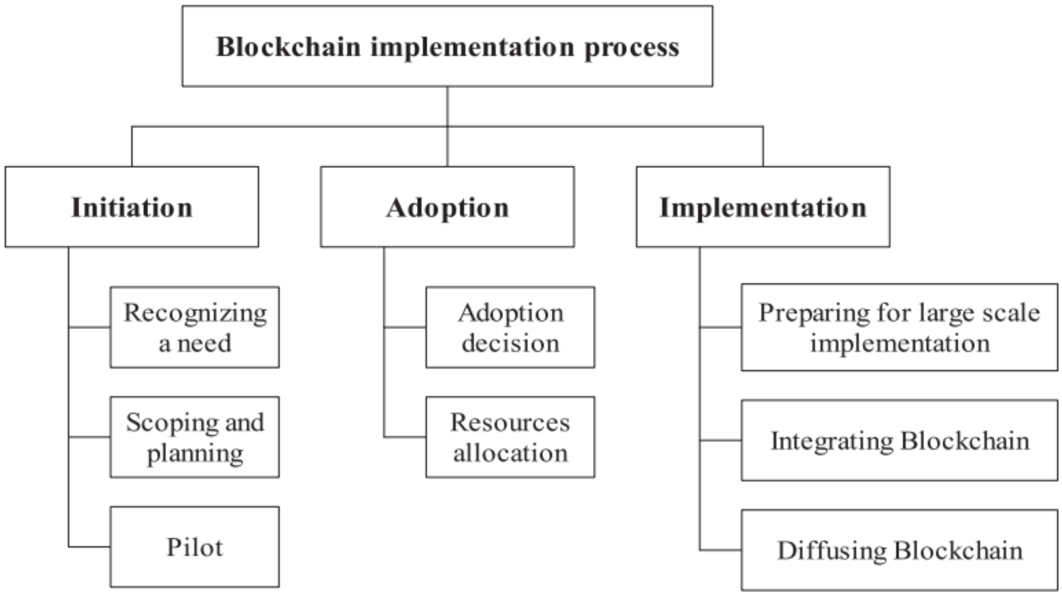

Figure 3-2. Overview of the process.

During the initiation phase, companies start by recognising a need for Blockchain as a potential solution to overcome challenges in the FSCM. For instance, P1 stated, "*we want to capture as the product moves through the chain. And then, how do we share that with our chain partners; and then, how do we use the blockchain technology to help us do that?*"

Once deeming Blockchain worth exploring, companies go through the necessary steps to kickstart their project, starting with identifying the scope and the plan of the project. P7 recalled,

"*We started with workshops to do a bit of brainstorming around the scope of the project … frame the problem, identify the scope, timeframes, key contacts, and who else we needed to talk to them, whom we didn't have in that room during the brainstorming workshop*".

As Blockchain can be utilised for various aspects of FSCs, a well-defined and achievable scope, even if it is narrow, can help firms maintain their focus during the initial stage of the project and direct the solution to tackle the most prevalent issues faced by the businesses. P1 recalled:

"*insufficient scope at the start cost us 12 months. Initially, we focused on building the temperature logs, but we have other technologies available for that task. After the first 12 months, I moved the focus away from them (the Blockchain service provider) building temperature loggers to look at what is the important information and how do we share it with the help of Blockchain*".

Next, a plan for Blockchain implementation is developed, starting with reflecting on the current operation (*to implement any solution, you have to know your supply chain first, so the first thing we do is mapping data, participants, when and where the ownership of the products changes hands* – P2), identifying the starting point (*for our case, products offered for babies from 6 to 8 months are most suitable to offer the Blockchain traceability. We thought this is the right area, and it makes the most sense* – P13), and choosing a suitable Blockchain solution (*after defining the use case, you have to look at different Blockchain networks protocols and decide which protocol makes sense* – P8). A pilot is commonly found as the next step of the project. Piloting Blockchain on a certain product, or a line of products serves as a proof of concept to the company that the technology is a good fit and can provide benefits. This finding is interesting, as several technology implementation models include a pilot as part of the implementation phase, rather than the initiation phase (Kim and Garrison 2010; Pichlak 2016). P2 gave the explanation:

"*when our clients decide to scale, or to add more volume, or to do their entire supply chain, and this is a more strategic decision that takes time. To scale, we usually need integration, and for a company to take that decision (a larger investment), they would have wanted to test how the system works first*".

Thus, in the case of Blockchain for FSC, the adoption stage often begins after evaluating the results from the last step of the Initiation phase, the pilot. Typically, during the Adoption phase, companies finalise the decision of whether to use Blockchain. The majority of the participants agreed that initial engagement with Blockchain (researching the technology, piloting, etc.) does not necessarily mean the companies will fully commit to implementing the technology. P1 reinstated this point, stating

"*We recently completed a three-year project to investigate how Blockchain could improve our supply chains. This included pilot testing of the blockchain technology. We have decided not to proceed with implementing a blockchain at this time as we have other priorities to improve information flow in our supply chains*."

There is one instance where the company fully intends to use Blockchain from the very start. P15 shared:

"*we had no doubt from the start that Blockchain is a good fit for us. We piloted one line of product for now, but the rest will follow*".

However, this notion does not apply to the other companies interviewed. Next, after companies decide to embark on the Blockchain journey, finance, equipment, and human resources investments need to be made. P15 recalled

"*The process is the same with the pilot, with a bigger scale. We need to bring in all the relevant departments to work on the expansion of this Blockchain project. It also has to do with investment, as we have to buy more QR code machines for other product lines for example.*"

As indicated by experts' insights, the final phase of a Blockchain project is implementation, where companies look to integrate Blockchain into their business and diffuse the use of the technology to other entities in the FSC. Among the participants of this study, P5 and P9 have experience with an end-to-end Blockchain adoption, where the technology has been fully implemented and used in the adopting companies. The first set of activities in the Implementation phase looks to prepare for full integration of Blockchain to the adopting unit, such as further development and modification of the solution, and assign appropriate resources for large-scale deployment. P5 recalled from their project of creating a new financing model enabled by Blockchain for a large commercial farm in Asia "*After the discovery phase and the solution is deemed feasible, we had two banks prepared to work with the system to lend, based on the company due diligence report, and access to the raw data held on the Blockchain. We also did consult and coding for their Blockchain solution*". Further, this step includes determining what food products should be on the Blockchain system, and effectively what should not be. P13 emphasized that certain food products, such as food for infants, would be scrutinized more closely by consumers than low-priced and common products such as snacks. This implies that specific food products would harness more benefits through Blockchain traceability and validation, at least for the time being.

Integrating Blockchain to the current business is the next logical step, as P9 described:

"*We successfully integrated Wholechain, our Blockchain solution, in our seafood at scale. It is used in every delivery, not just a pilot or only some product lines*".

Lastly, the adopting company aims to diffuse the technology to the network. Insights from participants indicate that the target of this activity is to onboard final consumers and/or direct buyers of the food products with the Blockchain experience. P9, who successfully applied Blockchain at full scale for their business, stated:

"*for the next step, our focus is on maximising usability for the end-user (end-consumers). So we spend time developing user experiences such as the mobile app for tracking our seafood. This will make onboarding others with Blockchain traceability that much easier*".

3.4.2 Determinants of Blockchain implementation

Determinants of the Blockchain implementation process in the FSC are crucial aspects of building an implementation framework. By understanding them, organisations can better prepare and grasp the projects. Various contextual factors to the process of implementing Blockchain for organisations in the FSC are identified from the analysis of the qualitative data. Guided by the pre-determined conceptual framework, we categorise them into technology, organisation, environment, and management, as shown in Figure 3A-3.

For the technology context, it is found that relative advantages, complexity, compatibility, and cost of Blockchain are relevant to the process of implementing Blockchain. Experts perceived that Blockchain possesses relative advantages over existing IT systems by bringing new values, improving current processes, and facilitating a more transparent food chain. New values can be interpreted as

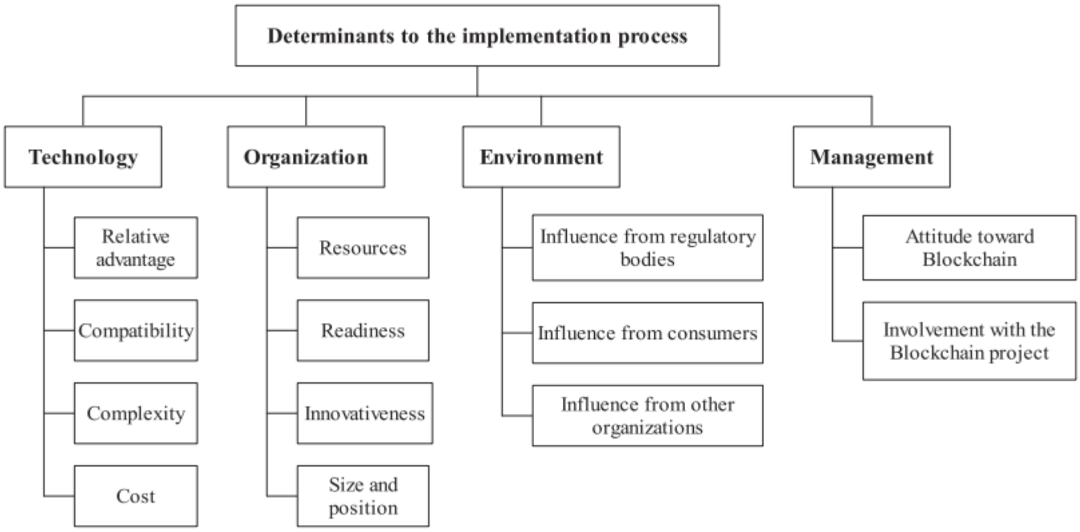

Figure 3-3. Overview of the determinants of the Blockchain implementation process.

novel capabilities enabled by using Blockchain. For instance, P5 successfully deployed a Blockchain solution for a novel financing model, enabling their client to have more capital for expanding their farming. P6 further elaborated on the added value that their Blockchain solution can bring to companies

"*One thing that we are selling is both visibility and connectivity … By using a public blockchain where all the actors can be connected, you get information from your supplier's supplier's supplier and give to customers' customer all the way to the end customer, and you can open a communication channel all the way to your end consumers and get this interaction with your consumers.*"

Food recalls are often the example that experts mention while discussing how Blockchain can improve existing processes. P2 theorised how Blockchain could help with the case of an E. coli outbreak due to Romaine lettuce in the US

"*for example, the IBM food trust is about having easy access to data on specific shipments. So the famous example with lettuce in the USA, if you have a problem with one, you will not recall everything, because you will know exactly where these problematic containers are coming from.*"

Other participants highlighted that, with trustworthy information, companies could also look into better inventory management, especially when perishability is a crucial factor for numerous food products. With Blockchain, companies gain trustworthy data on shelf-lives and past journeys of products; thus they can plan to store and transport products, accordingly, assuring the quality and safety of food. Regarding the transparency enhancement effect of Blockchain, P10 gave an example:

"*we work with a big brewing company who wants to source the barley directly into their malt houses. They don't want to get their barley mixed up; they want it from certain areas with quality assurance … They want all that information on the Blockchain system so they can check and award the business to the most honest and trustworthy suppliers*".

Compatibility of Blockchain is another essential aspect, as suggested by the interviewees. The technology must align with the adopting unit's needs, goals, processes, and other technologies already in use. P4 warned

"*There's very little chance that you'll be able to entirely change the whole process, just for the sake of implementing a new piece of technology. So, it's rather adopting the existing processes and being able to appreciate them and leverage them in the best way possible to get the value*".

The interviewees frequently mention complexity, as companies should be conscious of the time and effort needed to master Blockchain. Complexity may arise from the fact that Blockchain is a complex technology, or there are too many solutions to choose from in the market, or from configuring and modifying the solution to fit with the objective; as P7 recalled,

"*One of the biggest challenges, we found, was how to scale up the solution in a sustainable way. What is the self-sustaining model for running the Blockchain solution for everyone, and at the same time with low entry barriers for more to join?*"

Lastly, the cost is an important factor of Blockchain that can affect the adoption of the technology. P4 expressed that

"*at the end of the day, in the food industry as a whole, the margins are really tight … . so whatever you do, you should not add cost*".

P14 also emphasised that, while many solutions have high-end commercial organisations in mind, they recognise that entities with limited financial resources such as farmers are also an important part of the food chain. Thus, the Blockchain solution pricing should take such entities into consideration, and part of P14's solution popularity is attributed to their reasonable pricing. Further, participants highlighted that not only the implementation cost but also the cost associated with running the Blockchain in the future (e.g. fee for storing information on-chain), even though it might be considered small at the moment, should not be neglected. Findings from the interviews further indicate that resources, readiness, innovativeness, and size and position of the adopting firm are influential to the implementation process. For resources, while the role of financial capability is self-evident, human resources are also essential. P5 shared

"*All of the staff there were very young, but they were exceedingly talented people, and that was such an advantage*"

This showcases that having skilful people from the adopting company involved is an integral part of their successful Blockchain project. Next, the readiness of a firm for Blockchain can be represented by the existing infrastructure in place for traceability, how capable an organisation is with technology, and a ready-to-change mindset when it comes to technological change. P3 found the integration of Blockchain into their business not too challenging because

"*We already have strong traceability technologies and process in place for our aquaculture products. When this Blockchain project presented itself, we knew that we were capable of doing it. Of course, there were some challenges but not too difficult to overcome … we have had over 40 years of being in the aquaculture industry, with experience of implementing many technologies*".

P10 further shared that many actors in the food chain, especially in the upper stream of the FSC, are not well equipped to understand advanced information technology such as Blockchain fully, and thus are very hesitant to change, making it difficult for the technology to penetrate such entities – "*they only know running their farms for a long time, still use the same milking process, treat their livestock in the same specific ways for years. So when you start with Blockchain technology, you lose them quickly*". Moreover, the innovativeness of a company plays an important role in starting and advancing the Blockchain project. P1 expressed that

"*We've got a very strong R&D investment program because innovation and improvement are critical to our future development*".

Other than strong R&D investment and infrastructure, interviewees implied that companies who actively seek for and encourage trials of new ideas are likely to consider Blockchain and advance far with their endeavours. P5 recalled

"*during the early development, the fact that they were happy to fail, you know, this is an experience that large companies rarely give us the opportunity to do to experiment and fail is an important part of this Blockchain development*".

Lastly, size and position of a firm can also be critical, as per P12's view "*the farmer in Africa cannot dictate to Nestlé to adopt Blockchain. It has to be the management of Nestlé who will ask the farmer in Africa to be onboarded for traceability and visibility for their consumers. That's how it works*". The FSC is typically long and complex, and Blockchain is an inter-organisational solution in nature (Wamba and Queiroz 2022); therefore, initiatives from large enterprises within an FSC can heavily influence others to follow. The interviewees also recognise influential factors coming from outside the adopting company, suggesting that regulatory bodies, consumers, and other organisations within FSCs can impact the implementation process. The influence of regulatory bodies can come from their encouragement for attempting Blockchain, as well as their tendency to tighten policies regarding food products in the future. Many participants referred to the recent publication from the FDA in the US, in which this agency communicates the demand for more rigorous food traceability in the near future, while also listing Blockchain as an important instrument to facilitate better food provenance (US Food & Drug Administration 2021). On the other hand, consumers can play a critical role in driving companies to consider Blockchain for food products; as P9 commented

"*Consumers play an important part in driving Blockchain adoption; you see it in the market and reports. Consumers demand trust, with more and more food recalls being more frequent, consumers' demand really is becoming significant*".

Further, several interviewees also believed that consumers are willing to spend more for more transparent and safety-proven products. Lastly, other organisations can have an impact on one's Blockchain progress, as the participation from multiple parties is needed for large-scale use of Blockchain, collaborative culture can help speed up the process, and competitive pressure can motivate a firm to embark on the Blockchain journey. P2 recalled

"*Our Blockchain-enabled traceability system is end-to-end, and we are usually working with a minimum of two or three connected companies in the supply chain, sometimes even more, to apply our solution to a supply chain*".

P7 also shared an interesting observation "*In our project of using Blockchain for tracking meat qualifications, we had three companies, who are also competitors in the market, joined. We start with one company, and it is interesting that, almost like a cascading effect, because the other two knew about that, they wanted to join as well*".

Management characteristics are the last important cluster of determinants inferred from the qualitative data. P11 stated that "*In order to integrate Blockchain into a company, managers have to be ready for the change and also have to be ready to be in charge of such change*", indicating the role of management's attitude toward and during the Blockchain project. Involvement from top managers is also critical to the project. Over numerous projects discussed by the participants, there are three instances where the CEOs of the adopting companies were involved, personally, from the start. Among these three cases, two CEOs (P13 and P15) participated directly in this study. P15 recalled

"*To start the project we needed to connect all departments in the companies. We were involved in meetings regarding granular details such as what to upload, what data to share, timing, etc. There is overall a great deal of involvement from the management of the company in the project*".

In turn, these projects have had various degrees of success, ranging from successful pilots to full adoption of Blockchain.

3.5 Evidence-based Blockchain implementation model and implications

In this section, first, the empirically validated and revised model for Blockchain implementation is presented. Later, the theoretical and practical implications of this study are discussed.

The initial conceptual framework described in Section 2.2 provides a good starting point to grasp how Blockchain technology would unfold at the organisational level within the FSC setting. Based on the findings drawn from the semi-structured interview data, the conceptual framework was validated and further improved to capture the overall process of implementing Blockchain for companies in the food industry, along with the main determinants of such a process. The end product is an empirically driven and practical model for Blockchain implementation in the FSC, as presented in Figure 3-4. Consistent with our thinking, a purely conceptual framework cannot fully be aligned with the phenomenon in practice; thus there are noticeable changes/ upgrades between the conceptual framework (See Figure 3-1) and the final model (See Figure 3-4). At a glance, the main phases of implementation remain the same in the final model. However, the pilot activity is now moved to the Initiation phase. As can be seen for P15, P13, and especially P1 (where the company halted the decision of using Blockchain after the pilot), companies would conduct a pilot of using

Blockchain for food products before making a definitive decision of committing to use the technology.

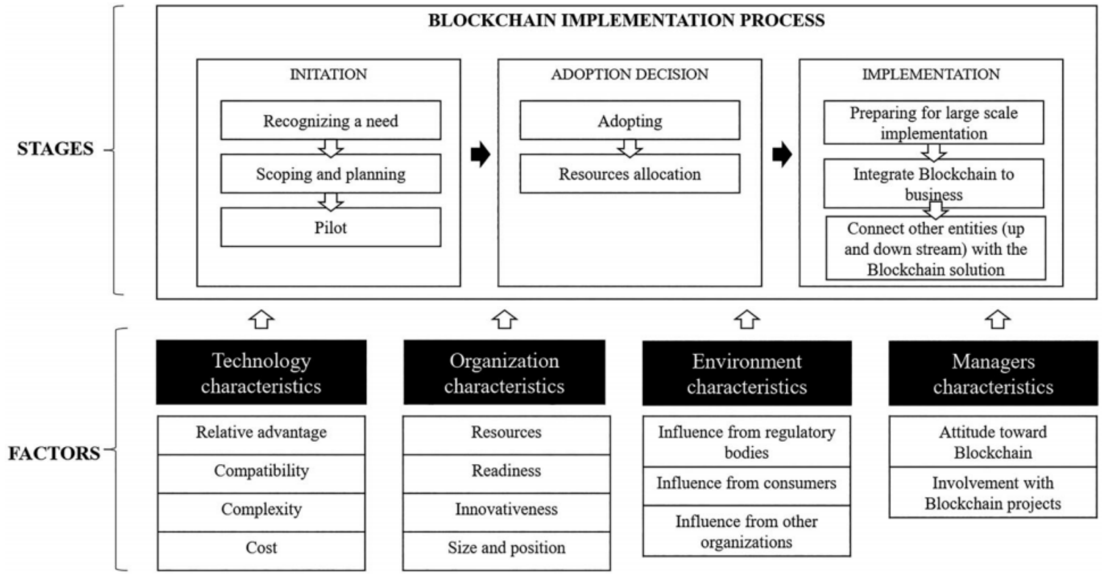

Figure 3-4. Evidence-based framework for implementing Blockchain in FSC.

Further, learning from the experience of P5 and P9, the last step in implementing a Blockchain solution is onboarding other stakeholders to the system. As suggested by the initial conceptual framework, the implementation phase would typically stop after the innovation is incorporated into the organisation’s structure (Hameed, Counsell, and Swift 2012; Pichlak 2016). However, the case of Blockchain could differ, as the technology would provide greater benefits if it can be adopted across the supply chain network (van Hoek 2019); thus, the necessary activity after successful implementation in one organisation, would be to connect other entities to the Blockchain system. The changes to the activities within each implementation phase are captured in the final evidence-based model shown in Figure 3-4.

Moreover, insights from the interviews are useful in expanding the conceptual framework, especially in determining determinants of the implementation process of Blockchain. The conceptual framework identifies four general clusters of technology, organisation, environment, and managers characteristics. However, the literature has identified numerous factors that could feature in each category (for a comprehensive list of potential factors see Hameed, Counsell, and Swift 2012 or Pichlak 2016). As the aim of this study is to develop a pertinent model of implementation for Blockchain technology in the specific FSC setting, only relevant factors to the context were included in the final model (as depicted in Figure 3-4). Empirical insights from the interviews were used to validate and capture the most important and relevant determinants to the context. As discussed in Section 3.4.2, one main part of the interview is exploring the factors that are critical to the success of each and every stage of Blockchain adoption. Since the interviewees' experience was strictly based on Blockchain projects for food products, their perspectives highlighted contextual and relevant influential factors of adopting Blockchain in the specific context of FSC. Further, IA concepts were utilised in the coding process to ensure that insights provided by interviewees were aggregated and classified into pertinent IA terminologies (See Figure 3-3). This allows for validating empirical findings with the literature, to select the most relevant factors for the model inclusion.

Insights from the interviews help discover the most relevant determinants in the case of implementing Blockchain in the FSC setting. For example, consistent with what DoI suggested, interviewees found relative advantage, compatibility, and complexity of Blockchain technology to be critical in the process of adopting Blockchain. DoI also proposed that trialability – 'the degree to which an innovation is perceived as possible to learn by doing', and observability – 'the degree to which the results of an innovation are visible to others' (Pichlak 2016, 481), were not highlighted by interviewees. Findings from the interviews also pointed to an additional determinant, the cost of Blockchain, as an important influential factor in the process of integrating the technology into organisations, which is understandable as "margin is tight for the food industry as a whole" (P4) and "to onboard people such as farmers or co-operatives the cost of the Blockchain solution must be competitive" (P14).

Following the same approach of contrasting insights from interviewees to the literature, other factors, that experts view to be pertinent to the specific setting of FSC are uncovered for the other three main groups of determinants –

organisation, environment, and management. Consistent with what the literature has suggested (Pichlak, 2016; Wamba et al., 2020), insights from the interviews suggested that resources and the readiness of an organization are critical when adopting Blockchain. Interestingly, findings also implied that the innovativeness and commanding power (indicated by a firm's size and its position within an FSC) of the adopting entity play a significant role in implementing Blockchain. This is understandable since Blockchain can be considered a novel technology, thus early adopters of the technology are likely to possess certain adventurous traits in their culture. Further, since Blockchain is an inter-organizational solution, for successful diffusion of the technology, the adopting company must be able to convince / mandate others to come onboard. Regarding environmental factors, influences from regulatory bodies, consumers, and other organisations in the food chain were considered important by interviewees. While other organizations' influence on one's innovation adoption decision was considered in previous models (Martins et al., 2016), consumer and regulator roles are specific to Blockchain implementation in the FSC. A possible explanation is that since Blockchain is commonly utilized for enhancing food traceability and safety (Zhao et al., 2019), consumers and state agencies emerge as important stakeholders who can drive the decision of adopting Blockchain forward. Finally, it was evident that the attitude toward Blockchain adoption and the involvement of the top managers during the project are two critical determinants under the managers' characteristics cluster. Damanpour and Schneider (2006) also suggested demographical characteristics of managers such as age, education, experience, etc to be relevant to the implementation process. However, those were not evidenced by the empirical findings. Overall, qualitative data provided in-depth insights to bridge the gaps between a conceptual framework and an evidence-based model for Blockchain implementation in the FSC.

In sum, the evidenced-driven model of Blockchain implementation in the FSC, as depicted in Figure 3-4, is an elaboration of theoretical perspectives and models regarding the adoption of innovation at the organization level. As such, the model developed in this study better explains the specific context of interest, which is the integration journey of Blockchain technology for organizations in the food industry. The author argues that the evidenced-driven model is more suitable for understanding this context because established theoretical constructs were refined and elaborated with contextual insights from the empirical data. The empirical data came from interviewing experts in the field, who have had first-hand experience in adopting Blockchain at their organizations. Therefore, insights from the interview are guaranteed to be pertinent and specific to the implementation process of this technology in the particular setting of FSC. Findings from the empirical data advanced the preliminary understanding, which derived from IA theories, in two ways. First, the findings elaborated on a theory-driven construct and determined how such a construct is applied in the context under study. This is particularly explicit when explaining the various phases of Blockchain adoption. Under the guidelines of established theoretical models (e.g., Damanpour and Schneider, 2006), three broad phases of Initiation – Adoption – Implementation are pertinent for the scenario of integrating Blockchain for organizations in the FSC. As discussed previously, empirical findings shed light on specific activities that companies in the food industry typically carry out during each of those phases. Through that, contextual insights of the FSC and Blockchain are reflected in the construct. An example is the pilot activity of Blockchain is classified as a step in the Initiation phase, or preparing the solution for large-scale adoption (in the Implementation phase) must include identifying which food products are applicable, considering the cost-benefits of adoption. Second, when theories suggest various determinants towards the implementation process of a new technology, empirical insights served as an effective tool to distill and select the most pertinent set of influential factors, considering the FSC setting. This is evidenced in the previous discussion regarding the determinants in certain dimensions. For instance, regarding the technology characteristics, experts viewed relative advantages, complexity, and compatibility as important factors in the implementation process. However, trialability and observability are not as highly regarded. Instead, interviewees suggested cost as another critical determinant when adopting Blockchain, as the margin in the food industry is comparatively low. In sum, relying on pertinent and specific insights from interviewing FSC experts enable the final model to reflect and capture the process of integrating Blockchain in the specific setting of the FSC.

3.5.1 Theoretical implications

Findings from this study contribute to the extant literature in two ways. First, this study advances the literature on SCM in the wake of Industry 4.0 developments, providing an in-depth understanding of the implementation process by which Blockchain is integrated into organisations for better management of the supply chain. As discussed earlier, the majority of existing studies were interested in the constitutional factors to the adoption decision/intention of Blockchain in the area of SCM. However, this study expands current thinking by exploring another facet of technology adoption, providing the comprehensive life cycle of the Blockchain from initiation to the point of full integration. Thus, this study responds to several calls for empirical research on Blockchain implementation in a specific industry setting (van Hoek 2019; Wamba and Queiroz 2022). Further, our study emphasizes combining contextual empirical evidence with the extant understanding of innovation adoption to develop a pertinent and specific model of Blockchain implementation in the food industry. This is different from the conventional approach of examining literature to identify relevant determinants to the adoption process theoretically, then validating with empirical data, which has been employed commonly to study other technologies (e.g. Hossain, Quaddus, and Islam 2016; Martins, Oliveira, and Thomas 2016) including Blockchain (e.g. Wamba and Queiroz 2022). This particular approach can be impactful in the specific case of Blockchain implementation in the FSC since both the technology and the use of the technology in the setting are at an infancy stage. Thus, instead of picking possibly relevant determinants from the extant literature to include in the model, the approach of this study allows researchers to engage with the novel context and determine pertinent influential factors from rigorous evidence (stemmed from perspectives of experts who have had first-hand experience in deploying Blockchain for food products). Therefore, the process of deducing a model for Blockchain implementation in the specific setting of FSC is robust, providing a concrete basis for future statistical validation and testing (in the Quantitative study)

Second, this study offers an elaboration approach to advance the IA body of literature by bridging the general theories and concepts of the innovation adoption concept to the specific context of Blockchain in the FSC. Theory elaboration can be a strong approach to applying an existing general theory to a setting that is not well-known, deducing useful premises and testable hypotheses (Ketokivi and Choi 2014). In this regard, several propositions can be developed and tested using quantitative methods in the future.

Third, this study utilises a qualitative approach to assess and improve the adoption process of a new technology, thus advocating the use of qualitative methods in exploring the phenomenon of a novel technology, especially when the current body of literature is under development. Previously in the IA body of literature, quantitative approaches (in the form of statistical tests) are dominant in studying the implementation process of a new technology (Zhu et al., 2006; Martins et al., 2016; Hossain et al., 2016; Wamba et al., 2020). However, when the context is under development, it can be challenging to develop models and hypotheses directly from past knowledge, as emerging innovations and different settings might require different sets of determinants. Venkatesh et al. (2013) suggested that the qualitative approach can be powerful in such instances, generating a pertinent model of implementation or adoption with contextual insights, before researchers engage in the conventional approach of statistically analysing the phenomenon under examination. This study contributes to this thinking, by demonstrating the usefulness of interviews for exploring an emerging area before conducting additional quantitative analysis (which will be carried out in the next stage – Chapter 4).

3.5.2 Managerial implications

Several implications for practitioners in the FSC can be drawn from the implementation model proposed in this study. First, the model suggests a comprehensive and practical approach to adopting Blockchain. Valuable lessons can be learned from the experience of early adopters who participated in this study. For instance, Blockchain should only be considered when there is an actual need for the technology. Blockchain is not a silver bullet to all challenges in FSC (Kumar et al. 2020). However, when companies perceive a critical challenge, such as the need to communicate information regarding food provenance and quality in a trustworthy and secure manner, Blockchain could be a promising solution. At the beginning of the project, the adopting company needs to spend considerable time understanding the technology and their SCM processes. Nevertheless, the objective of the project, and the use of Blockchain for the company, must be extremely clear to set the course correctly for the rest of the project. Furthermore, a pilot is highly recommended to test the suitability and capability of the technology, and the adopting company needs to be aware of what is required to progress the technology further.

Second, the opinion from industry experts about the most important and influential factors to the integration of Blockchain in the FSC is captured and embedded in our model. Thus, an evidence-based model could be useful in suggesting to managers what determinants could arise due to special characteristics and conditions of the food industry and how they could potentially shape the Blockchain project. For instance, the degree of readiness for advanced technology such as Blockchain is critical, as companies with already robust processes of food traceability can find the adoption of Blockchain considerably straightforward. Readiness and technological know-how can also be crucial for the expansion of Blockchain within a network of food actors, as actors in the upstream food chain can have noticeable resistance to implementing the technology. Further, in the specific context of FSC, organisations can expect that major sources of motivation and pressure to explore Blockchain come from consumers and regulatory bodies, as most of the interviewees saw a significant rise in the end consumers' demand for more trustworthy information about their food products at and after the point of purchase and believed that traceability of food products in the near future would be under much stricter scrutiny. Under the same vein, other FSCrelevant determinants included in our final models (with the discussion of what they mean in the context of the food industry in Section 4.2) can also be helpful for managers in the field to anticipate influential factors and possible challenges, achieving a smooth and successful integration of Blockchain. Understanding how a technology assimilates at an organisational level is critical to obtaining successful implementation and realising business values from the technology (Zhu et al. 2006).

3.6 Conclusion

The objective of this paper was to develop a practical model of implementation for Blockchain technology in the context of the FSC. First, building on previous work (Vu, Ghadge, and Bourlakis 2021) and drawing from relevant IA theories and models, a conceptual framework was developed for Blockchain implementation in the FSC. After collecting and analyzing the empirical data, this framework was improved into an evidence-based and practical model, including three main phases of adoption and four determinant categories of the process. From the results, it is established that Blockchain unfolds through the phase of Initiation (where the adopting company recognises a need for the technology, defines the scope and plan for the implementation, and runs a small scale pilot), Adoption (where the adopting company makes the final decision of whether to adopt Blockchain, and assign sufficient resources if so), and Implementation (where the adopting company makes the necessary preparations for large scale adoption, integrates the technology to the business, and diffuses it further into other relevant entities such as consumers and partners). Moreover, it is also identified that influential factors for four validated determinants of the Blockchain implementation in the FSC comprise: relative advantages, compatibility, complexity, and cost (Technology), resources, readiness, innovativeness, and size and position (Organisation), influences from consumers, regulators, and other organisations within the FSC (Environment), and attitude and involvement from top managers (Management).

Validation and improvement of the implementation model are based on a limited number of semi-structured interviews. As with all qualitative research studies, the limitation of this study lies in its ability to generalise the results to a broader setting. Nevertheless, the knowledge obtained from this study can be of importance when planning the implementation of Blockchain under similar circumstances. Moreover, the findings are largely inferred from the view of the respondents. Thus, biases might exist, even though interviews were conducted carefully to gather exact facts and insights about the Blockchain projects, and questions were asked in a way to minimise subjective answers. Another limitation of this study is that the results are very context-specific – FSC in this case and may be difficult to generalise.

Following the results of this study, many exciting future research directions are recommended. Literature has identified a lack of quantitative studies in this domain (van Hoek 2019); thus, quantitative studies including simulation, can be used to validate and generalise this study's findings. A potential direction for quantitative research is to determine the impacts of determinants on the process of Blockchain adoption. Although the final model suggests various determinants to the process of implementing Blockchain for FSC, the impact of a particular determinant (such as technology advantage or the organisation's readiness) might vary between different phases of adoption, and statistical tests are more suitable to uncover such insights. Furthermore, it can be observed that practitioners have achieved a certain degree of success in implementing Blockchain. Given the rapid development of Blockchain in the FSC, an in-depth examination of Blockchain implementation projects could further uncover specific and valuable insights, such as how the system is configured and/or governed. Therefore, case studies are highly recommended as promising future research avenues to continue expanding the current knowledge about Blockchain adoption.

Moreover, studies attempting to combine Blockchain with existing information systems (e.g. ERP, WMS) or other Industry 4.0 technologies (e.g. IoT, AM) would provide more opportunities to explore the robustness of

Blockchain technology. Future research attempting to identify skill requirements to adopt disruptive/novel technologies is expected to further benefit SC practitioners. Empirical research with quantitative approaches is recommended to validate our findings. Finally, although this study proposes a pertinent model of Blockchain implementation in the context of FSC, further advancements of the model at a more granular level can be considered. Particularly, future research can use our model as a foundation to explore how various entities in the food chain could approach Blockchain implementation and uncover the differences depending on the position of the entities.

Data availability statement

The data that support the findings of this study is available from the corresponding author following a reasonable request.

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4 A QUANTITATIVE ASSESSMENT OF THE BLOCKCHAIN IMPLEMENTATION PROCESS AND ITS IMPACTS.

Abstract

With the important role of sustaining human lives, the food supply chains (FSC) constantly need to address persistent challenges such as information asymmetry, low transparency, food quality and authenticity, and unnecessary waste. In the wake of Industry 4.0, Blockchain arises as a promising solution to help the FSC overcome those issues. The extant literature has studied various aspects of Blockchain for FSC such as how the technology can be used to combat food fraud and facilitate end-to-end traceability. However, two perspectives are still missing. One is a quantitative assessment of the determinants of Blockchain implementation process, and the other is an analytical evaluation of the overall impact of Blockchain adoption on the FSC operational performance to draw clear evidence on the benefits of Blockchain-enabled FSC. This study provided a unique blend of empirical and analytical approaches to investigate this research gap. Under the lens of Innovation Adoption theoretical perspectives, this study collected questionnaire data to analyze the relationships between technology, organization, environment, and management contexts and the process of implementing Blockchain. Further, system thinking and System Dynamics (SD) modelling perspectives were used to develop different FSC models and evaluate the impact of a successful Blockchain implementation on the key performance metrics of the system such as inventory level, lead time, service level, and operations cost. Findings from the study identified important determinants in each of the adoption phases, and further indicated significant improvements to the overall operational performance of the FSC, brought in by Blockchain adoption. The results of this study contribute to a more comprehensive understanding of the Blockchain phenomenon in the FSC, and further, propose SD modelling as an effective approach to examine Blockchain adoption. The results also inform managers in the field about the important influential factors when adopting Blockchain, and the impact of Blockchain on operations. The developed models can serve as a useful framework to evaluate the technology for specific business cases.

Keywords: Blockchain, food supply chain, performance, system dynamics.

4.1 Introduction

The food supply chain (FSC) plays an important role in producing and supplying food and agricultural products to sustain the world population (Barbosa 2021). Due to specific characteristics of the FSC (globalized, fragmented, and complex) and food products (perishability, seasonality, temperature sensitivity, etc), the FSCs often face the challenges of monitoring and maintaining food quality, safety, and authenticity, fragmented data, and promoting sustainability (Zhao et al., 2019, Rana et al., 2021). A recent article by Deloitte emphasized the lack of communication and cooperation across the FSCs which can cause severe inefficiency, disruption, and damage to the global food chain, especially under the effects of the Covid-19 Pandemic (Szegedi, 2022). The United Nations Environment Programme (UNEP) reported that food waste remains a severe problem, and it can occur at any node of the FSC (UNEP, 2021), advocating for stakeholders in the FSC to continue working together and solving this critical problem. As a promising solution to help overcome those persistent challenges, Blockchain technology has gathered significant interest in recent years from food industry practitioners and researchers (Li et al., 2021; Ahmed et al., 2022).

Blockchain provides unique technological advancement to Supply Chain Management (SCM) since it can help transform and improve the process of sharing information between entities, leading to better transparency, better product traceability, and more efficient processes (Kurpjuweit et al., 2021; Rao et al., 2021). Blockchain applications in FSC have been ramping up in recent years, with the introduction of numerous Blockchain platforms for food product traceability such as Famerconnect, OriginTrail, Seafoodchain, and Wholechain, alongside established projects such as the IBM Food Trust platform. Regulatory bodies are also interested in the use of Blockchain for FSC, for instance, the U.S Food & Drug Administration highlighted that Blockchain is a key technology for food producers and suppliers to meet the requirements of traceability set by the agency in the near future (USFDA, 2021). Further, the stream of research on Blockchain in FSC has grown considerably in the last few years and investigated multiple interesting aspects such as designing Blockchain solutions for food products (Casino et al., 2020), examining the use of Blockchain in certifying the authenticity of food products (Denese et al., 2021, Gligor et al., 2021), or exploring multiple facets of Blockchain adoption and implementation in the FSC (Rana et al., 2021; Vu et al., 2022). Note that Vu et al. (2022) is the publication result of Chapter 3 of this thesis.

While the extant literature has accumulated an impressive body of knowledge regarding potential benefits, pilot use cases, and adoption approaches of Blockchain in the FSC (Zhao et al., 2019; Denese et al., 2021; Rana et al., 2021); there are still two areas that need further attention from researchers.

First, there is an evident need for researching the implementation of Blockchain for organizations. Early attempts at exploring this topic have been made in the extant literature, as many studies investigated the antecedents of the decision to adopt Blockchain (For example see Wong et al. (2020) and Queiroz et al. (2020)). It is, however, observed that less effort has been put into studying the journey by which Blockchain gets integrated into an organization. Studying this particular aspect could uncover valuable insights that lead to a smooth and successful implementation of Blockchain technology for companies, creating business values (Pichlak, 2015). To address this gap in the current literature, the Qualitative study of Blockchain implementation (Chapter 3) collected and analyzed empirical data to identify the phases of the Blockchain implementation process and its associated influential factors in the specific FSC context. Thus, the Qualitative study established important groundwork to better understand the process of integrating Blockchain for organizations in the FSC. It is necessary to advance this knowledge further by evaluating the relationships between the determinants and different diffusion stages, as for each stage the importance of a factor can change (Wamba et al., 2020a). By understanding this facet, a holistic picture of a novel technology adoption process can be established (Martins et al., 2016; Wamba et al., 2020a). Therefore, this Quantitative study (Chapter 4) takes a step further to investigate the relationships between Blockchain implementation stages and how the determinants can influence each adoption stage.

Second, there is a lack of in-depth studies investigating the Blockchain’s impact on the processes, actors, and performance of the FSC. In a recent comprehensive review of over 50 Blockchain projects, including many in the food industry, Ahmed et al (2021) found that process efficiency and cost reduction are two main motivations for companies while exploring Blockchain technology. Nevertheless, an extensive explanation of what and how Blockchain can bring changes and improvements to the operation of different stakeholders in the FSC is yet to be established. Thus, scholars continue to call for in-depth and specialized research on how businesses and processes in particular industries can benefit from Blockchain-enabled digital transformation (Wang et al., 2019; Martinez et al., 2019; Ahmed et al., 2022), including the FSC.

Examining the impacts of Blockchain technology on the key performance indicators of the FSC provides a good starting point to measure and evaluate how this technology can affect the processes, stakeholders, and performance of the FSC. In essence, "*performance measurement is the process of developing a set of performance metrics and collecting, analysing, reporting, and reviewing performance data to quantify the effectiveness and efficiency of organizations' processes*" (Kara et al., 2020, p3-4). Hence, by quantifying and measuring the changes in key performance indicators of the FSC (for instance inventory level, cost, lead time, etc), researchers can uncover the impacts of adopting Blockchain to the system, bringing a holistic picture of benefits created by this technology. While the extant literature heavily emphasized the effects of Blockchain on the particular processes of food supply chain management (FSCM) such as food traceability and food authentication (Casino et al., 2020; Danese et al., 2021), there is still a need for research linking Blockchain to the wider topic of operational performance of companies (Wamba et al., 2020b; Stranieri et al., 2021). The importance of this topic is also echoed by practitioners, as a recent report about Blockchain adoption in the industry by Capgemini stated that to successfully adopt and make use of Blockchain, "organizations need to know what success looks like. How will it be measured? What metrics will be key?" (Capgemini, 2021, p.8).

Considering the need for examining the relationships between contextual determinants and Blockchain implementation stages, and the holistic impacts of Blockchain on the FSC processes and performance, this study seeks to answer the following research questions (RQ):

RQ1: What are the important factors that affect the Blockchain implementation stages in the FSC setting?

RQ2: What is the impact of adopting Blockchain on key performance indicators of the food supply chain?

While Blockchain is considered a disruptive technology, adopting technological innovation in the SCM domain is not a new phenomenon. In the past, several transformative technologies have emerged for better SCM such as RFID (Reyes et al., 2016), and big data analytics (Kache and Seuring, 2017). When studying the adoption of technological innovation, Innovation Adoption (IA) theories have been commonly used in the extant literature. In a broad sense, IA perspectives theorize and explain why and how an innovation (i.e., a product, a process, or a technology), that is new to the adopting units (i.e., organizations or individuals) is introduced, developed, adopted, and implemented (Pichlak, 2016). Prominent IA theories and concepts have been used to a great extent to study the adoption of technologies such as RFID (Hossain et al., 2016; Reyes et al., 2016), and the Blockchain integration process in a generic SCM setting (Wamba and Queiroz, 2020b). Drawing from prominent theoretical lenses of IA, the Qualitative study in Chapter 3 (Vu et al., 2022) developed a multi-stage model to capture different phases of Blockchain adoption and their determinants. This study leveraged the qualitative findings to address RQ1, by proposing twelve hypotheses about the key relationships between primary determinants and adoption phases. Then, quantitative data was collected using surveys to statistically test and validate the model to uncover what the key influential factors to each of the adoption stages are, in the specific context of FSC.

To assess the impacts of Blockchain adoption on FSC performance (RQ2), this study proposes to use the System theory and System Dynamics (SD) approach. SD is a holistic analytical modelling and simulation approach that aims to understand complex systems (Sterman, 2000). The FSC can be understood as a complex system with numerous nodes and flows (inventory, information, finance, and so on), and Blockchain technology is an intervention that has the potential to affect the relationships and interactions within the system. Thus, SD can be a very effective tool to investigate the changes brought by Blockchain at a supply chain level, as in the past it has successfully been utilized to study the impact of other technological innovations on SC performance such as RFID (De Macro et al., 2012), cloud computing (Kochan et al., 2017), and Internet-of-Things (Qu et al., 2017). Particularly, SD is employed in this study to examine the extent to which the use of Blockchain could affect the complex interactions between inventory management and information sharing in an FSC setting.

Due to the lack of an established approach to capture the complex and dynamic interactions between Blockchain technology and various FSC processes, a mixed/hybrid method was followed for this part of the study. Relevant insights from the survey and additional interviews were used to develop the models and simulate two scenarios for comparison: a conventional FSC and a Blockchain-integrated FSC.

The study makes the following contributions. First, it advances the current understanding of the Blockchain diffusion process in the FSC context, by determining the relationships between implementation stages, and what determinants are most important in each stage. Second, it sheds light on an important and frequently discussed topic in the current literature regarding Blockchain and SCM, that Blockchain can optimize and enhance processes and performance (Cole et al., 2019; Ahmed et al., 2022). Third, this study is among the first to provide an in-depth and analytical angle of exploring the effects of adopting Blockchain technologies on activities and interactions among FSC stakeholders, and quantifying and evaluating the changes brought by Blockchain to key performance metrics such as inventory level, lead time, service level, and operation cost. Subsequently, the findings from this study inform the managers of the quantifiable benefits (and risks) of adopting Blockchain to their operations. Further, the findings can provide a useful reference for practitioners in the field when adopting Blockchain, especially when the technology is still at the embryonic stage of development. The study also contributes to elaborating IA theoretical perspectives to better fit with the specific FSC context, and to advancing the system thinking approach through the development of SD models that practitioners can adapt to their current business to evaluate the Blockchain adoption impacts themselves.

The rest of the paper is structured as follows: Section 4.2 provides the background to the research, Section 4.3 discusses the methodology employed, Section 4.4 reports the quantitative assessment of the Blockchain implementation in FSC, Section 4.5 presents the SD modelling process and the simulation results, Section 4.6 discusses in-depth the findings, and Section 4.7 concludes the study.

4.2 Theoretical background

4.2.1 Blockchain in the food supply chain

The modern FSC has struggled with persistent challenges such as counterfeit products (Danese et at., 2021) or low visibility and transparency, which lead to concerns regarding the quality and safety of food products (Gligor et al., 2021). These challenges stemmed from the fact that modern FSCs are typically long, complex, and involve numerous entities from across the globe. Blockchain has been seen as a promising solution that can help the FSC to overcome those issues. The core attributes of Blockchain include real-time information sharing, enhancing cyber security, and providing an immutable, unified, and trustworthy track of records (Casino et al., 2020; Li et al., 2021). Subsequently, in the FSC setting, Blockchain provides significant improvements in terms of food traceability, food quality and safety, visibility and transparency, and waste reduction (Casino et al., 2020; Gligor et al., 2022). More importantly, as Blockchain is append-only and has embedded validation protocols (also known as consensus mechanism), existing records cannot be tampered with, and all changes to the data are recorded faithfully in the system. Thus, not only businesses will get further visibility up and downstream of a supply chain, but they are also assured of the trustworthiness of the information, or at the very least of the auditability of the information stored on the chain (Zhao et al., 2019; Vu et al., 2022).

There have been compelling cases of Blockchain applications in the food industry. Well-known projects such as IBM food trust platforms, Walmart's initiatives of tracking mango and pork with the help of Blockchain, and Provenance tracking fishing activities and products were highlighted in the extant literature (Cole et al., 2019; Vu et al., 2022). In recent years, many more Blockchain platforms have gone live, tracking and tracing millions of food products with various degrees of perishability – from grain and coffee to poultry and seafood (Kamilaris et al., 2019; Li et al., 2021).

Enhancing the traceability of food products continues to be among the most highlighted benefit of Blockchain for the FSC, illustrated by not only industry use cases, but also research specialised in Blockchain solutions development such as Caro et al. (2018), Casino et al. (2020), and Zhang et al. (2020). Another key advantage of Blockchain is to communicate important information about food products such as authenticity and provenance to the end consumers (Danese et al., 2021; Gligor et al., 2021), especially when the general public has become increasingly aware of and vocal about the information asymmetry between businesses in the FSC and the consumers (Kendall et al., 2019). Due to the inherent reliability and accountability of information stored and shared with Blockchain, consumers know that they can trust the information supplied by Blockchain applications, than a simple claim on the label of a product. Blockchain can further foster a more sustainable FSC, by utilizing the ability to build an immutable track of records to monitor the use of natural resources (Zhao et al., 2019), labour conditions, and human rights compliances, and to oversee that sustainable farming practices are properly carried out across the supply chain (Rana et al., 2021).

4.2.2 A model for Blockchain implementation in the FSC

There are two main streams of research in the IA literature: a dichotomy of the process approach and a factor approach (Pichlak, 2016). The latter focuses on influential factors that constitute the decision to adopt a new technological innovation, meanwhile the former examines the process by which technology gets integrated into an organization. As this study explores the course of Blockchain diffusion in FSC organizations, it is more aligned with the second stream of IA research. Prior to this work, the Qualitative study explored the process of implementing Blockchain in FSC organizations with empirical data from in-depth interviews (Vu et al., 2022). The result is a model that represents the adoption activities, adoption broad stages, and contextual determinants of the adoption process for FSC organizations (For reference see Figure 3-4 in Chapter 3). Inspired by the prior work, this study's research model proposes three distinct phases of Blockchain implementation at the organizational level, which are Initiation (INI) – where an organization explores the potential and suitability of Blockchain, Adoption (ADOP) – where the final decision of adopting Blockchain is made and organization details the plan to integrate the technology, and

Implementation (IMPL) – where the organization takes necessary steps to fully deploy the technology.

Further, it is important to conceptualize the main determinants of the implementation process, since they will directly derive the exogenous constructs for the quantitative assessment at the later stage. The results from the Qualitative study indicated four broad categories of determinants, namely technology, organization, environment, and managers' characteristics. Important details of the influential factors in each category were also found from the analysis of interviews conducted in the Qualitative study. Next, the IA literature was utilized in conjunction with the previous qualitative findings to conceptualize the determinant constructs. Particularly, the influential factors determined from the Qualitative study are contrasted, matched, and aggregated into constructs that were proven to be representative and testable by established research in the area of IA. Thus, using the literature can provide another layer of validity in formulating constructs, an approach that is followed by other research in the same stream such as Wamba et al. (2020a). Table 4-1 presents the detailed development of constructs for this study.

Table 4-1. Determinant constructs of the Blockchain implementation process in the FSC.

Findings from the Qualitative study	Construct	Description	Reference
Technology characteristics			
Experts perceived that Blockchain possesses relative advantages over existing IT system by bringing new values, improving current processes, and facilitating a more transparent food supply chain.	Relative advantage	This concept refers to what perceived benefits for organizations can be brought by adopting an innovation.	Rogers (2003), Martins et al. (2016)
Experts suggested that Blockchain technology must align with the adopting unit's needs, goals, processes, and other technologies already in use.	Compatibility	This concept refers to the degree to which an innovation or new technology may be integrated with the adopting entity's current process and systems.	Rogers (2003), Hameed et al. (2012), Martins et al. (2016)
Complexity arises from the fact that Blockchain is inherently complex, with various solutions available in the market and a certain degree of difficulty in configuring and modifying the technology to fit with organizations' needs.	Complexity	This concept refers to how much an innovation is perceived as hard to understand, implement, and use.	Rogers (2003), Hossain et al. (2016), Martins et al. (2016)
Cost is an important factor that can affect the adoption of Blockchain technology, as experts expressed that the margin in food industry is relatively tight.	Cost	Perceived cost and possible return on investment are carefully weighted by firms before purchasing new technologies.	Chan and Chong (2013); Hossain et al. (2016)
Organization characteristics			
Experts shared that both financial resources and human resources are important to implementing Blockchain.	Resource	This concept refers to the availability of resources that enables the adopting entity to implement a new innovation, including finance, personnel, and technology.	Hossain et al. (2016)
The commanding power of one entity in the FSC can dictate the wide adoption of Blockchain in their up and downstream partners.		To this end, the innovative culture of an organization and its social capital can be	

Interview findings indicated that early adopters of Blockchain are actively seeking new ideas and investing in R&D.		considered intangible resources of the adopting unit.	
Experts found that having existing infrastructure for food traceability, technology capability, and a ready-to-change mindset can get a business ready for Blockchain adoption.	Technology competency	This concept refers to the organization's technological infrastructure and know-how in using and implementing technology.	Martins et al. (2016), Wamba et al. (2020a)
Environment characteristics			
Experts acknowledged that regulatory bodies encouraging the use of Blockchain and envisioning tighter restrictions of food traceability and safety can drive companies to consider Blockchain.	External pressure	This is the pressure exerted on the adopting unit by other entities upon which they are dependent. This concept sometimes is also referred to as coercive pressure.	Chan and Chong (2013), Martins et al. (2016), Hossain et al. (2016)
Experts recognized that customers are demanding more trustworthy and reliable information regarding food products.			
The support from other organizations in the same FSC, as well as the desire to mimic competitors in exploring Blockchain, can motivate one firm to consider Blockchain.	Other organizations' influence.	This concept refers to the influence of other organizations such as their support in adopting the technology or competitors' pressure exerted on the adopting unit.	Chan and Chong (2013), Hossain et al. (2016)
Management characteristics			
Successful cases of Blockchain adoption showed that top management was very active during the implementation project.	Managers' support	This refers to the commitment, initiative, and encouragement from top managers toward integrating new technology.	Martins et al. (2016), Hossain et al. (2016), Wamba et al (2020a)
Management attitude toward Blockchain is recognized as an important driver for a firm to explore Blockchain.			

Finally, a research model is developed for the quantitative assessment of the determinants of the Blockchain implementation process in the FSC. Figure 4-1 presents the research model, which is derived from the results of the Qualitative study and relevant literature. The research model includes 12 hypotheses to evaluate the relationship between the adoption stages (Initiation – Adoption – Implementation) and between the 9 main determinant constructs (as depicted in Table 4-1) and each of the adoption stages.

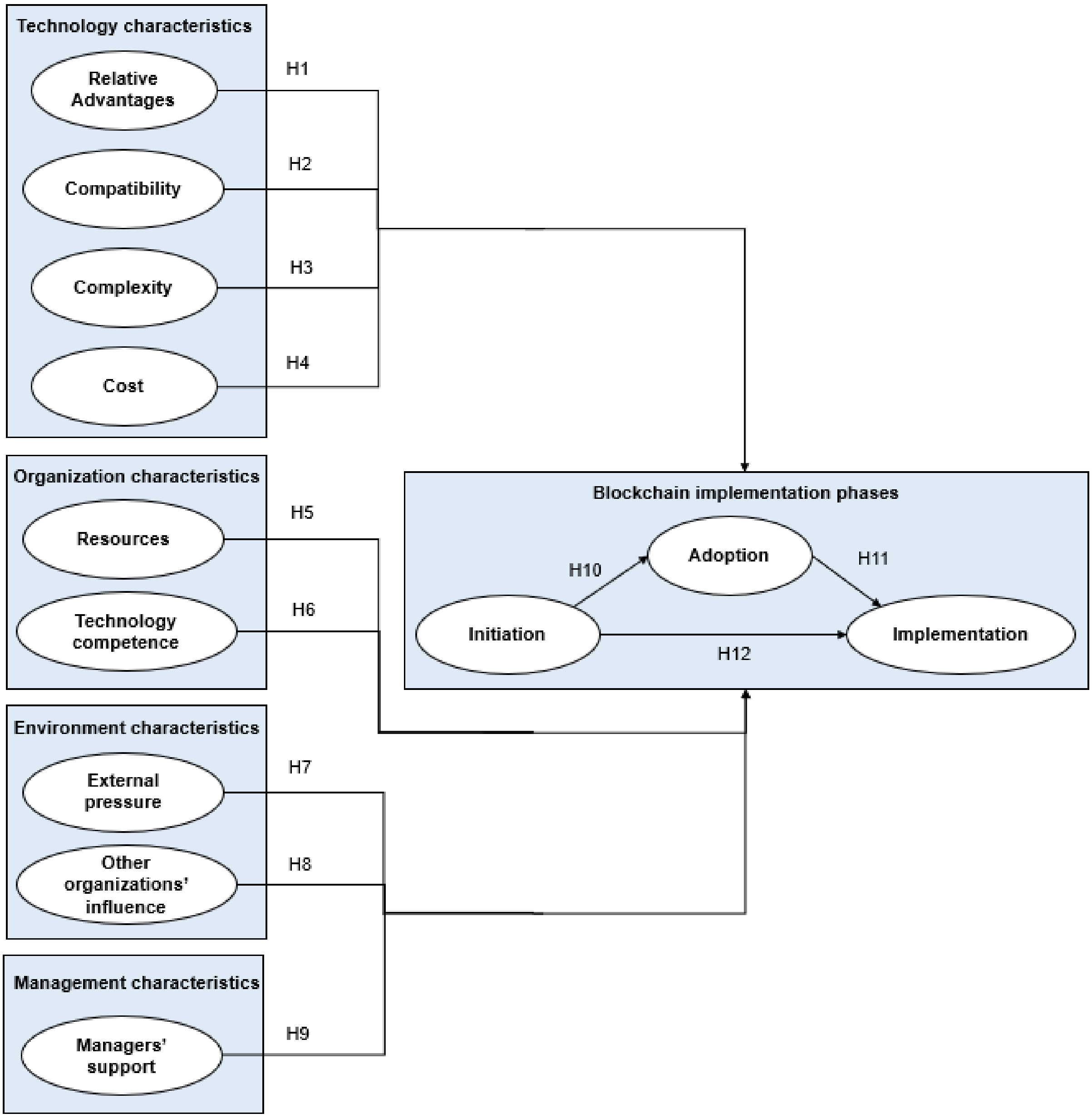

Figure 4-1. The quantitative assessment of the determinants research model.

The hypotheses are presented next. To provide a general view of the test, 12 aggregated hypotheses are shown. The quantitative assessment will focus on testing the relationship between each construct (determinant of Blockchain implementation) and *a single stage of implementation* for the first 10 hypotheses. Thus, each of those 10 hypotheses is broken down into three lower-level hypotheses to reflect the actual assessment that follows.

H1: Blockchain's relative advantages (RA) are positively related to Blockchain initiation, adoption, and implementation.

- *H1a: RAs are positively related to Blockchain initiation.*
- *H1b: RAs are positively related to Blockchain adoption.*
- *H1c: RAs are positively related to Blockchain implementation.*

H2: Blockchain's compatibility (CPA) is positively related to Blockchain initiation, adoption, and implementation.

- *H2a: CPA is positively related to Blockchain initiation.*
- *H2b: CPA is positively related to Blockchain adoption.*
- *H2c: CPA is positively related to Blockchain implementation.*

H3: Blockchain's complexity (CPX) is negatively related to Blockchain initiation, adoption, and implementation.

- *H3a: CPX is negatively related to Blockchain initiation.*
- *H3b: CPX is negatively related to Blockchain adoption.*
- *H3c: CPX is negatively related to Blockchain implementation.*

H4: Blockchain's cost (CST) is negatively related to Blockchain initiation, adoption, and implementation.

- *H4a: CST is negatively related to Blockchain initiation.*
- *H4b: CST is negatively related to Blockchain adoption.*
- *H4c: CST is negatively related to Blockchain implementation.*

H5: Organization's resources (RESO) are positively related to Blockchain initiation, adoption, and implementation.

- *H5a: RESOs are positively related to Blockchain initiation.*

- *H5b: RESOs are positively related to Blockchain adoption.*
- *H5c: RESOs are positively related to Blockchain implementation.*

H6: Organization's technology competence (OTC) is positively related to Blockchain initiation, adoption, and implementation.

- *H6a: OTC is positively related to Blockchain initiation.*
- *H6b: OTC is positively related to Blockchain adoption.*
- *H6c: OTC is positively related to Blockchain implementation.*

H7: The external pressure of adopting Blockchain (EXTP) has a positive influence on Blockchain initiation, adoption, and implementation.

- *H7a: EXTP has a positive influence on Blockchain initiation.*
- *H7b: EXTP has a positive influence on Blockchain adoption.*
- *H7c: EXTP has a positive influence on Blockchain implementation.*

H8: The influence of other organizations (ORGIN) has a positive influence on Blockchain initiation, adoption, and implementation.

- *H8a: ORGIN has a positive influence on Blockchain initiation.*
- *H8b: ORGIN has a positive influence on Blockchain adoption.*
- *H8c: ORGIN has a positive influence on Blockchain implementation.*

H9: Managers' support (MSP) toward Blockchain has a positive influence on Blockchain initiation, adoption, and implementation.

- *H9a: MSP has a positive influence on Blockchain initiation.*
- *H9b: MSP has a positive influence on Blockchain adoption.*
- *H9c: MSP has a positive influence on Blockchain implementation.*

H10: The Initiation stage (INI) positively influences the adoption stage.

H11: The Adoption stage (ADOP) positively influences the implementation stage.

H12: The Initiation stage (IMPL) positively influences the implementation stage.

4.2.3 System thinking and System Dynamics approach

The underpinning theoretical perspective used for the assessment of Blockchain's impact is system thinking. System thinking is "*the ability to see the world as a complex system, in which we understand that 'you cant just do one thing' and 'everything is connected to everything else'*" (Sterman, 2000, p.4). In essence, the system thinking perspective advocates to holistically view the world as a complex system, where every component (which might be a complex sub-system itself) is interlinked to others, and changes in a certain part of the system will likely have effects on the other parts and the system as a whole (ibid.) Subsequently, the SD approach, based on system thinking, is a method to analyse, evaluate, and enhance the learning about the behaviour of complex systems over time (Sterman, 2000). SD approach is useful to model the relationships between critical factors, to simulate the overall interaction, and is especially powerful to evaluate different policies and their impacts on the system following the simulation of the system (Lyneis, 1999; Kara et al., 2020).

SD modelling has been applied to examine the implications of the adoption of technologies (De macro et al., 2012; Fang et al., 2018;). In the field of information systems, for example, most studies assume a variance logical structure – where relationships between constructs are one-way and time-invariant, whereas the SD approach offers an alternative viewpoint that takes into account the possibility of feedback between constructs, circular causality within a system, and changes over time (Fang et al., 2018). Thus, the former is powerful to study why and how a technological innovation diffuses into a population, whereas the latter is useful to examine what factors can drive/hinder the expansion of such innovation after successful adoptions of the first few, and to paint a picture of the diffusion process over time (ibid.). SD approach also has been employed to study various phenomena in the domain of SCM/FSCM. Kochan et al. (2017) used this approach to assess the effect of cloud-based information sharing in the context of a hospital supply chain (HSC), simulating and comparing the results of a conventional HSC versus a cloud-enabled HSC. Kara et al. (2020) employed this approach to model the impact of climate change risk on supply chain performance. Kazancoglu et al. (2020) evaluated the performance of the reverse logistics operation in the food industry with SD modelling and simulation.

4.3 Methodology

4.3.1 Quantitative assessment of the implementation model

Quantitative data gathered following the questionnaire survey is utilized to test the proposed hypotheses and analyze the implementation stages. This is a common method in studying the adoption process of technology (Hossain et al., 2016; Wamba and Queiroz, 2020; Wong et al., 2020). The initial survey questionnaires were adapted from relevant works in the literature (e.g., Chan and Chong, 2013; Hossain et al., 2016; Martins et al., 2016). Further, a pilot round was conducted with 15 industry experts to validate the relevance and clarity of the questions. These 15 individuals were the interviewees of the Qualitative study, therefore they have an adequate understanding of Blockchain implementation in the FSC. The main purpose of the pilot survey was to determine if the questions make sense to practitioners, if the terminologies used are understandable, and the approximate duration of completion. Minor wording changes were made to the list of questions after the pilot. The final version of the survey was used to collect data from individuals working in the UK food industry. Surveymonkey service was used for data collection. The list of the questions and their corresponding measurement items are shown in Appendix 3.

To make sure the respondents of the survey had the appropriate expertise regarding implementing Blockchain, three rounds of screening were performed. First, the author instructed the survey service to only invite people who are working in the agriculture and food sector. All occupations, ages, and genders were allowed. Second, a set of screening questions was used at the beginning to gauge whether a respondent has a basic understanding of Blockchain technology, and where their company currently is in terms of Blockchain adoption. Candidates who unsuccessfully answered the screening questions were not able to take part in the survey. 200 responses were collected after this round. Finally, the author analyzed the logic of the survey responses to exclude insufficient answers. For example, if a candidate provided high scores for the Implementation questions but low scores for the Adoption questions, such a response is deemed illogical and thus excluded. At the end of this process, 159 responses remained. Table 4 - 2 summarizes the demographic profile of the respondents to the survey. The respondents come from a variety of businesses in the food industry, spreading across the value chain from raw food producers to retailers and food services. Almost 58% of them currently assume managerial roles at their organization, and a majority of them have considerable experience in the field (only 19% have less than 5 years of working in the food industry). Regarding the current stage of the Blockchain adoption projects, as expected from the author, the majority of the companies (approximately 42%) are at the early phase of discovering the technology (researching, planning for the project, or piloting). 6% of the respondents claimed that Blockchain technology is in use at their business. Even though this figure is comparatively small, it signals that Blockchain is making good progress in penetrating the FSC, given the infancy of the technology.

Table 4-2. Respondents of the survey.

	n	%		n	%
Current position			**Experience**		
Senior managers	36	22.6	Less than 5 years	30	18.9
Middle-level managers	56	35.2	5 to 10 years	57	35.8
Staffs	52	32.7	10 to 15 years	37	23.3
Not specified/ Others	15	9.4	More than 15 years	35	22
Company main function			**The current stage of Blockchain project**		
Raw food producer	10	6.3	Researching	22	13.8
Food processor	28	17.6	Planning/Developing	25	15.7
Food distributor/ wholesaler	35	22	Piloting	21	13.2
Food services	26	16.4	Considering full adoption of the technology	30	18.9
Retailer	30	18.9	Starting to implement at large scale	30	18.9
Blockchain service provider	21	13.2	In use	10	6.3
Other	9	5.7	Other	21	13.2

Moreover, Partial Least Square – Structural Equation Modelling (PLS-SEM) was chosen as the analytical approach to analyze the results and test the model. PLS-SEM is a strong method for an exploratory study, where researchers want to extend current theoretical foundations to understand a developing area (Hair *et al.*, 2019). Particularly for this case, the author aim to elaborate on established IA theories and concepts to explain a new phenomenon – the adoption of Blockchain in the FSC domain. A basic guideline for selecting a sample size is that it should be at least equal to the number of structural paths directed at a single construct (indicated by the arrows in the model) (Hair *et al.*, 2012). In this case, IMPL has the largest number of 11 structural paths connecting to it, thus a sample of at least 110 is required for testing this model. Therefore, 159 responses collected for this research prove to be a sufficient number of data points for the analysis. SmartPLS 4 software was used to aid the analysis process.

4.3.2 SD modelling approach

The second part of this research aims to understand how Blockchain can change the FSCM processes and interactions between FSC stakeholders, and then evaluate the effects of the technology on the performance of the FSC. System thinking, subsequently, is a suitable lens for examining this subject, since the FSC can be viewed as a complex system with many participants and is constantly changing (Kumar and Nigmatullin, 2011; Melkonyan et al., 2021) and Blockchain technology can be considered as an intervention to the system. The SD approach (following system thinking and theory) is effective to assess not only changes but also the causes of changes for interventions in a system for varying scenarios (Lyneis, 1999).

A challenge with modelling in this study is that, to the best knowledge of the author, there has not been an explicit and widely agreed approach to model the Blockchain integrated supply chain system. Therefore, this study uses a mixed-methods approach to achieve the aim of the research. Empirical data was collected to uncover the changes in business processes after the adoption of Blockchain. Later, empirical insights were combined with relevant literature to develop the SD models for two different scenarios: a conventional FSC and a Blockchain-integrated FSC. By simulating and comparing the two scenarios, this study can determine Blockchain adoption impacts on FSC. This particular approach of gathering empirical data to help develop the SD models is commonly used in SD studies (for examples see Kumar and Nigmatulin, 2011; Kara et al., 2020; and Melkonyan et al., 2021), because it is an effective mean for determining the context (what phenomenon is under examination), understanding the key components of the models (material and information flows), and setting the boundaries of the models (what process, entities, and variables should be included). To this end, this study was conducted in three phases:

Phase 1: *Survey* and *semi-structured interviews* were conducted to investigate a typical structure of the FSC and the effects of Blockchain on the processes and key aspects of operations.

Phase 2: Two *SD models* were developed to quantitatively analyze the impacts of Blockchain on the FSC.

Phase 3: Simulation studies were conducted, and the results were analyzed and discussed.

In the first phase, data were collected in two stages. In the first stage, a questionnaire survey was distributed to professionals working in the food industry to gauge their perspectives regarding the adoption of Blockchain and its associated aspects. The main aim of this survey is to inform the implementation process of Blockchain in the FSC, which is the first objective of this study. Nonetheless, the survey also provides useful insights to understand the potential impacts of Blockchain on the FSC. The targeted respondents were primarily based in the UK, and come from businesses that are either stakeholders in a food supply chain network (producer, food processor, retailer, etc) or are related to Blockchain applications for agri-food products (IT service provider, IT consultancy, etc). From 200 responses received initially, 159 responses were checked and deemed valid. SurveyMonkey and Qualtrics services were used to reach out to the author' network and other potential respondents for data collection. The first stage was conducted in September 2021.

In the second stage (which happened between September and November of 2022), semi-structured interviews were conducted to gather in-depth data regarding the effects of using Blockchain in the FSCs. The author carefully picked Blockchain projects that onboard multiple entities in the same supply chain, to capture a holistic view of how the technology would impact the flow of products and information between members of an FSC. To identify these cases, the author relied on news sources to determine Blockchain initiatives for food products. These projects need to meet certain criteria, namely the initiative must be ongoing and there must be companies from various nodes of the supply chain actively participating in the Blockchain platform. Cases of using Blockchain for a single organization were not selected, since they would not give useful insights into how Blockchain can impact a network of stakeholders in the FSC. Three cases of Blockchain adoptions were identified, and individuals from those companies were reached out. The first case is using Blockchain for tracking organic coffee from individual farmers to their farm co-operative to processors and finally to cafes and retailers. The second case utilizes a Blockchain platform to track the juice production process from the point of raw material (fruits) to the point of final products being bottled. The third case uses Blockchain to keep track of sustainability compliances, alongside product movement, in palm oil production. Invitations to take part in the research were sent out via emails or LinkedIn messages. Four interviews were conducted via the Zoom platform, and each interview lasted approximately an hour. The rights of data, alongside the consent for the recording and the use of data, were communicated to interviewees in both written form and verbally. In three very detailed and in-depth interviews, 100 pages of transcripts were produced. Nvivo software is later used to aid the qualitative data analysis.

Findings from the empirical data aided the modelling process in the second phase (which will be elaborated more in Sections 4.2 and 4.3). SD methodology follows a specific and logical approach to modelling. A causal loop diagram (CLD), a visual presentation of key variables and their relationships (including feedback), is constructed initially, utilized insights from the empirical data. The CLD plays an important role in determining the crucial components (entities, activities, etc.) of the FSC system, the key relationships between those components (including feedback relationships), and the changes to the system brought about by the adoption of Blockchain. This led to the development of the stock-and-flow diagrams (SFD) for the two scenarios (a conventional FSC and a Blockchain-integrated FSC). The SFDs include input, output, and rates (fulfilment, consumption, etc) of the system, which are defined by mathematical equations and parameters. The SFDs are derived directly from the CLD and are further inspired by fundamental SD principles and practices introduced in Sterman (2000) and other established works of modelling the supply chains following the SD approach such as Kochan et al. (2017), Ghadge et al. (2020), and Kara et al. (2020).

Finally, in the third phase, we ran simulations on the SFDs, analyzed the results and discussed the implications.

4.4 A quantitative assessment of the implementation model

In this section, the analysis results of the research model with the survey data are presented. Two main sections of the model are analyzed: the measurement model and the structural model. The measurement model, sometimes referred to as the outer model, includes the indicators of a construct (Hair et al., 2019). In another word, the assessment of the measurement model indicates whether a construct (e.g. Relative advantage – RA) is reliably and validly measured by its indicators- the measurement items. Each measurement item of a construct is captured by one question in the survey, where a Likert scale of 1 to 5 (with one being "strongly disagree" and five being "strongly agree") was applied. On the other hand, the structural model, sometimes referred to as the inner model, consists of the main variables (constructs) and their relationships. By assessing the path coefficients of the structural model, it is uncovered how exogenous constructs correlate with endogenous constructs and the predictive power of the whole research model.

To assess the validity of the measurement items (MI), the loadings value of each item is utilized. The outer loading of each MI first needs to be statistically significant, and further should be at least moderately strong (no less than 0.4 according to Hair et al. (2012)). The initial calculation of the model thus excluded *ORGIN1* and *ORGIN2* due to insufficient loadings value. As seen in Table 4-3, the rest of the MI are statistically significant and have strong loading values, indicating that they effectively measure the corresponding constructs (a measured-by-single-item construct always has a loading of 1). Furthermore, to test the reliability of the MI in measuring the constructs, a CR score is used. A higher value of CR indicates a higher level of internal consistency reliability of the indicators for measuring the construct, and a value of 0.6 or higher is acceptable in exploratory research (Hair et al., 2019).

Table 4-3. Loadings of measurement items and average variance extracted (AVE) and composite reliability (CR) of the constructs.

Construct	CR	AVE	Measurement Item (MI)	Loading	P value for MI

INI	0.731	0.478	INI1	0.598	0
			INI2	0.734	0
			INI3	0.732	0
ADOP	0.755	0.606	ADOP1	0.759	0
			ADOP2	0.797	0
IMPL	0.727	0.475	IMPL1	0.797	0
			IMPL2	0.583	0.002
			IMPL3	0.67	0
RA	0.79	0.567	RA1	0.552	0.068
			RA2	0.714	0.011
			RA3	0.942	0
CPA	0.81	0.687	CPA1	0.959	0
			CPA2	0.674	0.004
CPX	0.801	0.575	CPX1	0.855	0
			CPX2	0.757	0.001
			CPX3	0.65	0.013
CST	0.884	0.792	CST1	0.919	0
			CST2	0.86	0
RESO	0.799	0.575	RESO1	0.805	0.002
			RESO2	0.591	0.05
			RESO3	0.853	0.005
OTC	0.802	0.583	OTC1	0.802	0
			OTC2	0.553	0.077
			OTC3	0.894	0.001
EXTP	0.795	0.495	EXTP1	0.681	0.038
			EXTP2	0.642	0.016
			EXTP3	0.819	0.003
			EXTP4	0.66	0.079
ORGIN	1		ORGIN1*	0.116	
			ORGIN2*	0.081	
			ORGIN3	1	
MSP	0.843	0.642	MSP1	0.78	0.012
			MSP2	0.85	0
			MSP3	0.771	0.01

**Discarded due to insufficient loading value*

As presented in Table 4-3, all constructs are reliably measured by their MI, with CR scores of at least 0.7. Constructs that are measured by a single indicator always have a CR score of 1. At the construct level, AVE is used to assess the convergent validity of the constructs. An AVE value of 0.5 or higher implies that the construct, on average, “explains more than half of the variance of the indicators” (Hair et al., 2012, p. 115). The majority of the constructs are qualified with this test. The exceptions are INI, IMPL, and EXPT, which have an AVE value of 0.478, 0.475, and 0.495 respectively. When a construct’s AVE score is under the threshold value, Lam (2012) recommended evaluating CR scores in conjunction with AVE scores to indicate the convergent validity of constructs. INI, IMPL, and EXPT have higher CR scores than the acceptance level of 0.7, therefore the internal reliability of measuring these constructs is acceptable. The final evaluation of the outer model is to assess discriminant validity, the extent to which a construct differs from others in an empirical sense (Hair et al., 2012). The Fornell-Larker criterion approach is utilized. The results, as seen in Table 4-4, imply that a construct shared more variance with its associated indicators than with any other construct, thus discriminant validity is not an issue with this study.

Table 4-4. Fornell-Larcker criterion for all constructs.

	ADOP	CPA	CPX	CST	EXTP	IMPL	INI	MSP	ORGIN	OTC	RA	RESO
ADOP	**0.778**											
CPA	-0.05	**0.829**										
CPX	-0.199	0.047	**0.759**									
CST	-0.11	0.057	0.451	**0.89**								
EXTP	-0.117	0.496	0.16	0.208	**0.704**							
IMPL	0.509	0.194	-0.132	-0.103	-0.077	**0.689**						
INI	0.418	-0.079	-0.1	-0.12	-0.075	0.455	**0.691**					
MSP	-0.104	0.53	-0.01	0.229	0.572	0.043	-0.089	**0.801**				
ORGIN	-0.165	0.22	0.302	0.24	0.467	-0.111	-0.279	0.276	**1**			
OTC	-0.124	0.421	0.085	0.257	0.585	-0.053	-0.085	0.599	0.337	**0.763**		
RA	0.151	0.467	0.103	0.012	0.331	0.085	-0.049	0.278	0.182	0.298	**0.753**	
RESO	-0.064	0.584	0.015	0.232	0.62	0.011	-0.124	0.606	0.328	0.636	0.451	**0.758**

Table 4-5. VIF value for the structural path.

	ADOP	CPA	CPX	CST	EXTP	IMPL	INI	MSP	ORGIN	OTC	RA	RESO
ADOP		1.85	1.45	1.45	2.21	1.36	1.10	2.08	1.49	2.05	1.41	2.61
IMPL	1.36	1.86	1.51	1.46	2.22		1.32	2.08	1.49	2.06	1.51	2.61
INI	1.10	1.85	1.45	1.45	2.19	1.32		2.08	1.39	2.05	1.41	2.60

Subsequently, the structural model, also known as the inner model is assessed. Before the path coefficient of the main relationships between exogenous and endogenous variables, and their p-value, are evaluated. Hair et al (2019) recommended checking for collinearity issues (high level of correlations between predictor constructs) of the inner model using the variance inflation factor (VIF). VIF value for the inner path is considered satisfactory with a value less than 3. As indicated in Table 4-5, collinearity is not an issue for this study.

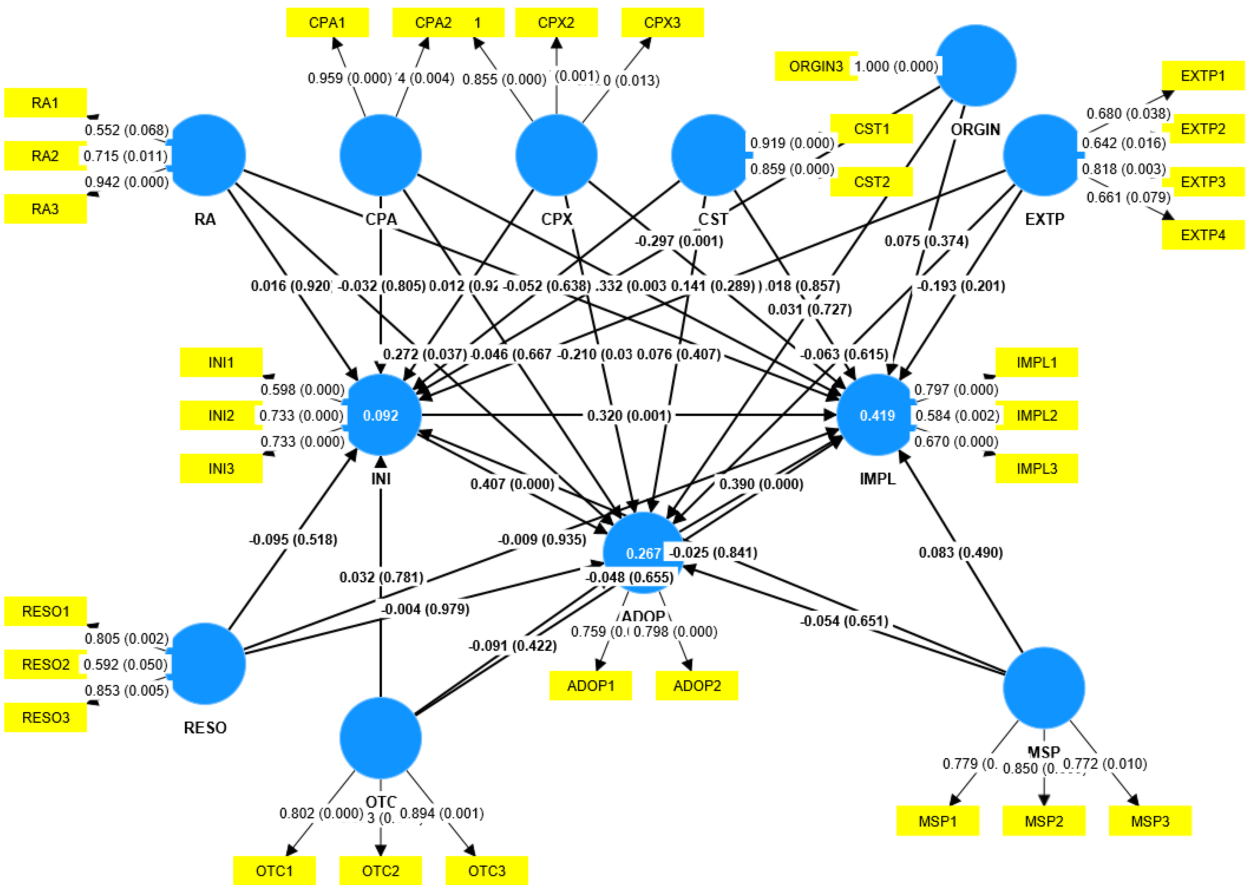

Figure 4-2. Bootstrapping results of the research model.

Figure 4 - 2 provides a holistic view of the assessment of the structural model, together with the loading value of the reflective indicators for their associated constructs. Subsequently, a bootstrapping procedure was carried out to estimate the path coefficients of the structural model and the significance levels.Sizable and significant relationships between the main constructs, as the results of evaluating the research model, are reported in Table 4-6. Generally for exploratory research such as this study, researchers can assume a significance level of 10% (Hair et al., 2012). Thus, the p-value is utilized to assess the significance level of the relationships between endogenous and exogenous constructs of this study's research model. When assuming a significance level of 10%, the p-value must be smaller than 0.1 to indicate that a relationship is statistically significant. As shown in Table 4-6, all significant relationships found are in the 99% and 95% confidence interval, exceeding the expectation for an exploratory study.

Table 4-6. Path coefficients between exogenous and endogenous constructs.

Hypothesis	Relationships	Path coefficient	P-value	Testing
H10	INI -> ADOP	0.407	0	Accepted
H11	ADOP -> IMPL	0.39	0	Accepted
H12	INI -> IMPL	0.32	0.001	Accepted
H1b	RA -> ADOP	0.272	0.037	Accepted
H2c	CPA -> IMPL	0.332	0.003	Accepted
H3b	CPX -> ADOP	-0.21	0.036	Accepted
H8a	ORGIN -> INI	-0.297	0.001	Rejected

Next, path coefficient values are evaluated for the strength of the relationships between the main constructs of the inner model. According to Table 4-6, the significant relationships concluded from statistical tests range from moderate (from 0.2 to 0.3 of path coefficient value) to moderately strong (close to or more than 0.4 of path coefficient value). From the results of the PLS-SEM bootstrapping process, three hypotheses were accepted (H10, H11, and H12), three hypotheses are partially accepted (H1, H2, and H3), and one hypothesis are partially rejected (H8). The partially accepted/ rejected hypotheses are partial due to the testing of an exogenous construct against a particular stage of adoption does not have a statistically significant result. Take the case of H1 for example, while RA shows a positive and significant relationship to the ADOP stage, it did not yield an acceptable p-value for the relationships with INI and IMPL stages.

Finally, the coefficient of determination (R^2 value) is evaluated. This is an important and commonly used measurement for the predictive power of the model. R^2 represents the amount of variance in the dependent constructs explained by all of the independent constructs associated with it (Hair et al., 2019). In this case, R^2 is calculated for the three constructs representing the three stages of adoption: INI, ADOP, and IMPL. The respective values of their R^2 are 0.092, 0.267, and 0.419 (as seen in Figure 4 - 2). Thus, it can be concluded that, in terms of predictive accuracy, the research model proposed in this study has a moderately strong level of accuracy when predicting IMPL, a moderate level of accuracy when predicting ADOP, and a weak level of accuracy when capturing INI.

4.4.1 Assessing the determinants of the Blockchain implementation process in FSC.

In the first part of Chapter 4, a model was proposed to understand the determinants of Blockchain adoption stages, as well as the inter-relationships between the stages, in the specific setting of FSC (See Figure 4-1). The quantitative analysis showed that each stage of implementing Blockchain has a positive impact on the following stage, and among all the identified determinants of the Blockchain integration process, relative advantage, complexity, compatibility, and other organizations' influence are statistically important.

Regarding the phases of Blockchain diffusion in the FSC, our testing revealed that the Initiation phase positively influences the Adoption phase and the Adoption phase positively influences the Implementation phase. These are indicated by the acceptance of H10 and H11, with the respective path coefficient values of 0.407 and 0.39, and a significance level of 1% for both relationships (See Table 4-6). This finding is in line with other IA studies' conclusions (e.g. Martins et al. (2016) or Wamba et al. (2020)), highlighting the importance of each stage in setting up the next one for success. For this specific case of adopting Blockchain in the FSC, it can be concluded that if a firm gained a good understanding of Blockchain's potential, where to apply this technology, and good pilot results, they would be more inclined to fully adopt the technology. Moreover, when a firm shows commitment to implementing Blockchain and assigns appropriate resources for the large-scale integration (the results of the Adoption phase), they are more likely to succeed in the Implementation phase. Additionally, this study proposed and test the relationship between the Initiation phase and the Implementation phase, with the premise that good preparation during the beginning of the project can lead to greater success at the last stage of Blockchain adoption. The acceptance of H12 (with a 0.32 path coefficient value and 1% significance level) supported our hypothesis. It, therefore, can be argued that an adequate understanding of the Blockchain, a well-formulated plan for its adoption, and technology know-how can contribute greatly to the implementation and deployment of the technology at the end of the project. This hypothesis and finding were not reported in previous IA studies of the innovation implementation process, to the best of the author's knowledge. Thus, this study harbours new knowledge and important implications.

With regard to understanding the determinants of the Blockchain implementation process in the FSC, the direct effects between a determinant (exogenous construct) and each of the implementation phases (endogenous construct) were statistically evaluated. As indicated in Table 4-6, several structural relationships fall into an acceptable range of confidence interval (which is at least 95% for this study), meaning they are statistically significant enough to conclude upon. Specifically, the Relative advantages of using Blockchain is found to be positively related to the decision of adopting Blockchain. A similar study, but in a different context, by Wamba et al. (2020) found that RA correlates with both Initiation and Adoption stages of Blockchain adoption process. A possible explanation for this difference is that companies in the FSC might consider the relative advantages of Blockchain when they have to make the adoption decision, whereas the Initiation phase focuses more on discovering what advantages can be harnessed by using Blockchain. On the contrary, the complexity of Blockchain is found to be negatively related to the adopting decision.

Concerning the implementation stage of Blockchain, compatibility is found to be the most relevant factor to the success of this stage. These findings are consistent with what the author predicted at the beginning, and with what the literature has suggested. The potential improvements to the FSC from Blockchain, such as the ability to improve food traceability, strengthen food safety and authentication, and uplift brand images, were important drivers for firms to consider the technology (Bumblauskas et al., 2020; Danese et al., 2021). On the other hand, the complexity of Blockchain technology could hinder the desire to explore it, especially for FSC stakeholders that lack the technical know-how (Cole et al., 2019; Vu et al.,2021). Compatibility of Blockchain with existing IT systems and process is also important for the full incorporation of Blockchain into a business (van Hoek, 2019). The quantitative assessment also indicated that other organizations' influence is negatively related to the Initiation phase of Blockchain. This finding came as a surprise to the author, hence the partial rejection of H8. A possible explanation for this is that these companies are likely the early adopter group of the industry. Therefore, they aim to be the first to gain competitive advantages by initiating Blockchain, rather than being reactive to competitors' actions. This also explains the important role of relative advantages in the adoption phase.

4.5 The SD modelling process and the simulation results

Section 4.3.2 specifies a three-phase approach to the modelling work of this study. Specifically, phase 1 analyzes the relevant insights from the survey, which was used predominantly to assess the Blockchain implementation process in the first part of this study. In phase 1, additional insights from three cases of large-scale Blockchain use are gathered and examined to aid the modelling process. Next, SD models are built for two scenarios – a conventional FSC and a Blockchain-integrated FSC. Last, simulations were run and results are interpreted. This section, 4.5, reports the outcomes of those three phases.

4.5.1 Findings from the surveys

Certain insights from the survey of the first part of this study are useful for understanding the potential of Blockchain for improving FSC operations. Those specific insights are extracted and summarized in Figure 4-3.

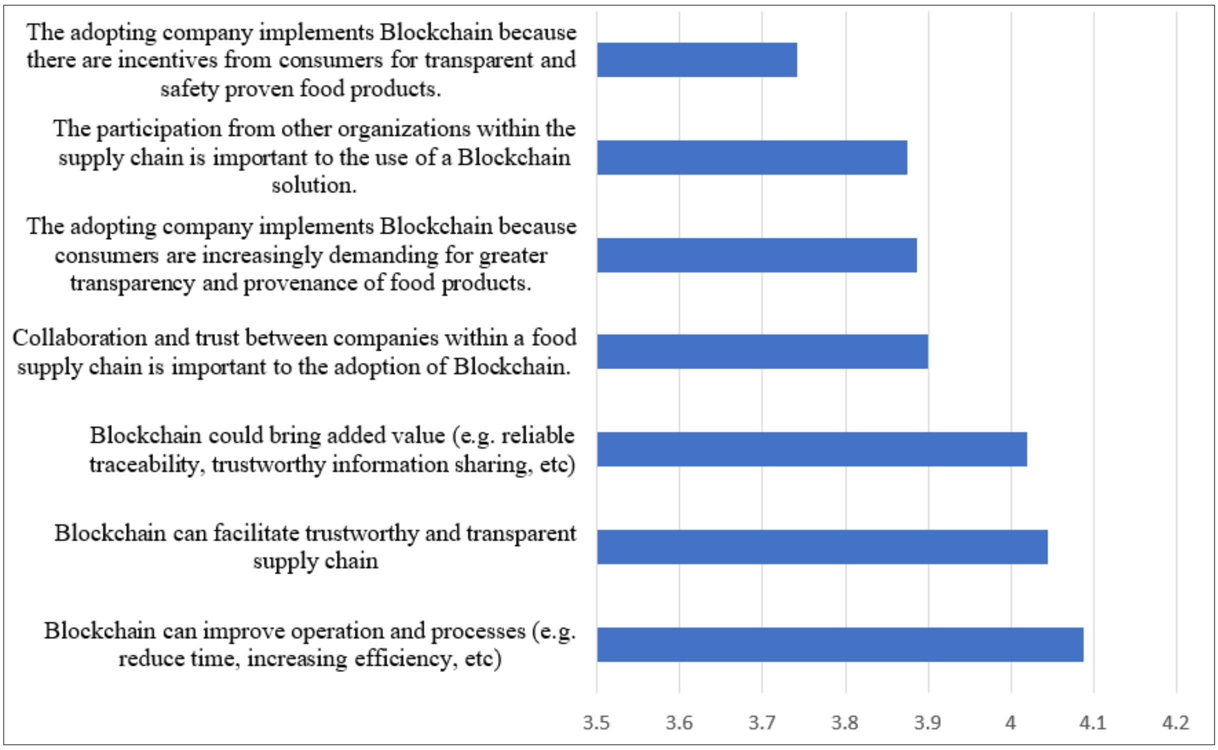

Figure 4-3. Response for potential benefits of Blockchain to operation.

Insights from the survey highlighted the potential changes and impacts of adopting Blockchain in FSCs. Respondents highly rated the potential of Blockchain to bring improvements to the current FSC (via facilitating a more transparent supply chain, reliable traceability, and more trustworthy information sharing), and also strongly agreed that Blockchain can help to improve the speed and the efficiency of processes in FSC. Respondents also firmly believed that the technology needs the full presence and collaboration of stakeholders in a food network for successful adoption. Furthermore, from the respondents' perspectives, there is a recognized drive from consumers for safer and authentic food products, which could potentially lead to an increase in demand for food products, that are verified with Blockchain technology.

Findings from the survey call for attention to an interesting aspect of Blockchain, which is the impact of the technology on the operation and processes of companies in the FSCs (highest score given). When discussing the benefits and usages of Blockchain for agri-food products, the extant literature predominantly emphasizes its use in enhancing the traceability and authenticity processes (Zhao et al., 2019; Danese et al., 2021). Blockchain is hypothesized to enhance, optimize, and streamline processes in the SCM, as highlighted in early works (Cole et al., 2019; Wang et al., 2019), however, the literature has yet to explore this dimension extensively. Since the industry highly rated Blockchain's ability to improve processes and performance – according to the survey results, it strengthened the belief and motivation of the author to investigate further Blockchain's impacts on the operation of the FSCs. Thus, in-depth interviews were planned and conducted.

4.5.2 Findings from the interviews

Three cases of Blockchain usage for FSCs, with a certain degree of success (summarized in Table 4-7), were identified. Whenever possible, the author conducted interviews with different members of the Blockchain system, capturing holistic insights and perspectives. The focus of the semi-structured interviews was on the impacts of Blockchain on the operation and key performance indicators of the FSCs. The protocol for the interviews is presented in Appendix 4.

Table 4-7. Overview of the Blockchain applications and the interviewees.

Participant (P)	Occupation	Organization main function	Experience	Blockchain project case No
P1	Manager	Processing	5 years	1
P2	Manager	Producing raw coffee	7 years	
P3	Team leader/ Product owner	Blockchain service provider	3 years	The blockchain platform is built for tracking juice production from sourcing fruits to the end product. The platform has successfully piloted for a number of products and is projected to go live at the end of 2022.
P4	Co-founder	Blockchain service provider	10+ years	The blockchain solution is developed for tracing palm oil products from the source, and verifying the origin to make sure the fruits are grown sustainably and the sourcing is ethical. The solution is

	successfully adopted and is expanding.

The coffee supply chain for case 1 Blockchain project consists of 4 main stakeholders: individual coffee farmers, Farmer Produce Organizations (FPOs, which represent a group of farmers, aggregate products, and deal with buyers), processors (which buy green bean coffee, roast, package and sell to buyers), and cafes and other retail outlets which are the buyers? and distribute coffee to the end-consumers. The blockchain platform is built for tracking the movement of coffee from bean to cup. The platform has been successfully deployed, and the stakeholders are currently expanding the range of products that are managed with the system. The first three entities are mainly responsible for providing inputs to the Blockchain system, whereas the last one currently just receives the traceability information from upper stream.

The juice supply chain for case 2 Blockchain project consists of 4 main stakeholders: fruit farmers, processors/producers which process raw fruit into concentrate or purée (mixed and blended fruits in liquid form with uniform), bottlers which mix and finalize the end products, and retailers. The blockchain platform is built for tracking juice production from sourcing fruits to the end product. The platform has been successfully piloted for a number of products and is projected to go live at the end of 2022. The first three entities are currently active with the Blockchain platform, and retailers will come onboard at a later stage.

The palm oil supply chain for case 3 Blockchain project connects various stakeholders of that supply chain. In general, the supply chain can be categorized into five main stages: farmers which produce fruits, mills which process fruits into oil, other entities which refine and process the oil further, producers which make food and beauty products using the oil, retailers, and end-consumers. The blockchain solution is developed for tracing palm oil products from the source, and verifying the origin to make sure fruits are grown sustainably and the sourcing is ethical. The solution is successfully adopted and currently onboarding farmers, mills, and producers of palm oil. The future plan of this project is to include final users of the oil (food processing companies, beauty products producers, etc) in the platform.

Inductive coding was utilized to interpret the qualitative data and obtain crucial insights. The author carefully reviewed each transcript, assigned each datum with a code that captures the overall meaning of the datum, and later grouped related codes into an appropriate group. Three main themes emerged from the qualitative data: the overview of the respective FSCs for each Blockchain project, the changes to process and stakeholders' interaction brought by Blockchain, and the impacts on key performance indicators of the FSC. Table 4-8 summarizes the key findings from the interviews.

The interviewees shared that their respective food chains are complex systems that consist of numerous entities and extend over many countries. Broadly, food products go through three critical states of raw materials, processed food products, and finalized food products before reaching the end consumers. Findings from the in-depth interviews further cement the perspectives from the survey results and shed light on the impacts of Blockchain technology. The interviewees echoed the positive effects of Blockchain on the FSC. Acting as a single and reliable source of information, Blockchain technology facilitates effective and extensive communication and data sharing between stakeholders of the FSC. The timeliness, availability, and trustworthiness of data on the Blockchain system further help to improve certain processes such as monitoring and improving food quality, communicating back orders and market-specific requirements up to the upper stream entities, planning, and inventory management. Especially, interviewees expressed that Blockchain, as an engine for traceability, can bring important information to the stakeholders across the food value chain, which was a difficulty previously due to siloed data and the lack of a safe and common channel of communication. Consistent with what the extant literature has found (Danese et al., 2021; Gligor et al., 2022), interviewees highlighted the improvement to the traceability process and the certification of food origin, organic status, and various compliances to safety regulations and sustainability developments, using Blockchain technology. Further, two interviewees strongly acknowledged and experienced an improvement in their inventory level, waste reduction, shorter lead time, and higher service level – details are provided in Table 4-8.

Findings from the interviews helped the author to develop the SD models in later stages in several ways. First, by gaining an understanding of the entities involved in the Blockchain use case and their roles, the author can determine the focus of the model. It is unnecessary to attempt modelling the entire FSC when the Blockchain-enabled changes to operation are most visible at certain echelons of the supply chain. This is indeed to be the case, as the three Blockchain cases in this study were initiated and deployed for upstream stakeholders (such as farmers, processors, and producers of food) at the moment. This allows the modellers to set the focus of the models to where Blockchain impact would be most apparent. Second, insights from the interview help the modellers to pinpoint the processes that are under the influence of Blockchain adoption. Hence, the SD models are constructed to capture and examine the relevant processes. Last, but most importantly, findings from the empirical data described the exact effects of using Blockchain technology, thus enabling the author to reflect such changes in the SD models. For instance, when P1 and P2 described that the orders from their final customers (retailers and end consumers) can now be communicated instantly via the Blockchain platform, it can be inferred that the technology significantly transforms the communication and decision regarding procurement among the stakeholders. By reflecting on this change in process, the SD models can represent the differences brought by Blockchain and examine the behavior of the system with simulation.

Main themes	Insights from interviewees	Notes/ Representative quotes
Overview of the FSCs (cont.)	A common problem across the FSCs is fragmented data and low transparency.	*A vast amount of data in the food supply chain, juice chain included, are in silos, and not used or utilized in any way – P3.* *The supply chain we work with never had this level of transparency before, and there are a lot of concerns regarding the deforestation issue with producing palm oil. With our solution the chain of custody is clear, we can show with confidence where palm comes from and who has it all the way of the process – P4.*
	The flow of products and information, and the basic process of order, production, and fulfillment.	*More details in Section 4.3 – The modelling process.*
Changes to processes and interactions between stakeholders brought by Blockchain	Enhance the fulfillment and planning processes with holistic and real-time information on stocks.	*Our customers inquire us about their purchases, I can immediately check the system and communicate with farmers to check the stocks, it helps us organize and plan better, even in a little more chaotic situation* – P1. *Farmers and FPOs understand not only where they sell to here, but where products ultimately end up, maybe Korea or Japan. That helps with planning for particular markets.* – P2
	Increase the efficiency of procuring with better communication and information availability.	*It helps me personally in procuring coffee, instead of calling 70 farmers a day and visiting many of them, via the platform I know when stocks are coming in, and when stocks are available to pick up* – P1.
	Better quality control process with reliable records of supply and production.	*With buyers sharing back the information with farmers on this platform, together with the farmers we analyze to see what is lacking. It could be that they picked unripened coffee which would turn into black beans – a defect. Then we work with farmers to improve their farming practices and in turn the quality of coffee – P2.*
	Strengthened communication process across the supply chain.	*The Blockchain platform gives entities like processors of the juice a voice, to speak to the end consumers in a safe and controllable environment of Blockchain – P3.*

		The nice thing about Blockchain and the way we implemented it is that it is really easy to spot if somebody is trying to make a fraudulent update, since all the data is there the numbers just do not add up – P4.
	Potential changes can depend on how robust the SCM processes are.	*For us, since there are already strong processes in place and information is required in many steps of product movement, all we do is pick up the information and add it to the Blockchain solution. Our solution does not require people to do anything differently – P4.*
Impacts of Blockchain on operation.	Inventory: Real-time view of inventory. Reduce inventory level by better grasp and monitoring of stocks. Reduce waste.	*I can see and control the movement of inventory in my production, with real-time information. With this platform, we are looking to cut our roasted beans product cycle time by half* – P1. *With a total view of the inventory, we can plan transportation better and constantly move the coffee to reduce waste of sitting inventory. With better quality control we also reduce the waste of unqualified products, with the example of the black bean earlier* – P2.
	Lead time: improvement due to a real-time, reliable, and holistic view of the supply line, and better planning for dispatch.	*With the availability and reliability of data, we can organize fulfillment for buyers faster and more effectively. We have seen huge cut down of lead time, 50 to 60% of what it was* – P2
	Service level: improvement due to more control of the stocks at the upper stream.	*When customers ask if I have something, I can see it on my system, then send a message to everyone (farmers) to get hold of the stocks because we have an offer. Thus I can fulfill the orders reliably, timely, and satisfy my buyers* – P1.
	Cost: Have to consider the cost of investment and incurring costs. Have to consider the return on investment	*We currently charge a one-off fee of a few thousand EUR for companies to join our platform (the exact number is omitted to ensure the company's confidentiality – author note). It is relatively small compared to the cost of production of juice* – P3. *Blockchain platform has an initial investment for development, then the monthly cost of maintenance. For me, it does not increase our production cost significantly, but it is all about opportunity cost. For instance, I can*

	The cost of Blockchain currently is not a significant part of the cost of the products	*choose to buy more coffee or invest in Blockchain. If I don't think Blockchain will work I would rather have more coffee. But I do believe in this technology* – P1.

Table 4-8. Key findings from interviews.

4.5.3 The modelling process

CLD Development

A broad schematic of an FSC is depicted in Figure 4-5. In general, raw materials come from the sources (which could be domestic farms in the case of coffee and palm, or both domestic farm and imports in the case of fruit) to the processor (who is responsible for supplying the raw materials) to the producer/ processor (coffee roaster or juice bottler) to the seller and the final consumers. Even though there are various entities involved in the process, the flow of products is straightforward.

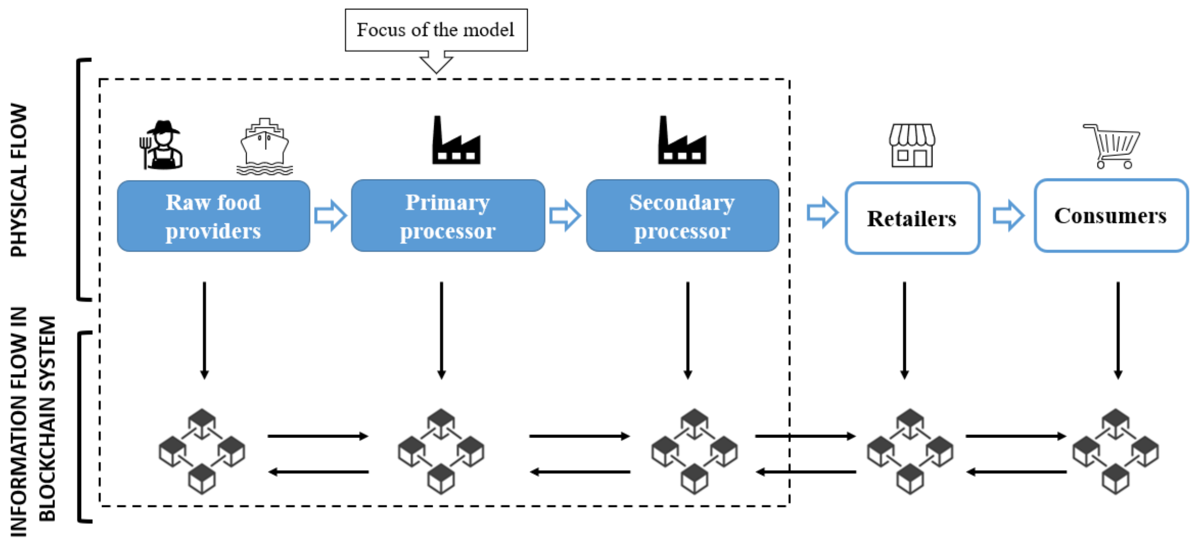

Figure 4-4. A simple schematic of an FSC and the focus of the model.

The focus of the models in this study is on the three echelons of raw food providers, primary processors, and secondary processors. Sterman (2000) recommended using the SD approach to focus on the issue at hand, rather than trying to replicate the exact structure of the whole system. By utilizing the SD model in this manner, the modelers can direct their time and efforts into solving the actual problem/ understanding interesting phenomena, rather than a simple recreation of reality in SD terminologies and notations. Moreover, the choice of the model's boundary takes into consideration of the empirical findings. From the interview insight, the technology was initiated and is currently widely used among the up stream entities, from producing raw material to making finished food products. Downstream stakeholders such as the retailers and end-consumers, are at the receiving ends of the information provided by the Blockchain platforms and are not actively interacting with said platforms. Hence, the material provider and processors are experiencing the most changes to their processes, interactions, and operations when adopting Blockchain. The boundary of the modelling process, thus, is set accordingly.

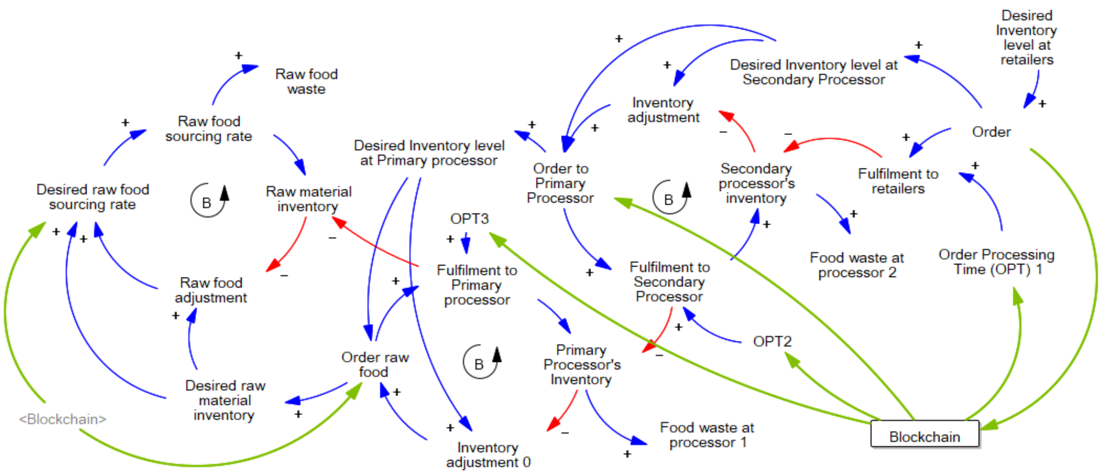

Figure 4-5. A CLD of the impacts of Blockchain on an FSC.

Figure 4-6 presents the CLD that describes the processes of purchasing, processing, storing, and selling food products for raw food providers, primary, and secondary processors in a food system. These particular processes were chosen to include in the CLD according to the empirical findings, as interviewees highlighted that these processes will experience changes under the use of Blockchain. The CLD conceptualizes the key components for those processes in the studied system and represents the relationships and feedback structures between these components. Each arrow depicts a causal link between two components. The positive or negative notation associated with one arrow indicates a positive (an increase in one element causes an increase in the related element) or negative relationship (an increase in one element causes a decrease in the related element).

The process starts with the retailers placing an order to maintain a certain level of inventory to meet the demand and achieve a defined service level. The secondary processors process and ship their finished products to the retailers. The secondary processors also want to keep a desired level of inventory, therefore they replenish by placing an order to the primary processors, after calculating the adjustments needed for their desired inventory. This typical process will be repeated for other upstream echelons. Important balancing loops in the system are denoted in Figure 4-6 (with letter B and counterclockwise arrow). These balancing loops imply how each entity manages their inventory to sufficiently fulfill the demand from the immediate buyer as well as to keep the stocks at the desired level. Further, food waste can occur at each echelon, which reduces the available inventory at each SC node.

Findings from the interviews further help to assess the impact of Blockchain on these processes. According to the interviewees, the effect of Blockchain is most apparent in how each company handles and processes the orders, in terms of both sharing information of demand and replenishment cycle among the FSC partners and the time it takes to procure food products for production and fulfillment. For each order received, a company must spend time communicating with their supply bases, procuring the necessary ingredients, and gathering stocks or processing food, to fulfill their customer's demand. Blockchain can improve this process by connecting all stakeholders and providing real-time, reliable, and holistic data on a united platform. For instance, P1 and P2 highlighted that the Blockchain platform allows them to always be aware of available raw products from farmers (upstream entities) and can effectively source, organize, and produce for the cafes and other retailers (downstream entities) in time. Insights from Blockchain cases 1 and 2 further indicate that holistic and trustworthy information stored on Blockchain can inform all parties of the downstream demand and need for production at each node, leading to better organizing and planning to match production closer with demand. In general, Blockchain does not alter the flow of products significantly, as it mainly serves as an additional support layer (for gathering, storing, and communicating data between food actors securely) to the existing infrastructure (Li et al., 2021).

SFDs development

The next step is to develop stock-and-flow diagrams (SFD) from the previously designed CLD, as the basis for running simulations to evaluate the changes to the system brought about by Blockchain adoption. Subsequently, two SFDs were constructed to represent the conventional scenario and the Blockchain case scenario (BC case), as shown in Figures 4-7 and 4-8. The variables' values and formulas for the base case are presented in Appendix 5. The parameters and equations for the SFDs were determined based on the empirical data given by the interviewees, secondary sources (literature and industry reports), and several logical assumptions (due to the lack of available data on Blockchain impacts in the FSC and to companies unable to disclose certain confidential information of their operation).

Similar to the CLD presented in the last section, the process initiates when an *Order from customers* is logged in the system. At the secondary processor, finished products are shipped to the customers, measured by the *Order Fulfillment 1* rate, and thus, the inventory level at *Finished Products for shipping* is lowered. *Finished Products for shipping* represents the amount of goods that the secondary processor has ready on hand for fulfilling customers' orders. Since the inventory level is now reduced, the manufacturing of food is now triggered to generate fresh inventory to achieve a *Desired Finished Products level.* The *Desired Work In Process 1* (WIP) is also set to determine the quantity of semi-finished products that the secondary processor needs, to meet the target production. The company also needs to take into account *Order Processing Time 1* and *Manufacturing Time 1* when planning their production, as these two factors serve as a delay to the process and the *WIP Inventory 1* needs to be adjusted accordingly to make sure the *Finished Products* rate (output rate of the production) are adequate to replenish the finished food products inventory to the desired level. The difference between the current level of *WIP Inventory 1* and the desired state (*Desired Work In Process 1)* is reflected by the *WIP Adjustment 1* variable, implying the act of monitoring and adjusting materials for production at the secondary processor echelon. *Spoilage Rate 1* simultaneously occurs, due to the perishability and quality control of food products. In the end, the secondary processor evaluates their need and put in a *Secondary Processor Order*, which comprises the amount needed for producing and meeting the customer's order, the stock loss due to spoilage, and any adjustment to their WIP inventory.

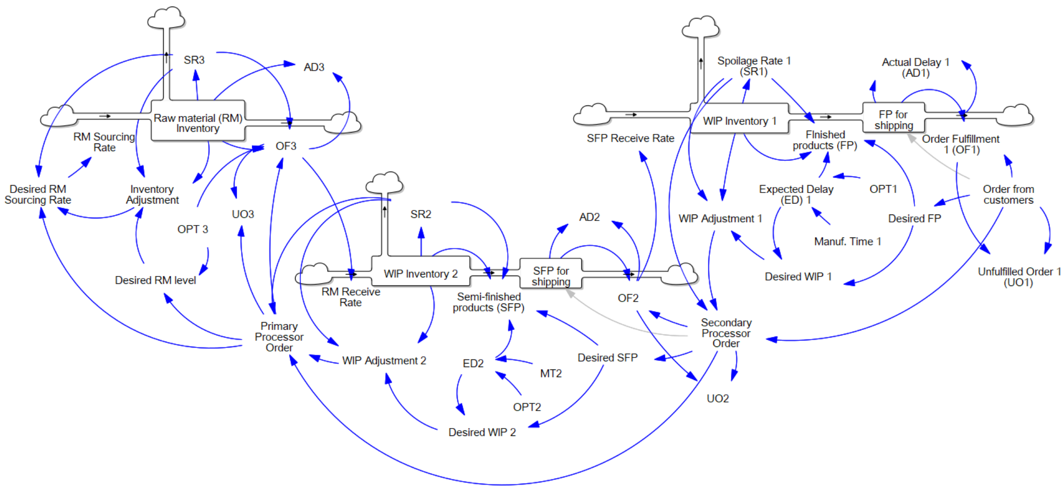

Figure 4-6. SFD for a conventional FSC.

The same processes are followed by the primary processor when they receive an order from the secondary processor, and subsequently, they will place an order to the raw food providers, with a sufficient amount of raw products to cover the desired inventory and incoming orders. The last echelon, the raw food provider, does not have any processing/manufacturing capacity, as their main task is to produce and or collect raw food and sell it to the primary processor. Subsequently, the following assumptions were made for modelling a conventional food supply chain, and subsequently the BC-integrated FSC:

- There are no backorders for food manufacturers (the primary and secondary processors in this case). In the FSC, unavailable food products often result in lost sales due to consumers easily finding and buying substitutes, thus SD modelling works for the food system typically does not include the backorder variable (For example see Kumar and Nigmatullin (2011) and Stave and Kopainsky (2015)).

- Orders are shipped immediately when products are available in stock.
- The production orders are assumed to be unconstrained by capacity and/or workforce. This helps to reduce the complexity of the model (Kochan et al., 2017).
- The raw material-to-semi-finished product ratio is assumed to be 1. This is not always the case for the food industry, for instance, coffee beans can retain the 1:1 ratio from raw materials to processed products but fruits typically will need a different ratio of conversion as a number of fruits are needed to make a unit of fruit concentration. The assumption is made to simplify the model and is inconsequential to the system behaviors.

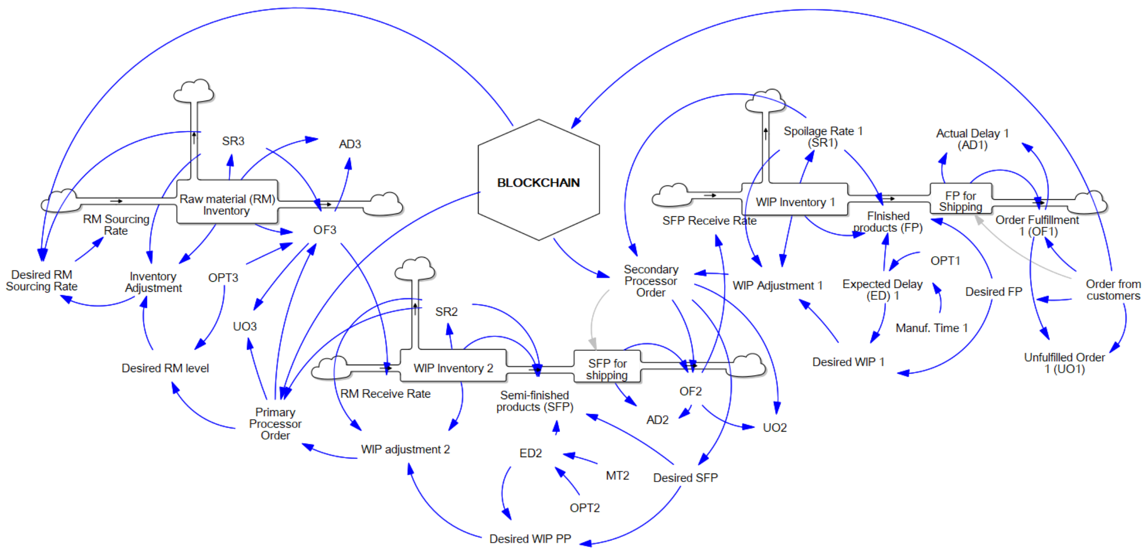

Figure 4-7. SFD for a Blockchain-integrated FSC.

In the BC case scenario, the same processes are followed at all echelons captured in the model. Two major differences, however, are presented. First, the information about the order from the downstream customer is now recorded and shared via the Blockchain platform. Thus the primary processor and the raw food provider now have better visibility of the demand and can plan their acquisition of stocks accordingly to the ultimate order. Adjustments of inventory needed for production are still captured in the orders put forward from one echelon to the next. Second, according to the empirical findings, the *Order Processing Time* will see improvements due to the reliable data-sharing capability of the Blockchain platform, and this change will be represented in the inputs for simulating the two scenarios in the next section.

4.5.4 Simulation results

4.5.4.1 Sensitivity analysis of the models

Before simulating the scenarios for comparison, sensitivity checks are performed to test the robustness of the developed models. Sensitivity analysis is necessary to check if the model behaves in a realistic fashion regardless of how extreme the inputs or policies imposed on it might be (Sterman, 2000). Two hypothetical scenarios are proposed to evaluate the models' behaviors, as explained in Table 4-9.

Table 4-8. Sensitivity analysis scenarios.

Aims and settings	**Scenario 1**	**Scenario 2**
Purpose	To evaluate if the models can achieve equilibrium states under the condition of stable demand over a period of time.	To evaluate if the models can behave realistically under an extreme condition of a sudden surge in order, that depletes the stocks completely.
Parameters for initializing the models	Order from customers (OFC) = 10,000. The rate of order is fixed over the simulation period.	OFC =10000 + STEP(X, 20) Whereas X = Finished Products for shipping at t_{20}

The first scenario is simulated with a demonstrative value of demand (10,000 units per week). Figure 4-9 presents the inventory levels at all three echelons. In the beginning, there is a warm-up period when the companies are adjusting their initial level of inventory to accommodate the demand. The models were simulated for 500 weeks. After a short period of 12 weeks, each entity can align its stock holding level with the upcoming order. Since the demand stays constant at all times, companies can stabilize their operation and there is no need for inventory adjustment. In another word, when demand is constant, companies always know the order amount, the required inventory, and the corresponding level of production to meet such demand, thus no oscillations can occur in the supply chain.

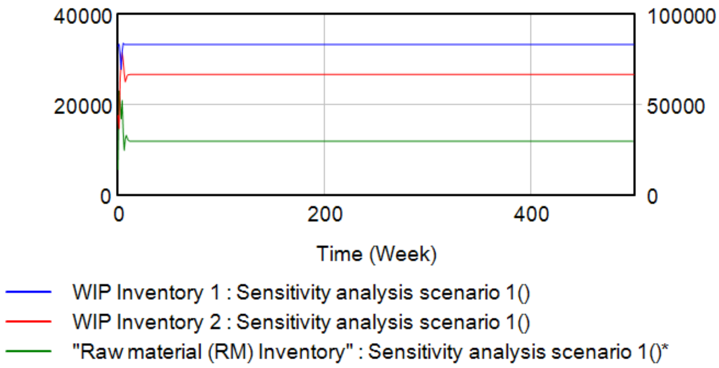

Figure 4-8. Inventory level at three echelons in sensitivity analysis scenario 1. (Note: the raw material inventory scale is on the right-hand side)

In the next scenario, a sudden surge in the order amount is introduced in week 20. In this scenario, all echelons are allowed the same warm-up period to adjust to the constant demand of 10,000 units per week, and in week 20 an increase of another 10,000 is put forward by the end customer. How the system reacts to this sudden surge of demand is uncovered by examining the order and fulfillment process, and the inventory level. As presented in Figure 4-10, when the demand starts to increase, the companies cannot immediately increase their shipment rate due to system inertia – that is it takes time for one entity to ramp up their production to meet the demand. Thus the rate of fulfillment lags behind and unfulfilled order increases. The unfulfilled orders are the lost sales for each echelon. Over time, as companies start to accumulate sufficient stocks for the new demand, the rate of supplying orders starts to rise and meet the order rate. Figure 4-10 presents the occurrence regarding orders and fulfillment at echelons 1 and 2. Similar behavior occurs at the raw food producer node.

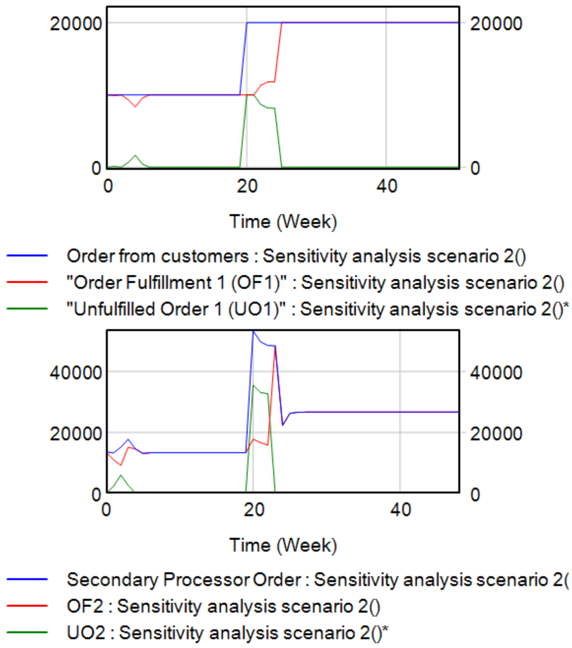

Figure 4-9. Order, order fulfillment, and unfulfilled orders in Scenario 2.

As showed in Figure 4-11, the inventory level at three echelons over the same period starts to rise significantly to first accommodate a surge in demand for processed products, then they start to seek a new equilibrium as the new demand remains. Overall, the models showcase the ability to generate realistic behaviors of the entities of an FSC.

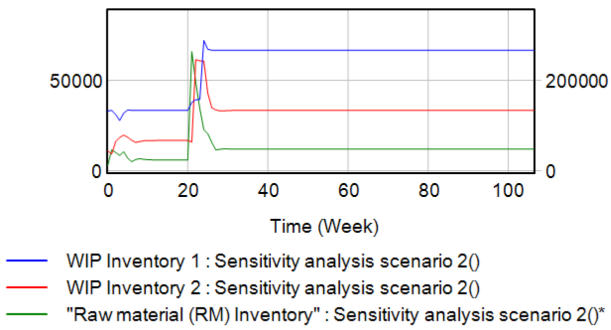

Figure 4-10. Inventory level at three echelons in Scenario 2. (Note: the scale of the raw material inventory is on the right-hand side)

4.5.4.2 Simulation and interpretation of results

After the robustness of the models is assessed and validated, the two SFDs for a conventional FSC and a Blockchain-integrated FSC are simulated. A condition of uncertain demand from downstream customers is set for both scenarios, as this is a common approach in SD modelling to resemble the supply chain system (Kochan et al., 2017; Kara et al., 2020). Key inputs and parameters for simulating the models are presented in Table 4-10. Findings from empirical data and secondary sources such as industry articles and reports are utilized to set up the demonstrative values for the simulations and associated assumptions when choosing such values, as explained in Table 4-10.

Table 4-9. Parameters for SD models.

Parameters/ Inputs	Conventional	BC case	Justifications
Order from customers	Normal distribution with μ = 10,000 items and σ = 5000		
Order processing time (OPT) 1, 2, 3	2 weeks	1 week	P1 and P2 reported a 50% decrease in their processing order time due to holistic information of stock availability.
Manufacturing time (MT) 1	1 week	1 week	In Blockchain case 1, the processing time for semi-finished products (dry coffee bean) is twice the time for finished products (roasted beans in packages).
MT2	2 weeks	2 weeks	
Spoilage Rate (SR) 1	10%	7%	FAO (2011) estimated that 9% and 25% of food are wasted as raw products at post-harvest and processed foods at manufacturers, respectively. Further, recent industry publications such as Hegnholt et al., (2018) and Birch (2022) estimated that solutions such as Blockchain can reduce food waste by 30 to 50%. Therefore, we made the assumptions for SR in the conventional case and the BC case accordingly.
SR2	20%	14%	
SR3	20%	14%	

To evaluate the impacts of Blockchain adoption in the FSC, four supply chain performance metrics, namely inventory level, service level, lead time, and operation cost, are used to compare the system behavior of the FSC in both cases. These metrics are utilized in other SD studies of the SC in the past (Kochan et al., 2017; Kara et al., 2020), and further these metrics are relevant to evaluate the efficiency, flexibility, and responsiveness of an FSC (Aramyan et al., 2006).

Inventory level

Figure 4-12 reports the inventory level at each echelon after simulations, with WIP Inventory 1, WIP Inventory 2, Raw material Inventory belonging to the secondary processor, primary processor, and raw food provider echelon respectively. In the first scenario, it is observed that the bullwhip effect occurs in the conventional FSC. Variation in demand leads to oscillation in WIP Inventory 1, as the entity is trying to keep the inventory level at a reasonable level, while still fulfilling the demand from the end consumer. Oscillation gets amplified throughout the supply line, leading to WIP Inventory 2 and Raw material Inventory to fluctuate at a greater rate. It is further observed that with the introduction of Blockchain, inventory level at each echelon is reduced, and the fluctuations are much more dampened. These are the results of Blockchain providing timely and accurate information, leading each actor in the supply chain to possess comprehensive information on the other entity’s demand and inventory level, allowing for a more proactive approach to meet highly fluctuating demand. Instead of information sitting in a silo at each echelon, companies now are well aware of the end customers' demand and the changes in the preceding entity’s inventory, enabling them to align their supply rate to the exact demand and thus maintain an optimal level of inventory.

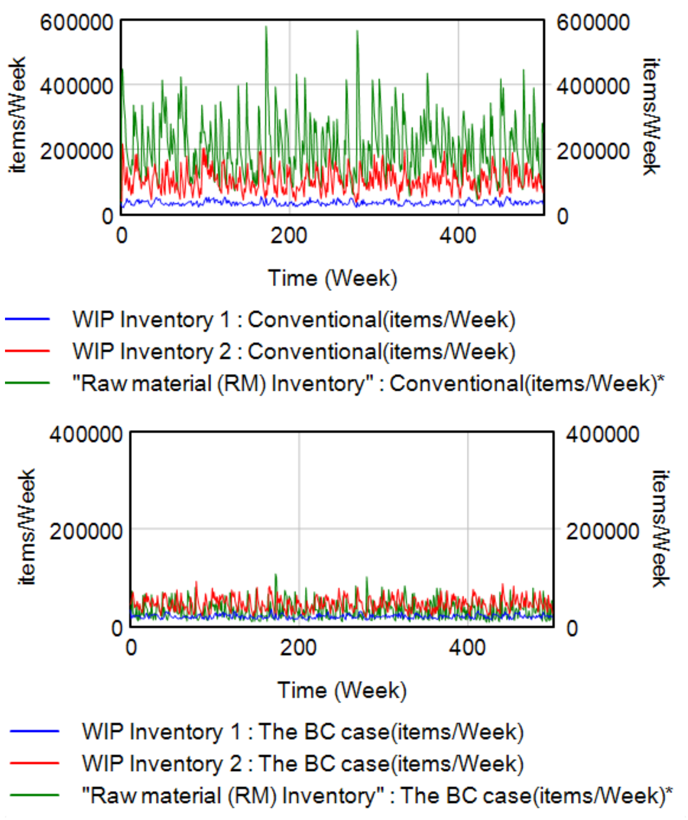

Figure 4-11. Inventory level for both scenarios.

Service level

Any time available inventory cannot fulfill an order, Unfulfilled Order (UO) rises to reflect the number of products that a company fails to supply to their customer. Since there is no backlog order for this particular supply chain, one entity then missed that opportunity for sales and does not meet the demand of the customers. Thus, UO can also indicate the service level of each echelon (Kumar and Nigmatullin, 2011). Kumar and Nigmatullin (2011) referred to this as a stockout situation and suggested that it is an important metric for measuring the performance of an FSC. Figure 4-13 presents and compares the UO of each echelon across the two scenarios. In terms of an absolute value, it can be observed that there is an improvement in the BC case, as the worst possible loss of sales for each of the echelons in the conventional case is considerably higher than the equivalent in the BC case.

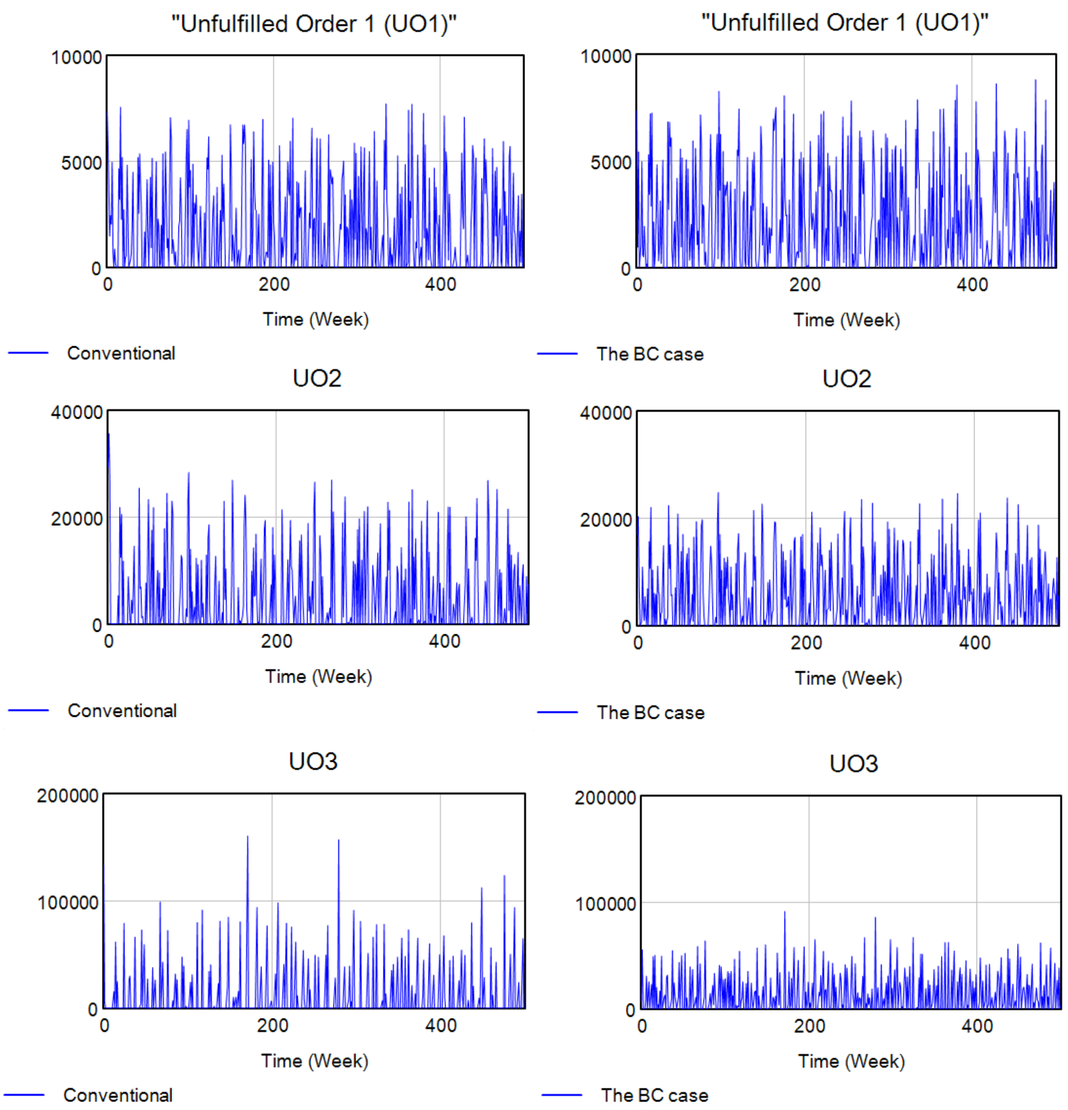

Figure 4-12. Cross-scenario comparison of unfulfilled orders in three echelons.

This is particularly evidenced at the raw food provider echelon. This can be attributed to the ability to align the operation at each echelon more closely with the other, driven by the visibility brought by Blockchain technology. However, the graphs indicate that the occurrence of lost sales for the BC case happens more frequently than for the conventional case. The reason for this behavior is that when companies in the BC case are intensely reducing their inventory level and matching their production levels with incoming orders, the amount of buffer inventory is consequently lower than in the conventional case. Thus, in a particularly turbulent condition such as the one set up for the simulations (demand varies on a weekly basis), a sudden increase in order next week could be troublesome for an echelon if they just adjusted their inventory level and intake rate based on a considerably lower level of order this week.

Lead time

Lead time, the latency between the point of food products entering one echelon to the point of moving to the next echelon, is another critical indicator of an FSC performance (Aramyan et al., 2006). Under the SD perspective, lead time serves as a delay that can generate system inertia, leading to fluctuations in inventory levels (Kumar and Nigmatullin, 2011).

Table 4-10. Actual delay in product movement.

	Conventional		**BC case**		**T-test results**		
	Avg	STDev	Avg	STDev	Df	t-stat.	P value
AD1	1.13	0.262	1.10	0.226	1000	1.87	0.06
AD2	2.85	21.27	1.75	6.31	1000	1.11	0.10
AD3	10.9	78	2.72	8.15	1000	2.34	0.009

N = 500, t-test assuming equal variances, $H_0 : \mu_1 = \mu_2$.

For the SD models designed in this study, the total lead time of the system consists of the expected delay, which is known and controlled by the companies (such as the manufacturing time and order processing time), and the Actual Delay (AD), which measures how quickly products (raw materials, semi-finished food products, or food products depend on the echelon) are to be moved to the next echelon. Table 4-11 presents the simulation results of the AD of all echelons in the two scenarios. If a company has more products in their storage (indicated by the inventory for shipping stock variables in the models) than the immediate order, the products remain on hold until the next order comes, thus delaying other operational activities. AD is introduced in the model to measure the change in actual delivery time and can be measured by the ratio of the rate of actual shipment to the next entity over the available read-for-shipping products (Sterman, 2000).

As shown in Table 4-11, the average delay for all echelons in the BC case is much improved compared to the conventional case. Further, a t-test analysis was conducted to see if there is a significant difference in delay between the two scenarios. The results summarized in Table 4-11 indicate that there is a significant difference in the AD3 values in both cases, with a confidence level of 99%. The differences in the AD1 and AD2 values in the two scenarios are much less pronounced, as the confidence level is 90%. Similar to the comparison of inventory level, raw material provider is conventionally more prone to variation in downstream demand due to inherently being the furthest away from where the initial order occurs. Thus, with the introduction of Blockchain and real-time and reliable information sharing, this echelon shows the key benefits in terms of inventory management. This subsequently leads to better planning of shipment and reduces significantly the delay and lead time for the raw material provider. By comparing the average and the standard deviation of the AD value for the primary and secondary processors between the two scenarios, it can be observed that improvements are also recognized in those two echelons.

Operations Cost

The operations cost for the two scenarios is evaluated to uncover the potential impacts of Blockchain on the cost of FSC operations. In this case, the operation cost of the FSC consists of the inventory holding cost, manufacturing cost, and delivery cost. The cost of labour is not included in the model. For better clarity of the models' figures, the cost element was not portrayed in the general depictions of the SFDs in Figures 4-8 and 4-9. The detailed calculation and modelling of the cost of the operation are presented in Appendix 6. The input and parameters, with their setups, for simulating the cost of the two scenarios are explained in Table 4-12. It started with the assumption that the total price of one unit is $10. This is a demonstrative value and it is used to create the basis for comparison between the conventional and the Blockchain-integrated FSC scenario. This study primarily focussed on evaluating the behavior of the system under the influence of Blockchain technology, thus using a demonstrative value for the unit cost is an appropriate approach when unit cost is expected to vary for different food products. The same approach has been utilized in other SD studies such as Kara et al. (2020). The assumptions regarding the cost of Blockchain were made based on Gopalakrishnan et al. (2020) and an estimation tool for Blockchain development price (Leewayhertz, 2022). According to these sources, the cost of integrating Blockchain into an existing platform could be broken down to a development cost from $ 102,900 to $161,700 in an estimated time of 30 weeks, and a maintenance cost from $11,172 to $12,348 per year. These figures are consistent with the insights shared by P1, as the company was quoted approximately $100,000 for the development of the Blockchain solution and two to three hundred dollars per month for maintenance. Therefore, to illustrate a generic cost of a Blockchain solution, a development cost of $150,000 and a recurring cost of $250 per week ($12,500 per 50-week year) are used in the setup.

Table 4-11. Inputs and parameters used in estimating operation cost for the models.

Variable	**Value/Formulas**	**Comment**
Inventory holding cost per unit	= Unit cost * 0.4%	Inventory holding cost is estimated to be 20% of the unit cost per annum, thus it is 0.4% per week assuming there are 50 working weeks per year. The unit cost is assumed to be $0.5 per unit.
Delivery cost per unit	= Unit cost * 0.5%	The percentage is adapted from Kara et al. (2020).
Manufacturing cost per unit	= Unit cost * 50%	
Blockchain development cost	$150,000 one-time cost	Explained in a prior discussion.
Blockchain maintenance cost	$250 per week	
Cost accumulation rate	= Inventory holding cost + Delivery cost + manufacturing cost *for the conventional case*	

	= Inventory holding cost + Delivery cost + manufacturing cost + Blockchain implementation cost + Blockchain maintenance *for the BC case*

The simulation results of the two scenarios (Figure 4-14) indicate that over the long run, the Blockchain solution can save operation cost for company. This can be mainly attributed to the ability to reduce inventory and better alignment of supply and demand for all echelons in the FSC, under the effects of Blockchain technology.

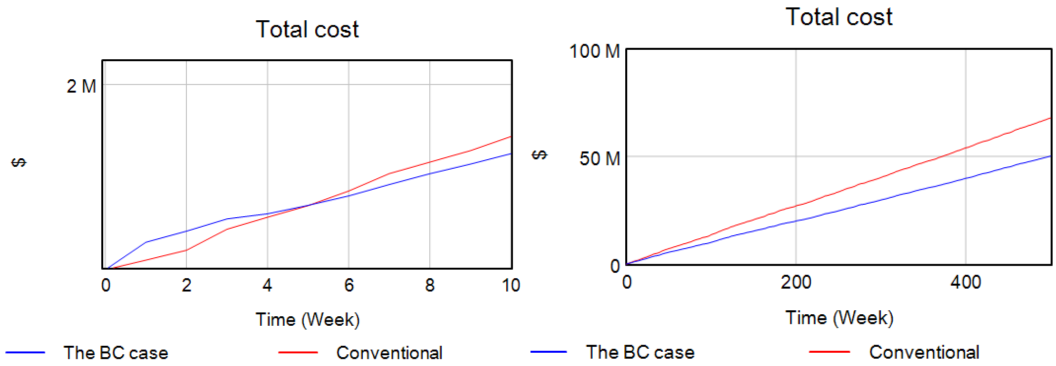

Figure 4-13. Simulation results of the cost in both scenarios in 10 weeks and 500 weeks.

Since the cost of Blockchain development spikes the operations cost in the beginning, a closer examination of the simulation results is provided in Figure 4-14. As can be seen, at the beginning the cost of the BC case far exceeds the same for the conventional case due to the high implementation cost associated with technology. However, the difference is quickly offset due to the savings generated from lower inventory, manufacturing, and delivery costs.

4.5.5 Modelling the impact of a successful Blockchain adoption

From the simulation results presented in Section 4.5, insightful observations can be made regarding the impacts of Blockchain on the performance of the FSC when comparing the results of the two scenarios. First, the inventory holding level of the raw food provider, along with the primary, and secondary processors see a considerable improvement in terms of lowering the inventory. This finding came as little surprise to the author of the study, since early on during the interview P1 expressed specifically that “*we currently have a 15 days cycle of roasted beans at our cafes. It is fresh, but with the help of Blockchain and the data we gather with the platform, we look to cut it down by half in the future*”. The value of having a united and trustworthy platform for information sharing – like Blockchain – can significantly help businesses to gather holistic information regarding food products, quality, and material availability at every node of the FSC, leading to better planning and arrangement of supply, shipment, and production and thus reducing the required stocks.

Furthermore, the simulation results indicate that adopting Blockchain can help reduce the lead time of food products moving through the FSC network. Even though lead time at the raw food provider experiences the most recognizable improvement, the overall lead time of food moving through the three SC echelons is also considerably shortened. When businesses are more synchronized and have greater visibility of the supply line, activities become more seamless and efficient, thus aiding the speed of processing products in each echelon and decreasing the overall lead time. P2 shared that with the frequent information sharing and interaction provided by the Blockchain platform, their entity has seen a drop of as much as 50 to 60 percent in the lead time.

The impact of adopting Blockchain on inventory level and lead time is more apparent toward the upper stream of the FSC, with the raw food provider experiencing the greatest reduction in those two parameters. This creates an interesting situation for Blockchain adoption in the FSC, as currently, large enterprises downstream are leading the exploration of Blockchain and onboarding other stakeholders (for example P3 shared that two major fruit processors are responsible for starting the project and their suppliers are added through the processors’ networking). Therefore, for possible large-scale adoption of Blockchain in the FSC, collaboration and long-term partnership remain the key, since the benefits of Blockchain might not be realized immediately by the adopters of the technology and companies must continue working together toward improvements at the supply chain level. Nevertheless, it must be noted that other advantages of adopting Blockchain such as the reduction of frauds and enhancement of reputation are not quantified and captured in the models, for which it is anticipated that downstream stakeholders of the FSC are the most beneficiaries.

Findings regarding the service level were also surprising, as it was anticipated that the service level of FSC would be greatly improved under the influence of Blockchain. As indicated by the simulation results, when matching the inventory and production level strictly with the final demand of downstream entities, there is a risk of forgoing buffer inventory and therefore companies might experience stockout situations often under volatile demand. However, understanding this risk to the service level can be of importance for businesses when adopting Blockchain. Adopters can consider using additional measures such as setting a certain level of safety stocks for buffering production during volatile demand, combined with matching operation and production closely with the demand information shared by the Blockchain platform, to strike an effective and optimal balance of stock holding level.

Finally, the simulation results suggest that Blockchain can help save operations cost in the FSC. It should be noted that the time for cost saving from adopting Blockchain technology to overtake the initial investment can largely depend on the scale of production. As the hypothesized scenarios run in this study imply a considerably large-scale production of food products (being able to supply 10,000 units per week), other cases of FSC with lower outputs can take much longer (compared to the simulation results) to rip the benefits of Blockchain adoption in terms of cost saving. This is a critical factor for consideration.

4.6 Conclusion

There are two primary parts of this study. The first part is a quantitative evaluation of the Blockchain implementation constructs, and the second one is an assessment of the Blockchain's impact on FSC operational performance. The underpinning theoretical lenses used in this study were IA, system thinking, and SD modelling. The former is appropriate for studying different relationships between the main variables of a new technology's integration, while the latter two advocate viewing the phenomenon of Blockchain adoption in FSC from a holistic perspective and evaluating the long-term the of the technology on the food network.

In the first part of the study, a research model was developed based on relevant literature and key findings of the quantitative study (Chapter 3). Subsequently, 159 survey responses were collected and analysed. The results indicated that the three phases of implementation (Initiation – Adoption – Implementation) were positively related to each other, with one stage playing an important role in shifting to the following ones. Further analysis showed that the relative advantages of Blockchain are enablers of the Adoption phase, while complexity can hinder the adoption decision. Compatibility is viewed as the most important factor for facilitating a successful implementation stage. Finally, influence from other organizations was found to be negatively related to the Initiation phase, signaling that companies are pushing toward being the first to adopt Blockchain instead of reacting to competitors' or partners' actions.

The second part of the study was conducted in three phases: gathering empirical data regarding the impact of Blockchain on the operations of entities in the FSC, modelling a conventional FSC and a Blockchain-integrated FSC scenario, and simulating and interpreting the results. The final outcome of the simulation indicates the expected improvement in inventory level, lead time, and operational cost for companies when adopting Blockchain. Service level, surprisingly, can be affected when matching the inventory too closely with demand, especially under volatile demand situations.

From the results of this study, several implications for theory, policy, and practice can be derived.

4.6.1 Implications to theory, policy, and practice

This study's contributions to the literature are three-fold. First, this study contributes to the research in the field of Blockchain adoption in the FSCM domain. The findings in the Quantitative study and the quantitative assessment part of this study together form a mixed-method investigation of the Blockchain implementation in the FSC. Thus, a holistic model of integrating Blockchain for organizations in the FSC is provided, with three main stages of adoption, detailed activities, four clusters of determinants, and a precise analysis of the most important factors in each of the adoption stages. This finding answered the call of studies such as Wang et al (2019), which suggested extensively studying the adoption phenomenon of Blockchain under the same lenses and approaches for investigating past IT innovations.

Further, the simulation part of this study provides additional and in-depth insights into the behaviours of a food system under the influence of Blockchain technology. While the extant literature has highlighted certain benefits of using the technology such as establishing total transparency, enhancing traceability, and combatting food frauds (Danese et al., 2021, Gligor et al., 2021; Rana et al., 2021), a critical aspect of using Blockchain to improve operational processes are mentioned but yet fully examined. Our study is believed to fill the gap in the literature, building towards a more comprehensive understanding of Blockchain technology in an FSC setting. By quantifying and examining the impact of Blockchain adoption on key performance indicators of an FSC, this study's results showcased in detail how Blockchain can facilitate improvements to information sharing, inventory management, lead time, and operations cost. Second, our study provides SD models of a food system, specifying the interplays between Blockchain technology and critical processes such as inventory management, procurement, fulfillment planning, etc. The models not only help to shed light on the impact of the technology on the operation of an FSC, but also contribute a holistic platform to investigate the Blockchain phenomenon in the future, under the lens of a system thinking approach.

Third, this study proposed system thinking and SD modellings as an effective approach to investigate the effects of interventions on the SCM. Our study focused on a particular topic of Blockchain adoption in the FSC, however, we believe our approach can pave the way for future research to employ the SD approach to examine how interventions (such as other novel technologies or new policies) can create changes to the behaviours of a supply chain system, thus evaluating the impact on such supply chain (such as performance).

Based on the findings of this study, several business implications are offered to managers in the field. First, businesses in the FSC can understand the critical factors of each of the Blockchain implementation stages and the importance of each stage in facilitating the next one. This would help managers to better plan for their Blockchain projects, foreseeing possible obstacles and promoting drivers for success. Second, the simulation results can inform managers of the benefits of Blockchain to key performance metrics of the FSC. Findings from simulations indicated that companies can better manage inventory, reduce lead time, and save cost thanks to the trustworthiness and timeliness of information sharing through Blockchain. These insights validate what has been suggested by the extant literature (Zhao et al., 2019; Ahmad et al., 2021). The results can further inform managers about the benefits and risks associated with adopting Blockchain. Third, the simulations indicated that Blockchain can bring considerable improvement to the FSC as a whole, whilst some entities might enjoy greater operational benefits from Blockchain than others. Therefore, this study advocates for stronger collaboration and togetherness between stakeholders of the FSC when adopting Blockchain to ultimately bring benefits to the end consumers. Finally, managers in the field can adapt and apply the models built in this study to their specific business environment to evaluate the specific impact of Blockchain on their business and operation.

Moreover, this study can be useful for food regulators, especially when several regulatory bodies are looking at promoting Blockchain as an effective means for tracking food movements and monitoring food safety. The models and the simulation results of this study suggest that multiple echelons of the FSC need to collaborate closely to reap the most benefits from Blockchain technology. Thus, regulatory agencies can play an important role in connecting businesses and fostering consortiums for effective Blockchain adoption. Further, as the impact of Blockchain on the operation is most visible to upstream entities who are typically not technically savvy (farmers, fishermen, etc), regulators can communicate the operational benefits of using Blockchain technology (as evidenced by the results of this study) to such entities and direct sufficient efforts to bring them to the Blockchain platform, realizing improvements to the whole FSC.

4.6.2 Limitations and future research directions

This study has a few limitations. As the study is grounded strictly in the context of FSC, generalization of the results to other settings must be done with care. Further, as Blockchain is still a developing technology in the field of FSCM, some respondents' understanding of Blockchain could be insufficient. Further, the developed SD models only considered a three-echelon FSC network (raw material provider, primary, and secondary processor) because the model designing process was strongly guided by the empirical findings from the three Blockchain use cases. Second, when constructing the SD models, we needed to make reasonable assumptions. Under different circumstances, these assumptions need to be revised and used with care to ensure the accuracy and robustness of the models. Third, due to the lack of an established approach to model Blockchain technology in the SCM setting, we had to rely on empirical data to design our models, and in some cases, primary data is absent due to participants not being willing to reveal critical operational information. Moreover, as the study is set to examine a very specific context of FSC, findings are difficult to generalize.

We recommend several future research directions to continue expanding and strengthening our findings. First, our SD models can be expanded to include other SC nodes/echelons (e.g., distributor, retailer, etc.). In the future with greater development and wider use of Blockchain, researchers can advance our models with data regarding operations and interactions of retailers and possibly customers. Second, the results of this work (both the implementation part and the SD simulation part) can be adapted to investigate the impact of Blockchain in other SCM settings, such as manufacturing or pharmaceutical supply chains. Finally, in-depth case studies or longitudinal studies can be conducted to validate the implementation model of Blockchain, and/or to gather specific primary data on a supply chain for improving the SD models proposed in this study.

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5 CONCLUSION

There are four sections in this final Chapter of the thesis. Section 5.1 summarizes each of the studies of the thesis, then highlights how a study contributes to answering the overarching research aim. This section also demonstrates the connection between all studies, and how together they organize a coherent research inquiry about the phenomenon of interest. Section 5.2 provides the theoretical contributions of the thesis to knowledge. Section 5.3 articulates how the thesis' findings can be useful for practitioners and policymakers. Section 5.4 discussed the limitation of the thesis, and future research direction. Lastly, a concluding remark on the thesis was provided.

5.1 Review of findings and objectives

In this section, a review of the findings from all the studies, and how they accomplished the set objectives (and consequently the research aims), is presented.

By selecting and analyzing 69 papers about the topic of interest, the Literature review study (Chapter 2) uncovered the most current understanding of Blockchain implementation and its impact in the specific setting of the FSC. the Literature review study followed the SLR method, which provides a scientific, replication, and transparent approach to select pertinent studies, synthesize critical knowledge, and minimize bias. Important themes from the extant literature were determined from a thematic analysis of the selected studies. Specifically, the four themes of the present understanding of the implementation process of Blockchain for companies in the food industry, drivers and barriers to Blockchain adoption, and the applications of Blockchain in the FSC, emerged from 69 relevant peer-reviewed papers. Important insights regarding how Blockchain can influence the operation and performance aspect of the FSC were also captured in the themes. Some examples include how Blockchain can optimize and improve processes, and businesses have to invest considerable financial resources to initiate Blockchain but the technology can save costs in the long term. More importantly, combining insights from relevant literature and the pertinent lenses of IA theories and concepts, a conceptual model for the integration process of Blockchain at organizations in the FSC was developed in the Literature review study.

In answering the overarching research questions of the thesis, the Literature review serves as an analysis of the extant literature, accomplishing Objective 1. Findings from this study indicate what is known, and not known, in the literature regarding the topic of interest. Hence, this study achieves a crucial step in this thesis, since it establishes a literature-based foundation of the phenomenon of interest (Blockchain for FSC) and further justifies the positioning of this thesis. Further, this chapter is an important step for building the groundwork for the following empirical studies. These implications are twofold. First, the Literature review contributed a conceptual model of Blockchain implementation in the context of FSC, using insights synthesized from appropriate studies and the theoretical lens of Innovation Adoption. This specific conceptual model serves as a critical basis for later expanding and strengthening with empirical evidence (the works in the Qualitative study). Second, the Literature review revealed several facets of Blockchain impact on the operation of an FSC. For instance, cost (high implementation cost vs reducing cost effect of Blockchain) and process enhancement (reduce time, middlemen, etc) were frequently discussed in the literature and captured in this study. These observations serve as an important guideline for designing the Quantitative study, in which the author delves in-depth into how Blockchain can influence key performance metrics of an FSC operation such as inventory level, cost, lead time, and service level.

The Qualitative study (Chapter 3) presents an in-depth investigation into the implementation process of Blockchain technology at the organizational level, under the context of FSC. Analysing empirical data from 15 interviews, the Qualitative study uncovers extensive insights into the Blockchain adoption process. These insights were contrasted with the initial understanding of the process, provided by the conceptual model in the Literature review study, to develop a specific and evidenced-based model of Blockchain implementation in the FSC. This model consists of three main phases (Initiation – Adoption decision – Implementation), nine general steps within the phases, and four clusters of influential factors. Next, a quantitative phase is followed to leverage the findings of the Qualitative study. This design followed Creswell and Plano Clark's (2012) guidelines for conducting mixed-methods research. The first phase aimed to obtain critical elements such as key constructs (e.g. stage of implementation, determinants, etc) and relationships, while the latter used the results of the first phase to design the statistical assessment instruments. Hence, the outcomes of the Qualitative study provided an important basis for constructing the measurement and research model in the following quantitative phase, which is one of the two primary parts of the Quantitative study (Chapter 4). In this part of the Quantitative study, the relationships between phases of Blockchain implementation, and between key determinants and each of the adoption stages, were statistically assessed. Numerical data from 159 survey responses were used for this quantitative analysis. The findings in the quantitative phase validated the prior understanding of how Blockchain progress at an organizational level, and determined what factors are most influential at each stage of the integration. In sum, findings from the Qualitative study and part of the Quantitative study finalized the evidence-driven implementation model of Blockchain in the FSC, by identifying the integration process and determining the key relationships between stages and their determinants.

The Qualitative study and part of the Quantitative study specifically address Objective 2 of the thesis and subsequently answer the research question of *how organizations in the FSC adopt Blockchain.* Building on the conceptual framework developed in the Literature review, the Qualitative study first enriched and adapted the framework with contextual knowledge obtained from interviewing experts, who have had adequate experience in deploying Blockchain in the FSC. Then, the model was further evaluated and finalized by quantitative analysis (part of the Quantitative study), based on responses to a survey from a wider audience. The end result of these two studies combined is an empirical-driven, practical, and feasible model of Blockchain implementation in the FSC settings. This model explained how organizations in the FSC adopt Blockchain by identifying three critical phases of diffusion (Initiation, Adoption, and Implementation), nine representative activities imbued in those stages, and key FSC-specific determinants to each of the stages (e.g. relative advantages brought by Blockchain is critical to make the adoption decision while management involvement and compatibility of Blockchain with legacy systems are key to successful implementation). Further, the interplay between the Qualitative study and the Quantitative study represents a mixed-methods research inquiry on the topic of Blockchain implementation.

The Quantitative study (Chapter 4) consists of two primary parts. One is described together with the Quantitative study in the previous discussion. The other part evaluated the impact of adopting Blockchain technology on the key performance indicators of the FSC operation, including inventory, lead time, service level, and cost. Employing a unique blend of empirical and analytical approaches, this part of the Quantitative study developed two models to capture two scenarios, particularly a conventional FSC, and a Blockchain-integrated FSC. The modelling process used a combination of survey data (from the first part of this study), insights from three cases of large-scale Blockchain applications for food products, and the principles of system thinking and SD modelling approach. Empirical data leveraged the SD models to closely represent the actual operation of an FSC and to capture the influences of Blockchain. Furthermore, system thinking and SD approach are useful tools to investigate a complex system and its behaviours, especially under the effects of introducing new policies/ interventions to the system (Sterman, 2000). In this vein, the FSC can be viewed as a complex system with numerous entities and processes constantly interacting with one another, and Blockchain adoption is an intervention in the FSC system. By simulating the two SD models, important implications of Blockchain adoption of the operation of an FSC were unveiled. Particularly, using Blockchain can enhance the visibility and coordination between FSC stakeholders, leading to improvement in inventory level and lead time. The simulation results also indicate that over the long term, the cost savings benefit of Blockchain can outweigh the initial implementation cost. Interestingly, while companies can significantly lower their holding stocks due to increased supply chain visibility provided by Blockchain, the service level might be adversely impacted if companies forgo too much of inventory buffers.

The Quantitative study accomplishes Objective 3 of the study, and subsequently answers the research question of *what benefits/ impacts can be anticipated from using Blockchain technology in the FSC.* The analytical part of the study provided a comprehensive examination of an FSC system and the impact on this system brought by using Blockchain. The modelling process was enriched by empirical insights gained from a portion of the survey and three cases of Blockchain implementation. The results of the Quantitative study showed that Blockchain can improve and optimize the procurement, data sharing, and communication processes of FSC stakeholders, and further indicated that Blockchain’s visibility and trustworthiness lead to lower inventory levels, shorten overall lead time, and reduce cost over a long period. The results also warn businesses that a certain amount of inventory buffers is still needed to ensure a sufficient service level. These findings are valuable for practitioners as they consider the potential benefits of adopting Blockchain technology in the FSC.

The key points of this section are summarized in Figure 5-1, which presents all the findings in the three research Chapters (2, 3, and 4) and demonstrates how they accomplish the Objectives and thus, answer the overarching research questions.

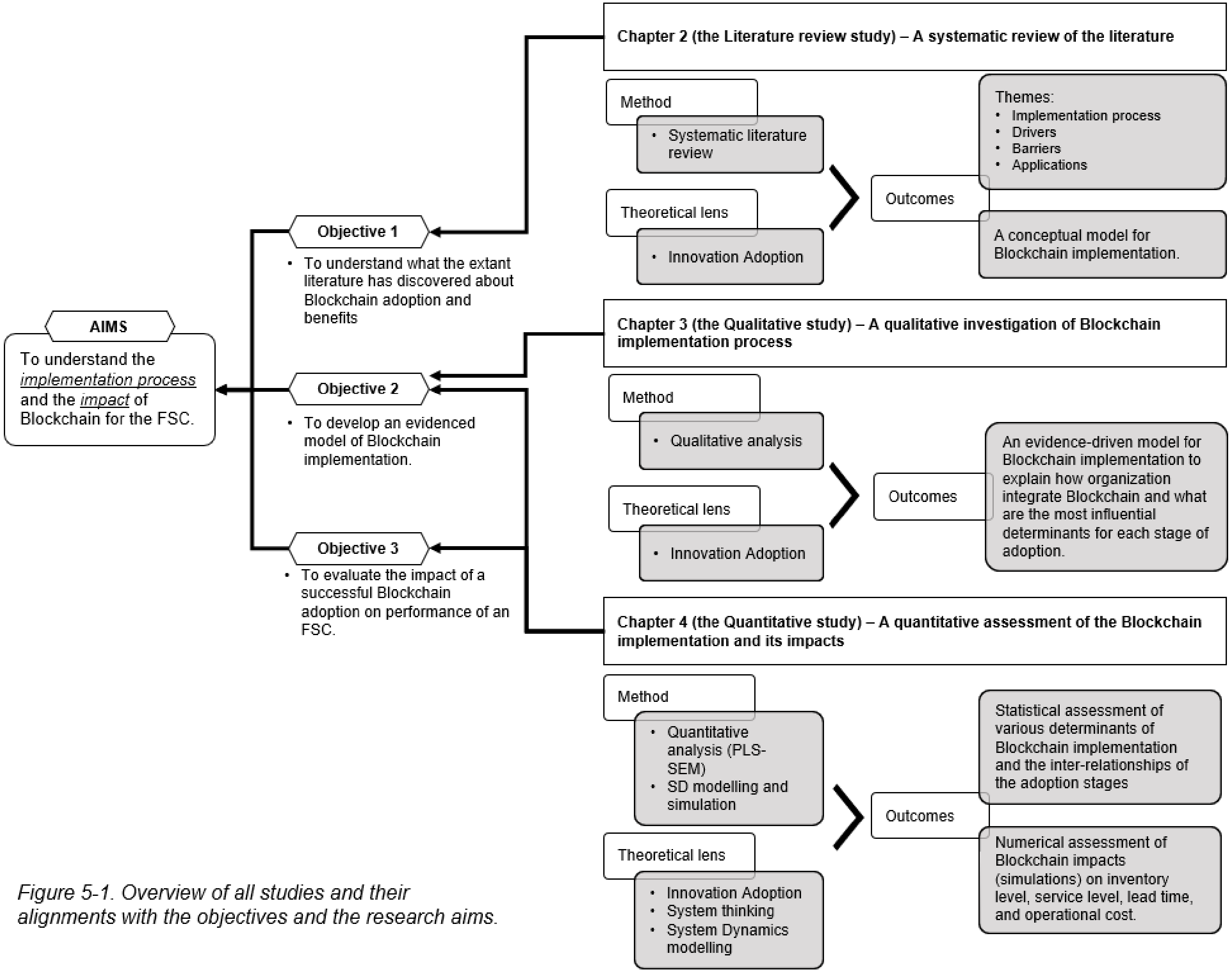

Figure 5-1. Overview of all studies and their alignments with the objectives and the research aims.

5.2 Contribution to knowledge

Several contributions of this thesis to knowledge are: extending the current understanding of the Blockchain phenomenon in the FSC context, elaborating pertinent theories for better examination of the topic of interest, demonstrating the usefulness of qualitative and analytical methods, and providing a useful basis for future works.

First, the works in the PhD thesis provide a meaningful advancement to the current body of knowledge regarding Blockchain technology in the FSC domain. As Blockchain's potential for improving FSCM is recognized, the growth of the technology in this realm has been tremendous in recent years (Zhao et al., 2019; Rana et al., 2021). However, compared to other transformative technologies (such as RFID), Blockchain's development in the SCM domain can still be considered to be at an infancy stage (van Hoek, 2019), warranting the need to continue researching this novel technology. This aligned with several calls from existing literature, which suggest that the exploration of this technology is just at the beginning and there are numerous opportunities for Blockchain-related studies (Cole et al., 2019, van Hoek, 2019; Wang et al., 2019). Some areas of great interest include the diffusion facet of Blockchain technology (Wang et al., 2019) and the impact of Blockchain visibility on actors and processes (Martinez et al., 2019). Early works in the extant literature, while providing useful conceptualization and implications of Blockchain's potential and benefits for food products (i.e., Zhao et al., 2019 and Bumblauskas et al., 2020), have not offered thorough research inquiries on the implementation process and impacts of Blockchain in the FSC. Thus, this PhD was positioned to explore these under-studied areas, contributing to a better understanding and a holistic picture of the Blockchain phenomenon. Specifically, findings from Chapter 2, 3, and 4 constituted a theoretically based and empirically driven model for the integration process of Blockchain at organizations in the FSC setting. Wang et al. (2019) observed that the field of Information Systems has long been investigating the diffusion of new technologies, and suggested the same research efforts for the topic of Blockchain for managing the supply chain. To this end, the implementation model for Blockchain in the FSC, developed in the Qualitative and Quantitative studies of this thesis, details a specific process of three sequential phases (Initiation – Adoption – Implementation), 9 comprehensive activities in these phases, and four categories of relevant and contextual determinants to the adoption process (Technology – Organization – Environment – Management). This model informs a roadmap for initiating and integrating Blockchain technology in organizations (grounded in the FSC context), bringing the cumulative knowledge of this technology one step closer to that of other established technologies such as RFID and ERP, of which the adoption process has been determined in both academic and practitioners' literature (e.g. Liang et al., 2007; SAP, 2022). Furthermore, the results of the Quantitative study's SD modelling shed light on Blockchain's impact on the operation of the FSC. While the literature has studied Blockchain's impact and benefits for the SCM area using methods such as quantitative analysis (Wamba et al., 2020) and case studies (Ahmed et al., 2022; Danese et al., 2022), this study is among the first attempts at using a combination of the empirical and analytical method to quantify and measure the impacts of using Blockchain on critical performance indicators of the FSC. Subsequently, the Quantitative study extended the conversation in the literature with detailed and valuable insights about how Blockchain can change FSCM processes and how specific performance metrics (inventory, lead time, service level, cost) are affected under Blockchain adoption.

Second, this thesis provides elaboration on existing theories, generating new theoretical insights to better examine and understand the specific subject under study (Blockchain in the FSC). This contribution is demonstrated explicitly in Chapter 3 (the evidence-driven model of implementation), and part of Chapter 2 (the conceptual framework of implementation). Lee et al. (1999) when reviewing qualitative management research, defined "theory elaboration" as when a study seeks to advance pre-existing conceptual ideas/theories/models for new theoretical insights, to accurately account for and better explain the empirical observation. Fisher and Ahuinis (2017) further described the theory elaboration process as starting with a ‘conceptualizing’ stage – specifying constructs, relations, and processes using established theoretical ideas and models, then followed by an ‘executing’ stage – assessing the fit of the theory-driven concepts and relations by empirical means. The works regarding the implementation process of Blockchain for organizations in the FSC in the Literature review and the Qualitative study adhered to the theory elaboration process and principles faithfully. First, the IA theoretical perspectives and models were identified as an appropriate lens to study the adoption process of Blockchain. This is evidenced by the successful use of such theories and concepts in examining new technology diffusion in the past (Zhu et al., 2006; Martins et al., 2016; Hossain et al., 2016). Based on appropriate IA theoretical perspectives and conceptual models, the Literature review study constructed a conceptual framework for implementing Blockchain in the FSC.

The Qualitative study leveraged this conceptual framework with empirical insights, particularly by employing a mixed-methods approach to empirically validate the Blockchain implementation process, and to further specify and adapt existing constructs and relationships with the contextual factors discovered from the qualitative and quantitative data analysis. As the result, the Qualitative study advanced the conceptual framework of the Literature review to an evidence-driven model of Blockchain diffusion in the FSC setting. The premise is that Blockchain adoption in the FSC is still an under-development area; therefore, while some studies attempted to directly adopt IA theories when examining the diffusion of this technology (e.g. Wamba et al., 2020), the author argues that the general theoretical concepts must first be elaborated to better fit the context. Thus, the Qualitative study used qualitative insights to refine the descriptions and relationships of key constructs of the Blockchain implementation, thus, bringing these theoretical elements closer to the context under study (FSC in this case). Then, a more traditional approach of statistical assessment was conducted to finalize the end model of implementation (the first part of the Quantitiatve study). Following this approach, the initial conceptualization of the Blockchain integration was extended and adapted to better explain the process in the specific setting of the FSC. The end product represented an attempt at elaborating IA theoretical perspectives and established models to better fit with examining a specific phenomenon (Blockchain adoption process in the FSC).

Third, this thesis contributes to paving the way for the use of some research methods in certain streams of literature. More particularly, two methods being discussed here are often not yet frequently employed by researchers in a particular research area. The first one is the use of qualitative investigation for the adoption of technology and information systems. Traditionally in this area of research, quantitative analysis is predominantly the method of choice, illustrated by a rich body of studies using statistical testing to study the integration of novel technologies such as Software-as-a-service (Martins et al., 2016), RFID (Hossain et al., 2016), or business analytics solutions (Nam et al., 2019). The notion of including qualitative techniques in the design of a research, was recently called for in the mid of 2010s by scholars such as Venkatesh et al. (2013) and Venkatesh et al. (2016). This notion is relatively modern, when compared to the existence of the Information systems body of research which dated back from the 1970s – the 1980s. The Qualitative study provided yet another piece of evidence of the qualitative method's usefulness when investigating the adoption of a new information system (Blockchain in this case). Given the infancy stage of the knowledge regarding the Blockchain phenomenon in the SCM domain at the time, and the complex dynamics involving both the technology and the specific context of FSC, the qualitative approach offered a meaningful medium to better understand the subject and to refine the broad underpinning theoretical perspective for a more accurate follow up quantitative assessment. The second research method, that this thesis is advocating for, is the SD modelling analytical approach. Specifically, while this method has been employed in operation research (e.g. Kochan et al., 2017; Kara et al., 2020), it is not widely used by researchers in the SCM domain, as illustrated by SCM-specialized academics journals rarely published research with SD modelling methods. The author is aware that pure analytical research normally is not included in the scope of such journals (International Journal of Operation and Production Management for example), nonetheless, the SD modelling is a unique approach in which empirical findings are often embedded in the modelling process. Therefore, the author argues that this approach is a hybrid approach, and advocates for wider use of this technique in researching the SCM, especially when the underpinning theory of System thinking aligns well with the complex-system-like characteristic of a supply chain network.

Finally, the findings in this thesis provide a meaningful basis for future works to continue building upon. The implementation model for Blockchain (resulting from the Qualitative and Quantitative study) provides an in-depth understanding of how the integration process unfolds in organizations in the FSC. To this end, this model can serve as a guideline for future works when exploring different cases of Blockchain adoption in the food and agriculture industry. Alternatively, the model, and the process of developing it, can be replicated to examine the Blockchain adoption process in other industries. The SD models built in Chapter 4 established a meaningful tool to represent the interactions between key actors of the food supply line and its dynamics. Using these models, researchers can better understand how information and products move between FSC stakeholders and various operational implications from the modelling; which can be particularly useful when future works look to model similar phenomena, the FSC, or other types of SCM.

5.3 Contribution to practice

This PhD thesis provides several useful insights for managers and policymakers in the area of FSCM and the wider food sector.

For businesses in the food industry, this PhD thesis offers the following implications:

- First, the findings of this research inform businesses of a Blockchain integration process. Whether a company currently considers exploring the technology or has started engaging with a Blockchain project, the implementation model developed in this thesis helps to understand the general process of adopting this technology and to form an appropriate roadmap for the adoption. Especially, companies can utilize the model as a useful reference to plan the general phases of adoption and create granular objectives within each phase, fostering a more defined and subsequently, more seamless adoption process.

- Second, the implementation model for Blockchain developed in this thesis also contains specific and contextual influential factors, which can affect the implementation process. By understanding what is most likely to be relevant when onboarding Blockchain technology, and more importantly, how one determinant can drive or prohibit the overall adoption process (e.g. managers' involvement can foster a better implementation phase, whereas the complexity of the Blockchain can hinder the adoption decision), managers can better plan for their project, increasing the success rate of the adoption.
- Third, the simulation study of this thesis (the second part of the Quantitative study) provided useful knowledge about how Blockchain can influence key processes and important performance metrics of the FSC. Specifically, managers are now informed of Blockchain potentials for operational improvements such as reduced inventory level, better communication, lower lead time, and cost-saving effects. Albeit increased visibility is often positive, businesses are also being warned that matching supply too closely with demand can hinder service level. Implications from the Quantitative study of this thesis, therefore, extend the understanding and expectations of managers regarding Blockchain capabilities and potentials, alongside known benefits of the technology such as enhancing transparency, food authenticity, and food traceability.
- Finally, businesses can adapt the SD models created in this thesis with their own inputs to better understand the behaviours of their specific supply chain. Furthermore, companies can run simulations themselves to understand further the impact of Blockchain, in their cases, and better prepare for the adoption of this technology.

Policymakers can also benefit from the findings of this thesis. Especially when Blockchain technology has gathered considerable attention from various regulatory bodies across the world, due to its ability to transform and enhance the management of food products. In previous chapters, the author mentioned that the US FDA included Blockchain in their list of recommended technologies that can enable companies to meet the future requirements of the agency in terms of traceability and food safety. The author believes that many countries will soon follow the same path of welcoming Blockchain to the food industry. Hence, by understanding the integration process and the impacts of Blockchain, regulatory bodies can act more effectively as a facilitating force for the wider application of this technology. For instance, as the findings in the Qualitative and Quantitative studies highlight the importance of readiness and full cooperation from FSC stakeholders to large-scale adoption of Blockchain, the governments and their agencies can direct greater efforts to help lesser technologically capable entities in the FSC (such as farmers and fishermen in some cases) understand and prepare for onboarding Blockchain. Another example is by understanding the key role of a pilot run during the Initiation phase, policymakers can further support the initial funding to spark interest from the industry, advocating for further use of this technology.

5.4 Limitations and future research direction

There are several limitations of the works in this thesis, which should be taken into account.

Since this thesis has been positioned solely within the FSC setting, the generalization of the findings to other contexts (i.e., automotive or pharmaceutical industry) can be limited. However, the author strongly believes that the design of the studies, the choices of underpinning theories, and the methods used still provide useful references when exploring the topic of Blockchain in other settings within the wider SCM domain.

The Literature review followed a robust design for identifying and selecting relevant literature to the subject under study, nonetheless, there is still a risk of overlooking pertinent studies. The author provides their best attempt at minimizing this risk by setting up a thorough search string and conducting an exhaustive search using three prominent databases for academic research. Moreover, as the body of knowledge regarding Blockchain in FSC is growing at a fast pace while the Literature review was conducted at the very beginning of this PhD project, new insights may have emerged by now. Therefore, another look at the current stage of the literature will be necessary for the near future.

There is an inherent risk of individual bias with the qualitative data collected in the Qualitative study, as interviewees answered the questions with personal perspectives. The author attempted his best to mitigate this risk by carefully selecting and inviting individuals with proven experience in implementing Blockchain solutions for food products. As this technology is moving forward and more companies adopt Blockchain, there is a possibility that people's opinions regarding the integration process might change.

For the Quantitative study, the limitations are two-fold. First, the survey responses were from a volunteer opt-in panel, thus there could be a limitation to the statistical significance of the results. As a countering measure, the author included a series of screening questions at the beginning of the survey, making sure that the respondents had an adequate understanding of the subject before answering. Second, the SD modelling process followed a robust and logical approach to develop the models of an FSC and a Blockchain-integrated FSC. These models however were constrained by the empirical insights gathered by the preceding analysis of qualitative and quantitative data. As Blockchain continues being developed in the industry, the source data for the modelling process will experience changes. Thus, a revisit to the models in the future is necessary to make sure that they can capture the most current knowledge. In many instances, real inputs were not shared due to confidentiality issues, thus the numerical study in this study needed to rely on assumptions. Even though the assumptions were logically formed by examining established simulation studies and secondary data (e.g. industry papers and reports), the lack of actual inputs can affect the validity of the results.

To address any shortcomings of this thesis, and to further build upon the works presented here, several future research avenues can be considered:

1. When Blockchain reaches a certain stage of maturity, future works can consider testing and validating the implementation model proposed in this thesis. Particularly, a cross-country analysis and comparison could be beneficial to extend the understanding of Blockchain diffusion. Additionally, a probability sampling approach is recommended to strengthen the generalizability of the results.
2. An in-depth case study into a specific FSC network that successfully adopted Blockchain, using the SD models constructed in the Quantitative study, is suggested to further advance the models and elaborate on the results of this thesis. This approach has a good chance of acquiring real business inputs for the simulations, thus generating more specific observations of the supply chain system behaviours under the effect of Blockchain technology.
3. Future studies are encouraged to bring the research frameworks developed in this thesis to apply to new contexts. The use of Blockchain is spreading across different types of SCM (Ahmed et al., 2022), thus, there are many opportunities to study the adoption process of Blockchain and its impacts in different sectors.
4. The author believes that the exploration of Blockchain for FSCM, and SCM domain, is far from over. There are still aspects of the technology that academics and practitioners can benefit from further investigation. The author suggests that the link between Blockchain technology and sustainable development is among the areas of future interest. One case of Blockchain use, which is a part of the empirical data set in the Quantitative study modelling process, was exclusively developed toward monitoring sustainability in the food chain. This trend is predicted to grow in the future, thus further research efforts are needed to inform policies and practices in this regard.

As the final note of this thesis, it is the sincere hope of the author that the studies in this PhD thesis have not only extended the current body of knowledge regarding the promising Blockchain technology for the management of food and agriculture products but also have laid concrete grounds for future studies to build on, harnessing the best of this transformative technology.

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APPENDIX 1 – INTERVIEW PROTOCOL FOR CHAPTER 3

Section	Question
Introduction	Interviewer confirms the name and position of the interviewee, asking for necessary permission such as recording.
	Could you briefly describe the Blockchain project which your company is/was undertaking?
Process related questions	I would like to know more about the phases and activities, which often take place in a Blockchain project. From your own experience, what was the first activity you do to set off the project? And after that? What was the most current activity that has been done?
Factors related questions	In your opinion, what are some of the influential factors to this project?
	What are some factors/ elements that makes the process of this project faster/ easier, or more difficult?
	What are some of the challenges when applying Blockchain for food chain?
	How would you rate the role of managers in this Blockchain endeavour?
Closing the interview	(If there are some points which the interviewer needs to be clarified or confirmed) About…, could you please elaborate….
	If possible, could you please introduce me to someone who is willing to participate in this research, who has had similar experience like yourself?

APPENDIX 2

Illustrative quotes	**First order concept**	**Second order theme**	**Aggregate dimension**
The traditional chains are actually fragmented and not collaborative. The traditional chain is actually transactional based, and that absolutely constrains the capacity to actually improve the chain. With Blockchain, we're trying to have a paradigm shift where we go from companies holding information to actually sharing it – P1 We started, roughly around 2011, working with a cooperative that was offering organic meat products to the market. There was not a way of efficiently communicate that there's a story behind this product, versus maybe some other product with might have come through a more intensive farming practices, or more of what we consider like factory meat. So we were looking at deploying a decentralized network of information, leveraged by Blockchain, for visibility, extermination of data silos, and defragmenting the whole supply chain network – P4	Recognizing a need for Blockchain	Initiation phase	Process
we start off with workshops really inception workshops to do a bit of brainstorming around the scope of the project, say what is achievable, what are your burning questions that we want to tackle and do a bit of prioritization exercises with them. Frame the problem identify the scope timeframes, key contacts, and who else we needed to talk to them, we didn't have in that room – P7. In the first 12 months of the project we let [service company] do what they want, and we did not learn a thing. After 12 months of working on the Blockchain project, I said to the [service company] that there was no need for you to develop temperature logs as we	Scoping and planning		

have the technology available. I moved the focus away from them building temp loggers and tracking temperature to know what the important information is, how to capture it, and how to share it with chain partners with the help of Blockchain – P1 the first thing we do is we support with the data mapping and the participants mapping so first to understand who is involved, who is doing what. When does the ownership of the products change hands what places, because that will also influence what data, who is to upload so we have to know that first so map out the supply chain, the participants? And then we also support in mapping out the data so understanding what details, do we need in what format are those in other existing systems do we have to work with simplified uploads. So that's the basically the first step to get started – P2.			
We made a pilot project last year last summer, with the halibut producer and distribution companies and slaughterers and all the way out to sushi restaurants. So we could track everything. We do it in in smaller incremental steps so starting with a small pilot showing that we can actually prove something we can do something. And then start integrating with iot sensors and you start integrating with the production system under ERP system, and so on – P6.	Pilot		

when they decide to e.g. scale to more volume or to do their entire supply chain this is a more strategic decision that takes time. After the pilot, there is usually an evaluation of the process and outcomes that lead to the decision to continue with the scaling (usually to more supply chains and more volumes). The point is therefore usually at the end of the pilot when they've tested the capacity of the system. To scale, we usually need integration, and for a company to take that decision (a larger investment) they would have wanted to test how the system works first – P2	Comes after evaluating the results of the pilot	Adoption decision phase	
After the discovery phase and the solution is deemed feasible, we had two banks prepared to work with the system to lend based on the company due diligence report, and access to the raw data held on the Blockchain. We consulted, did some coding for the company, but it really became their solution – P5	Preparation for large scale implementation	Implementation phase	
We successfully integrated Wholechain, our Blockchain solution, in our seafood at scale. It is used in every delivery, not just a pilot or only some product line – P9	Integrating Blockchain		
And in the other end if we thank my farmer consumer APP. It is a progressive web APP and there is really where consumer can see more information around their product see map that is powered by blockchain, where consumers can either learn more and understand what projects that are implemented in those communities and also where they want to, they can follow those and even support with a financial. That's the end-to-end system – P2	End user engagement		
One thing that we are selling is both visibility and connectivity, so companies today normally only have one tier up and tier down of information flow, you only get information from your first supplier, and you give it to your customer. By using a public blockchain	New values can be added using Blockchain	Relative advantage	Technology

where all the actors can be connected, you get information from your supplier's supplier's supplier and give to customers' customer all the way to the end customer, and you can open a communication channel all the way to your end consumers and get this interaction with your consumers – P6			
We work with a big brewing company who wants to source their barley directly into their malt houses. They don't want to get their barley mixed up, they want it from certain areas with quality assurance, biosecurity, compliance with chemical use and chemical residue. They want all that information on my Blockchain system, so they can check chronological hashing order to award the business to the most honest and trustworthy suppliers – P10	Facilitating a more trustworthy and transparent supply chain		
frictionless trade is a big thing for companies. one of the big drivers for the HMRC wine pilot is to see how it can link up with existing systems to you know offer that friction is trade perspective. So that if you are, for example, you're providing all the information, maybe it's an easier way to you know sign off those consignments – P7	Improving current process such as reducing time and increasing efficiency		
The Blockchain idea started when we were looking at securing data points for the quality measures in the meat red meat industry. There is no quality read on lamb, for example, and that is an issue. And securing those data points about red meat quality, is a natural home for Blockchain with the privacy and security – P10	Blockchain should align with the need and goal of the organization	Compatibility	
There's very little chance that you'll be able to entirely change the whole process, just for the sake of implementing a new piece of technology so it's rather adopting to the existing processes and being able to appreciate them and leverage them in the best way possible to get the value – P4	The use of Blockchain should correlate with the current process		

we were working with the different systems in food supply chains you're touching different IT vendors different systems, different file formats different or everything's different for anything from an excel file to a customed ERP/SAP and Oracle and Microsoft right. So interoperability of the Blockchain solution is to enable more fluent communication between the systems - P4	Blockchain should be able to integrate with current system/ technology		
We have a lot of discussions that are underway. But if I'm asked to put it, I would still view Blockchain as definitely being at education phase. People are still getting their heads around it and trying to figure out – P10	Blockchain is still a novel concept to business, so it takes time to grasp the technology and its use.	Complexity	
Private, public, and hybrid solutions of Blockchain are different, and are chosen depends on who we are onboarding on our solution. There are different solutions, depending on different group of use cases how we see the market being matured – P12	Many solutions to choose from		
One of the biggest challenges, we found, was that how to scale up the solution in a sustainable way. What is the self-sustaining model for running the Blockchain solution for everyone to sue, and at the same time with low entry barriers for more to join – P7	Difficulties in configuring and tailoring the solution to fit the business		
Because, at the end of the day, food industry as a whole it's a very the margins are really tight yeah so whatever you do, you should not add cost – P4 We focused on small holder farmers; our price point is very competitive. There are a lot of solutions that just want to focus on high end commercial whereas ours is for everybody and relatively inexpensive, so farmers love us – P14	Cost of implementing Blockchain is influential	Cost	
You have to be mindful of the cost of storing data on Blockchain because in the supply chain there is a lot of information generated.	Cost of running and maintaining the solution is influential		

So you have to get a balance of the speed of authenticating the data, and the cost of doing so – P1			
One type of investment in this kind of project, Blockchain, is providing money – P1	Organization needs sufficient fund for the Blockchain project	Resources	Organization
All of the staffs involved in the project were very young, but they were exceedingly talented people, and that was such an advantage – P5	Capable people on the project are an advantage		
For some companies, they are very much set up. They have systems in place, data is already standardized across, so it is very easy to work with them on the Blockchain project. In other places it's really scattered, certain companies in some countries have paper records still, and when that happens it's a difficult starting point – P2	Organization with better traceability infrastructure finds Blockchain implementation less challenging	Readiness	
When this Blockchain project presented itself, we knew that we were capable of doing it. Of course there were some challenges but not difficult to overcome. The Ecuadorian shrimp farming industry is very matured, and we have had over 40 years of being in the industry, with experience of implementing many technologies – P3	Adoption is easier when organization is technologically capable		
People do not like change. When we discuss Blockchain, some stakeholders loved it, and others were negative about it. It is a big issue because people sometimes are caught up with the old thinking of "he who owns the data will role the world of information", so Blockchain with connectivity and data sharing scares them – P10	Ready to change mindset is needed in an organization		
We've got a very, very strong R&D investment program because innovation and improvement are critical to our future development.	Strong R&D investment and infrastructure	Innovativeness	

A value of our company is recognizing the importance of investing in innovation – P1.			
We are always at the forefront of innovation; we always want to be at the top of the heap. We don't want to be at the bottom of the heap – P3.	Actively seeking new ideas		
From the start, [the adopting company] was really thrilled about blockchain… they've already heard about at least bitcoin or blockchain technology before, they're also very keen on experimenting with new idea – P8.	Encouraging trial of new ideas		
the farmer in Africa cannot dictate Nestle to adopt blockchain. It has to be the management of Nestle who will ask the farmer in Africa to be onboarded for traceability and visibility for their consumers. That's how it works – P12	Organization with more resources and commanding power in the network should be driving the project	Size and position	
An example is the the US government's FDA has new era of smarter, food safety report and in the FCC regulations, Section 2040, they have actually listed down few products that will be required to provide the end-to-end traceability (cheese, milk, etc). So those companies who are operating in those food chain, because of regulations, are pushed to adopt or apply blockchain because blockchain was mentioned in that regulation as well. So when I come to them, I don't have to explain a lot and already get the welcoming attitude – P12	Policies regarding food will be tighten, drive business to use Blockchain	Influences from regulators	Environment
Five projects that P1, P3, and P7 were involved with are directly funded by the governments	Encouraging the use of Blockchain from regulators		
Consumers play important part in driving Blockchain adoption, you see it in market and reports. Consumers demand for trust, with more and more food recalls being more frequent, consumers' demand really is becoming significant -P9	Consumers' demand pushes companies to use Blockchain	Influences from consumers	

It is the food that we are consuming, so if there is that little bit extra to make sure that they will be more secured, people are willing to pay it – P10	Consumers are willing to pay more for transparent products enabled by Blockchain		
Our Blockchain enabled traceability system is end to end, and we are usually working with minimum of two or three connected companies in the supply chain, sometimes even more, in order to apply our solution to a supply chain – P2	Blockchain solution needs participation from other organizations in the supply chain	Influences from other organizations	
Fundamentally it is a change in paradigm, in thinking, in the attitude of the businesses in the chain. So you really need the businesses to have a collaborative culture, where they are willing to participate and work together as a whole chain – P1	Collaborative culture in the supply chain is an advantage for implementing Blockchain		
For one of our projects, we had three companies, who are also competitors in the market, joined. We start off with one company, and it is interesting that, almost like a cascading effect, because the other two knew about that and wanted to join as well – P7	Competitive pressure drives companies to adopt Blockchain		
In order to integrate Blockchain into a company, managers have to be ready for the change and also have to be ready to be in charge of such change – P11	Management shows willingness to embark on the Blockchain journey	Attitude from managers	Management
When working with the client for the Blockchain pilot, there wasn't any negativity or concerns from top management. And I think that creates a healthy working environment – P8	Management is supportive throughout the project.		
Managers in companies we work with are not involved in day in day out of the project. But they are definitely aware of the progress. And it is a strategic decision to go towards digitalization, technology, traceability, and responsible sourcing, and it is really a management decision – P2	Management actively participates on formulating strategies and visions of using Blockchain	Involvement from managers	

We are actually seeing a really good amount of senior level managers involved, and that is really encouraging because ultimately it is them who have to drive the project and lead their organization in adopting Blockchain – P9	Management presence during the project is encouraging		

APPENDIX 3 – SURVEY QUESTIONS FOR PART 1 CHAPTER 4

Screening questions:

1. What is the current status of you company's engagement in Blockchain adoption? Note: if you are a service provider, please indicate the status of the most successful project that you have been a part of.
    a. Researching
    b. Planning/Developing
    c. Piloting
    d. Considering full adoption of the technology
    e. Starting to implement at large scale
    f. Blockchain is fully integrated to our business
    g. None of the above
2. Are food & related products part of the Blockchain project(s)? Y/N

Constructs	Measurement items
Relative advantages (RA)	RA1. Blockchain could bring added value for the adopting company (e.g. reliable traceability, trustworthy information sharing, etc)
	RA2. Blockchain could help facilitating a more trustworthy and transparent supply chain for the adopting company.
	RA3. Blockchain could help improving the adopting company's current operation and processes (e.g. reduce time, increasing efficiency, etc)
Compatibility (CPA)	CPA1. Blockchain is compatible with our existing process and operation.
	CPA2. Blockchain is compatible and integrable with our existing systems and technologies
Complexity (CPX)	CPX1. It requires a lot of effort from the adopting company to understand a novel technology like Blockchain and its use.
	CPX2. It is difficult for the adopting company to choose the right Blockchain solution because there are too many in the market.

	CPX3. The skills needed to adopt Blockchain is complex for the employee of the adopting company.
Cost (CST)	CST1. Blockchain has high set up and implementation cost.
	CST2. Blockchain has high running cost.
Resources (RESO)	RESO1. The adopting company actively seeks for new ideas and technologies to strengthen current business.
	RESO2. Having capable personnel working on the project is an advantage for Blockchain implementation.
	RESO3. The capital and/or revenue of the adopting company is high compared to the industry
Technology competency (OTC)	OTC1. The adopting company has established traceability technologies and processes in place before implementing Blockchain.
	OTC2. The adopting company has skills and technical knowledge of implementing and using technology in the past.
	OTC3. The adopting company has a ready to change mindset when it comes to experimenting/ adopting new technology
Innovativeness (INOV)	INOV1. The adopting company values and invests in R&D.
	INOV2. The adopting company actively seeks for new ideas and technologies to strengthen current business.
	INOV3. The adopting company encourages experiments and use of new ideas and technologies.
External pressure (EXTP)	EXTP1. The adopting company implements Blockchain because there are incentives from consumers for transparent and safety proven food products.
	EXTP 2. The adopting company implements Blockchain because consumers are increasingly demanding for greater transparency and provenance of food products.
	EXTP 3. Government and relevant authorities are encouraging and supporting the use of Blockchain in food industry.
	EXTP4. Regulations regarding food transparency and traceability in the future will get stricter, therefore driving the adopting company to consider Blockchain.

Influence from other organisations (OrgIN)	OrgIN1. The participation from other organizations within the supply chain is important to the use of a Blockchain solution.
	OrgIN2. Collaboration and trust between companies within a food supply chain is important to the adoption of Blockchain.
	OrgIN3. The adopting company is under pressure from competitors in the market to adopt Blockchain.
Management support (MSP)	MSP1. Top management shows interest and willingness to adopt Blockchain
	MSP2. Top management communicates their support throughout the project
	MSP2. Top management actively engages in various activities of the Blockchain project
Initiation phase (INI)	INI1. The adopting company recognizes a need for Blockchain to tackle the challenge in managing their supply chain.
	INI2. The adopting company conducted a pilot with clear scope and plan for the project.
	IN3. The adopting company has completed the initiation phase of Blockchain adoption, in which it determines the need for Blockchain, acquires knowledge about the technology, develops plan, and pilots the use of Blockchain.
Adoption phase (ADOP)	ADOP1. Functional areas in the adopting companies require the use of Blockchain technology.
	ADOP2. The adopting company invests resources in Blockchain enabled supply chain applications
Implementation phase (IMPL)	IMPL1. The adopting company has integrated Blockchain with its existing system/ operation.
	IMPL2. The adopting company now can communicate the Blockchain-enabled information to consumers
	IMPL3. The adopting company has completed the implementation phase of Blockchain, in which it successfully uses Blockchain for large scale business activities and can communicate the results to other entities(other companies, end consumers, etc)

APPENDIX 4 – CHAPTER 4 SD MODELLING PART INTERVIEW PROTOCOL

Section	Question
Introduction	Introduce self. Thanks the participant for their time. Give a brief about the research, data right, and what they can get in return by participating in this research.
Overview	Ask the interviewee about the Blockchain project, which is the focal point of the interview
	Follow-up questions if not all information is uncovered with the initial introduction: What is the scope of this project? What is the main use of Blockchain in this case? What is the current progress of the project? What are the companies participating in this Blockchain solution at the moment? How integrated is Blockchain into the current operation of the involved companies?
	Can you explain the roles, tasks, and contribution of each company in this Blockchain system?
Main section	Can you describe the structure of the food supply in this case? (ask participant about how products and information move between each node of the supply chain to help with mapping the process and modelling the system)
	What are the changes/improvements to the process as the results of using Blockchain? Do you anticipate any changes/ improvement to any process, once Blockchain is integrated?
	What are the impacts of Blockchain on the supply chain in this case?
	Follow-up questions if not all information is uncovered with the initial answers: About (certain aspect), how exactly does Blockchain help to improve it in this case? For this specific case of Blockchain use, have you observed any effects of Blockchain on the inventory management and inventory level of the companies? If yes how Blockchain can make a difference here? For this specific case of Blockchain use, have you observed any effects of Blockchain on lead time of the companies? If yes how Blockchain can make a difference here?

	For this specific case of Blockchain use, have you observed any effects of Blockchain on the service level of the companies? If yes how Blockchain can make a difference here? For this specific case of Blockchain use, have you observed any effects of Blockchain on the cost for companies? If yes how Blockchain can make a difference here?
Other	Have you observed any other impacts to the operation from using Blockchain?
	Can give an estimate of the cost of Blockchain in this case for the companies that are using it? Ideally like percentage estimation against product price?
	Outside of what we have discussed so far, do you expect Blockchain to bring any other benefits? Especially to the operating performance of the companies.
Concluding the interview, and ask to be connected with others	

APPENDIX 5 – EQUATIONS AND PARAMETERS FOR THE SD SIMULATION

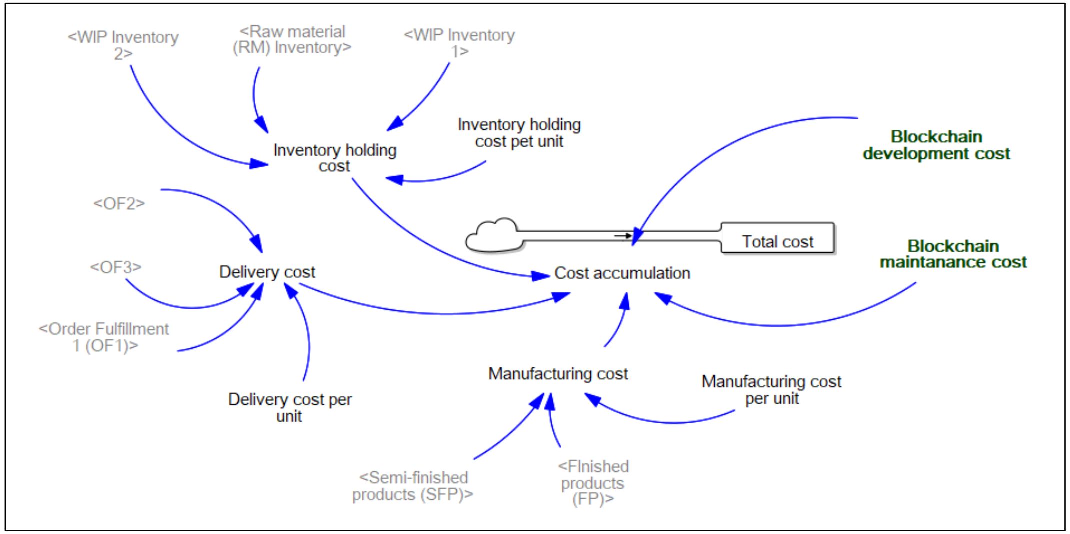
Formulas and values for variables used in simulating the SFD models of this study are presented here. Note that some are already explained in the paper and thus will not be included here.

Variables	**Formulas/ Values**	**Description**
Order from customer	=RANDOM NORMAL (5000, 15000, 10000, 5000, 1) Unit: product	To generate uncertain demand for the system.
Desired Finished Products (FP)	= Order from customer	Desired number of finished products that secondary processors need to meet order.
Order Fulfillment 1 (OF1)	= min(FP for shipping, Order from customers)	Rate of fulfillment from the secondary processor. When inventory ready for shipping is insufficient, even if the order is higher, the entity can only send what they have in stock. On the contrary, when there is more inventory than demand, the entity can only send what was ordered and the rest stays at the warehouse.
FP for shipping	= ∫ (OF1 – Finished Products, FP for shipping at t_0) FP for shipping at t_0 = Order from customer at t_0	Finished products on hands and ready for shipment.
Finished products	= min(Desired FP,(WIP Inventory 1- SR1)/ ED1)	Rate of making finished food products.
WIP Inventory 1	= ∫ (SFP Receive rate – Finished Products – SR1, WIP Inventory 1 at t_0)	Work in process inventory for manufacturing finished products. Spoilage rate takes away from the available inventory.

SFP Receive rate	= OF2	
Expected Delay 1 (ED1)	= OPT1 + MT1	Expected delays that the secondary processor knows they have. This is the combination of Order Processing Time (OPT) and Manufacturing time (MT)
Desired WIP 1	= Desired FP * ED1	Desired level of WIP stocks for the secondary processor, which has to take into account the delay in processing orders and manufacturing.
WIP Adjustment 1	= Desired WIP 1+ SR1 - WIP Inventory 1	Adjustment to make sure the WIP inventory aligns with the desired level.
Secondary Processor Order	= max(0, Order from customers + SR1 + WIP Adjustment 1)	Order put forward by the secondary processor, which is constrainted to be always positive (Sterman, 2000). The order needs to be sufficient to cover the order from customer, the difference in desired WIP inventory, and any stock lost due to spoilage.
OF2	= min(Secondary Processor Order, SFP for shipping)	Same logic as secondary processor
Desired Semi-finished products (SFP)	= Secondary Processor Order	Desired number of semi-finished products that primary processor needs.
SFP for shipping	= ∫ (OF2 – SFP, SFP for shipping at t_0) SFP for shipping at t_0 = Secondary Processor Order t_0	Semi-finished products on hands and ready for shipment.
SFP	= min(Desired SFP,(WIP Inventory 2-SR2)/ED2)	Fulfillment rate of the primary processor
ED2	= OPT2 + MT2	
WIP Inventory 2	= ∫ (RM Receive Rate – SFP – SR2, WIP Inventory 2 at t_0)	Work in process inventory for manufacturing semi-finished products.

Desired WIP at Primary processor	= Desired SFP * ED2	This is a flow to the ED, which is a stock valuable. When there is a gap between the actually demand and the expected demand, this value changes to update the expectation of seller about demand.
WIP Adjustment 2	= Desired WIP PP-WIP Inventory 2+SR2	This adjustment is to keep the inventory level in line with the desired level.
Primary Processor Order	= max(0,WIP Adjustment 2+Secondary Processor Order+SR2)	Order put forward by primary processor.
OF3	= min(("Raw material (RM) Inventory"-SR3)/OPT 3,Primary Processor Order)	Same logic as the other two echelons.
Raw material (RM) Inventory	= ∫ (RM Sourcing Rate – OF3 – SR3, WIP Inventory 2 at t_0)	RM kept at the warehouse of the raw food provider
Desired RM level	= Primary Processor Order * OPT3	
Desired RM Sourcing rate	= Primary Processor Order + Inventory Adjustment	
Inventory Adjustment	= Desired RM level – RM Inventory +SR3	
RM Sourcing Rate	= Desired RM Sourcing rate	

APPENDIX 6 – CALCULATING THE COST OF THE OPERATIONS FOR THE TWO SCENARIOS – SD MODELLING PART IN CHAPTER 4



The Figure in this appendix showcases the components that make up the total operations cost for a conventional FSC and a Blockchain-integrated FSC scenarios. In Vensim software, we developed the calculation of cost in a different view, using inputs directly from the main models in the form of "shadow variables" (with the name of the variable inside the < > notation). This function allows modellers to continue building on different parts of the system without compromising the readability and clarity of the main models. Cost calculation for both scenarios is similar for the most part, except in the BC case the costs of Blockchain development and Blockchain maintenance are included (variables in green text).