Unveiling the factors influencing transparency and traceability in agri-food supply chains: an interconnected framework

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Abstract

Purpose – The global food industry is faced with the dilemma of finding a balance between food wastage and food shortage. Approximately one-third of food produced globally goes to waste, while about 800 million people suffer from undernourishment. Given this context, the purpose of this study is to investigate the unresolved challenges related to enhancing transparency associated with products of high perishability and low shelf life.

Design/methodology/approach – The authors conducted 25 interviews with global agri-food supply chains (AFSCs) experts to ask what impedes the progress of the current technologies, such as blockchain, to enable transparency and traceability (T&T) in AFSCs.

Findings – The findings indicate barriers at the individual, firm and supply chain levels. Based on these barriers, the authors propose an interconnected framework to explain technologically-driven T&T and guide on barrier removal from AFSCs. The authors conclude that by applying technology (i.e. blockchain) the authors can resolve the tension of supporting T&T in AFSCs. This can enable the efficient and transparent tracking of goods, reduction of food waste and loss, as well as promotion of the use of recyclable packaging and further sustainable practices and materials, all of which are aligned with a range of UN Sustainable Development Goals (2, 8, 10 and 12). Moreover, the authors see that some factors are interrelated. Based on these factors, the authors build an interconnected framework to guide on barrier removal from AFSCs. Managers in AFSC would find the findings especially relevant.

Originality/value – Drawing on industrial network theory and signalling theory, the authors propose an interconnected framework for explaining barriers (challenges) and potential solutions (opportunities) to T&T in AFSCs. This framework is developed by examining the interconnections of barriers at micro, meso and macro levels and applying signalling theory to explain how solutions address these barriers. The specific contributions of this study are: the list of barriers that impede the implementation of technological solutions for T&T in AFSCs; and a three-stage framework that explains how to remove the barriers for T&T. The study is limited by the focus on blockchain, which calls for future research once the next decentralised technology becomes available.

Keywords Data transparency, Traceability, Supply chain management, Qualitative research, Agri-food, Blockchain

Paper type Research paper

1. Introduction

The World Economic Forum (WEF) has ranked the food crisis as the fifth highest risk in terms of impact for the year 2022 (WEF, 2022) and food is a common thread that connects all 17 UN Sustainable Development Goals (UN SDG) (Gerassimidou *et al.*, 2022). The increasing demand for food quality by customers and regulators highlights the critical challenges encountered within agri-food supply chains (AFSCs). Food quality is emphasised by globalisation and outsourcing, with key challenges within the sector relating to the shortage of transport infrastructure, cold chains and effective supply chain management (Krishnan *et al.*, 2021; Kamal *et al.*, 2022). Statistics related to sickness or deaths

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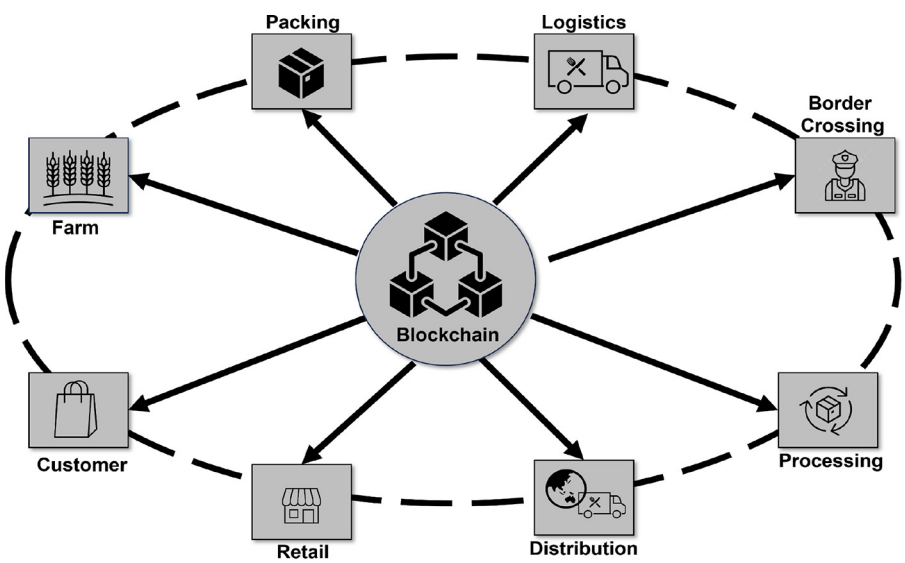
resulting from food-related issues are alarming, with an estimated 48 million people in the USA falling sick annually due to food-borne diseases and almost 5,000 dying as a result (CDC, 2021). For instance, food scandals, such as the horse meat (2013) and *E. coli* (2018), expose the vulnerability of AFSCs and call for an urgent improvement in transparency and traceability (T&T).

T&T in supply chains has been identified as a critical factor for achieving several UN SDGs (Zhao *et al.*, 2019). For example, zero hunger (UN SDG 2) aims to end hunger, achieve food security, improve nutrition and promote sustainable agriculture (United Nations, 2023). The low shelf life and perishability of food products in AFSCs have necessitated the exploration of new technologies to digitise conventional supply chain processes and enhance transparency, traceability and accountability (Hastig and Sodhi, 2020; Shin *et al.*, 2018; Gelsomino *et al.*, 2023; Kilubi and Rogers, 2018). Recently, there has been increasing interest in exploring technological solutions, particularly blockchain, to ensure T&T (Gaur and Gaiha, 2020; Hew *et al.*, 2020; Brookbanks and Parry, 2022; Markus and Buijs, 2022; van den Breul *et al.*, 2018). Blockchain technology has been reported as a viable solution because of its ability to provide an immutable and transparent ledger for transactions (Kayikci *et al.*, 2022; Kazancoglu *et al.*, 2021). While traceability can be also achieved through manual processing or electronic data interchange, blockchain can increase the scale of food safety improvement. In a blockchain-based system, each transaction in the supply chain is recorded as a block and linked to the previous one, forming a chain of blocks, and therefore, a permanent, tamper-proof record of the history of a product, including its origin, processing and distribution (Xu *et al.*, 2023). For instance, the "Farm to Fork" strategy (refer to Figure 1) launched by the European Union as part of its Green Deal (European Commission, 2022) recognises the significance of a sustainable food system in light of increasing concerns regarding food fraud, contamination and mislabelling. Blockchain enables tracing the journey of a product from farm to plate (Markus and Buijs, 2022) and also incorporates consensus mechanisms (Nakamoto, 2008) that improve the T&T of decision-making at each stage. In line with this, Walmart VP Frank Yiannis highlighted that blockchain dramatically reduced food tracking times from seven days to 2.2 s (Gutierrez, 2017).

Additionally, T&T can help reduce the environmental and social impacts of the products we consume by tracking the materials, energy and waste associated with production and facilitating accountability (Cousins *et al.*, 2019). For example, tracking the supply chain of a product from the source of raw materials to the final product reveals information on the working conditions, thereby reducing transaction time (Chaudhuri *et al.*, 2022), allowing consumers to make informed decisions and promoting greater accountability in the supply chain (e.g. Brookbanks and Parry, 2022; Giri and Manohar, 2021; Ramos *et al.*, 2021). It allows for better monitoring of working conditions and wages, helps to increase the income of small-scale farmers, reduces rural poverty and promotes food security, responding to the goal of decent work and economic growth (Goal 8). Blockchain can help establish direct connections between producers and consumers, enabling farmers to receive fair prices for their products and reducing the need for intermediaries (Garcia-Torres *et al.*, 2019), Goal 12. T&T can also contribute to reducing inequalities (Goal 10) by ensuring that supply chains are more inclusive.

While the benefits of blockchain technology in supply chain management such as improved transparency, traceability and increased accountability, have been widely acknowledged in many studies, including Rogerson and Parry (2020), Wang *et al.* (2018), Markus and Buijs (2022) and Brookbanks and Parry (2022), Queiroz *et al.* (2021) it remains unclear why there are only a few practical applications or implementations in the industry. Studies such as Markus and Buijs (2022) and Reyes *et al.* (2022) have recognised the importance of a better

Figure 1 Blockchain for farm to fork



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understanding of blockchain technology to enable informed decisions on its adoption and implementation within supply chain operations. The lack of practical implementation in the AFSC raises concerns regarding the unaddressed challenges that must be overcome for the widespread adoption of T&T. Other studies mention high efforts required for the implementation of blockchain in AFSC (Pandey *et al.*, 2022), which can be a significant deterrent for organisations, particularly smaller ones. In addition, the lack of standardisation and regulatory frameworks for blockchain technology can create challenges for organisations seeking to implement it (Janssen *et al.*, 2020; Feng *et al.*, 2020).

Although blockchain was introduced more than a decade ago, it is still in the conceptual stage for agri-food (Xu *et al.*, 2023). This study aims to contribute to the ongoing discussion about using technology (blockchain, in particular), to achieve T&T in AFSCs (Hew *et al.*, 2020; Rogerson and Parry, 2020; Markus and Buijs, 2022; Garcia-Torres *et al.*, 2019). Our motivation is twofold: we aim to provide state-of-the-art of T&T implementations and characterise the progress of technology implementation. The following research questions were developed to address the research aims:

RQ1. What are the barriers to technological support for transparency and traceability in AFSCs?

RQ2. What can improve technological support for transparency and traceability?

In response, we conducted 25 semi-structured interviews with 15 stakeholders from agri-food companies engaged with T&T pilots in AFSCs. By conducting a thematic analysis, we derive the factors characterising the adoption and implementation of the technology, such as barriers to technological support of T&T, layers of these barriers and potential solutions to tackle the challenges across the individual, firm and supply chain levels. Drawing on Industrial network theory (Hakansson, 1982) and Signalling theory (Spence, 2002), we propose an interconnected framework to explain barriers (challenges) and potential solutions (opportunities) to T&T in AFSCs. Industrial network theory considers the behaviour of actors in inter-organisational relationships and how these relationships impact strategic network positions. Signalling theory sheds light on the transfer of information to resolve information asymmetries, an issue prevalent in AFSCs. By combining these theories, we can holistically examine the challenges of T&T in AFSCs and propose appropriate solutions. This advances our understanding of the agri-food industry's challenges and provides practical implications for managerial decision-making.

The specific contributions of this study are: the list of barriers that impede the implementation of technological solutions for T&T in AFSCs; and a three-stage framework that explains how to remove the barriers for T&T in AFSCs. This framework was developed by examining the interconnections of barriers at the *micro*, *meso* and *macro* levels and applying signalling theory to explain how solutions address these barriers. We conclude that by applying technology (i.e. blockchain) we can resolve the tension of supporting T&T in AFSCs. This can enable the efficient and transparent tracking of goods, reduction of food waste and loss, promotion of recyclable packaging and further sustainable practices and materials, all of which are aligned with a range of UN SDG (2, 8, 10 and 12). Therefore, AFSC managers will find our study's findings exceptionally valuable.

The rest of the paper is structured as follows. Section 2 discusses the literature and presents theoretical underpinnings. Section 3 presents the research methodology comprising an inductive research approach for data collection and analysis methods. In Section 4, we present the study research findings. Section 5 presents a discussion of the findings. Section 6 concludes, acknowledges research limitations and suggests future research directions.

2. Literature review

2.1 Overview of transparency and traceability in supply chain management

Supply chain management has generally contended with the issues of T&T. As a matter of fact, supply chain T&T is a boundary-spanning phenomenon that is swiftly proliferating multiple aspects of business operations (Morgan *et al.*, 2023; Zhao and Li, 2023). Three primary mechanisms underpin previous and ongoing measures to achieve T&T in supply chains. They are corporation-led reporting, audit reports and eco-labels (Zorzini *et al.*, 2015). Corporation-led reporting communicates the organisation and its supply chain members' programmes and practices to ensure adherence to codes of conduct (CoC) and other external ethical standards. The corporation-led approach is critical for demonstrating compliance to CoC and other certifications or standards accredited by third parties to validate a company's position that can be a prerequisite for securing orders or contracts with some customers, especially for those in developing countries (Ehrgott *et al.*, 2011). Auditing and audit reports are deployed for assessing, monitoring and verifying firms' conformity with set voluntary standards. It emerged as a part of the private governance mechanisms alongside multi-stakeholder initiatives, CoC, standards and certifications to address both environmental and social issues (Lebaron *et al.*, 2017). The third, eco-labels, are used to communicate and ensure T&T across multiple stakeholders. ISO 14024 defines eco-labelling schemes as "voluntary third-party programmes that award labels based on independent audits" (ISO 14024, 2001). There are over 400 eco-labels that are provided to interested parties by independent labelling schemes that act as certification intermediaries by establishing voluntary standards while serving as a verification and certification body to supply chain networks (Castka and Corbett, 2016).

Traditional supply chain management systems, which rely on manual data entry and paper-based documentation, are prone to errors and fraud (Garcia-Torres *et al.*, 2019). The need for a more robust and reliable system for tracking and monitoring the flow of goods has led to the exploration of technology-based solutions, with blockchain being one of the most promising solutions (Hew *et al.*, 2020). T&T refers to the ability to track and monitor the journey of a product from its origin to its final destination and to communicate this information to stakeholders clearly and transparently (Hew *et al.*, 2020). Implementing T&T practices in supply chain management has been identified as a crucial aspect of ensuring sustainability, consumer trust and business efficiency (Rogerson and Parry, 2020). In particular, T&T have become increasingly important

due to the growing need to support sustainable and ethical production practices (Bateman and Bonanni, 2019). It can drive innovation and foster trust between stakeholders, leading to increased sustainability and ethical production practices in the supply chain sector (Brookbanks and Parry, 2022). Studies have shown that the supply chain sector faces numerous challenges in achieving T&T, including a lack of standardisation and limited collaboration between supply chain actors (Markus and Buijs, 2022).

The use of blockchain technology in supply chain management offers several advantages over traditional methods, including increased efficiency, security and immutability of data (Garcia-Torres *et al.*, 2019). In particular, the decentralised nature of blockchain technology, which allows for creating a shared ledger of all transactions in the supply chain, provides a secure and transparent platform for exchanging information between supply chain actors (Markus and Buijs, 2022). Blockchain eliminates the sole dependence on third parties, represented as "the middleman" or single point of truth, making it a disruptive innovation in the field of technology (Gurtu and Johny, 2019), and its potential to foster T&T is well-accentuated (Pournader *et al.*, 2020).

In contrast to traditional supply chains (SCs), which rely on centralised systems and intermediaries to manage and track the flow of goods and information (Hew *et al.*, 2020), food, diamond and pharmaceutical supply chains have already adopted the benefits of decentralisation via blockchain (Choi, 2019) such as T&T. For example, blockchain has enabled accurate data recording of emissions that can be collected along the whole supply chain (Upadhyay *et al.*, 2021), which creates accountability (Gualandris *et al.*, 2015; Saberi *et al.*, 2019; Rogerson and Parry, 2020; Khan *et al.*, 2022). Other blockchain applications include agricultural insurance, smart farming and food supply applications (Xiong *et al.*, 2020). Among the literature on blockchain in SCs, there are limited reasons to implement blockchain within AFSCs, as per Figure 2.

2.2 Barriers to blockchain-enabled transparency and traceability in supply chains

Within the broad literature of supply chain management, there is a growing appreciation of the potential challenges the implementation of blockchain can introduce. Some studies, for example, Li *et al.* (2020b), focus on the internal drawbacks such as code vulnerabilities, anonymity, immutable code and complexity, arguing for mitigating these risks. Some authors note external issues such as regulatory deficiencies, data privacy concerns and cross-border challenges (Baharmand *et al.*, 2021). Mukherjee *et al.* (2022) propose three thematic clusters of challenges:

2.2.1 Technical or technological barriers

The first view on challenges for enabling T&T in supply chains is *technical or technological,* as blockchain has been predominantly researched from a technical complexity view (Zhao *et al.*, 2019). These technological or technical barriers are a consequence of the complexity of the blockchain design, technological immaturity, high energy and infrastructure requirements and security issues (Mukherjee *et al.*, 2022). Integrating blockchain with existing systems and processes in the agri-food sector is challenging and requires a high level of technical expertise and knowledge (Mangla *et al.*, 2022; Sodhi *et al.*, 2022), which represents a barrier for small and medium-sized enterprises (SMEs) (Agarwal *et al.*, 2022).

2.2.2 Organisational barriers

The second category of challenges is organisational barriers, which according to Mukherjee *et al.* (2022) are evident in lack of finance and support from the top management, inadequate trust among various stakeholders, limited understanding and technical expertise to undertake or support the project, employee and stakeholder resistance to change and adopting the technology and insufficient tools for technology implementation.

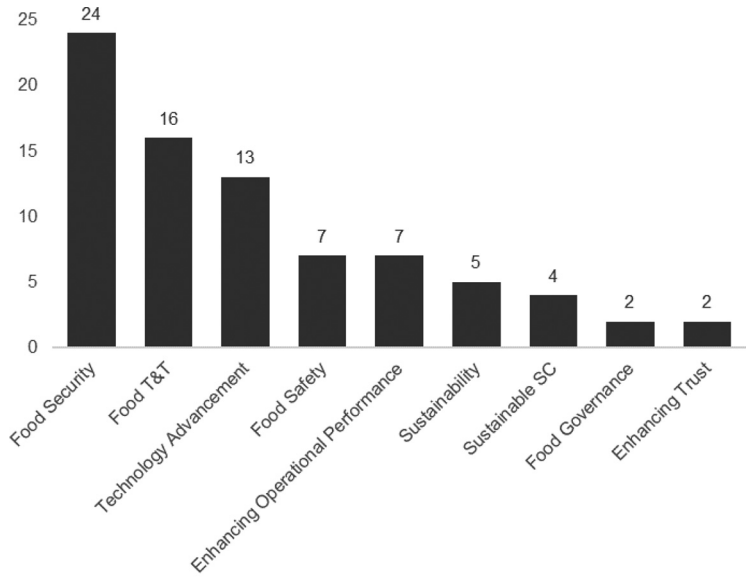
2.2.3 Environmental barriers

The third group considers *environmental barriers* to widespread adoption in AFSCs. Underpinning the environmental barriers are the issues of coordination/cooperation (Kramer *et al.*, 2021; Compagnucci *et al.*, 2022) and trust, which is predominant in the literature (Compagnucci *et al.*, 2022). The issues stemming from the environmental perspective include lack of governmental policies, uncertainty and market pressure, collaboration and coordination problems in the supply chain, limited interest in blockchain adoption, as well as security and legal implications (Mukherjee *et al.*, 2022). For example, Kramer *et al.* (2021) found that blockchain is significantly impacted by the collaboration between AFSC parties, which is determined by how information is shared, joint decision-making and collective learning differently. Despite the trustless and decentralised nature of blockchain technology, the agri-food industry still requires inter-firm trust and relationships between various stakeholders. For example, farmers may be reluctant to share sensitive information about their operations with intermediaries, such as processors or retailers, whom they may view as competitors (Li *et al.*, 2021). Figure 3 visualises these three groups.

The regulatory landscape has significant implications for the implementation and utilisation of blockchain technology in supply chain management. Regulatory frameworks can impact not only the adoption rate of the technology but also shape how it is used and the extent of its effectiveness. Current regulations may pose significant challenges to the full implementation of blockchain. For instance, data privacy laws, such as the European General Data Protection Regulation may conflict with the immutable and transparent nature of blockchain, potentially limiting its application (Haque *et al.*, 2021). Moreover, legal jurisdictions across the globe have varied and sometimes contradictory approaches towards blockchain technology, often due to a lack of understanding or clarity regarding its operation and implications. This lack of harmonised regulations can impede the effective integration of blockchain in global supply chains that span multiple jurisdictions (Cole *et al.*, 2019).

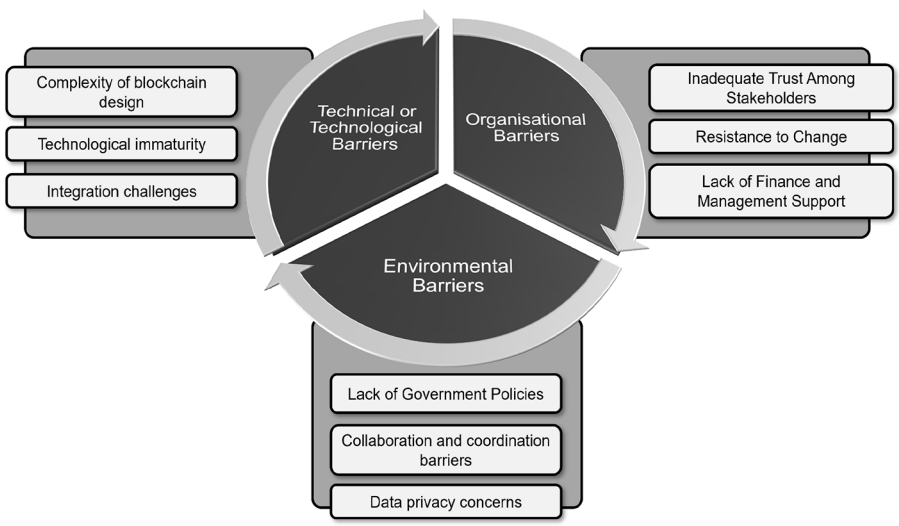
Despite these challenges, existing regulations can also stimulate the use of blockchain in supply chains. For example, the Food Safety Modernisation Act in the US requires enhanced tracking and monitoring of food supply chains, a functionality that blockchain technology can effectively facilitate (Queiroz *et al.*, 2019). In the pharmaceutical industry, the Drug Supply Chain Security Act mandates serialised

Figure 2 Specific objectives of blockchain implementation in AFSC, based on the literature review



Source: Authors' own work

Figure 3 Three clusters of barriers to T&T



Source: Authors' own work

traceability of prescription drugs, a goal towards which blockchain can contribute significantly (Sarkar, 2022). Additionally, there may be a need for more understanding and mistrust of blockchain technology among various stakeholders, who may see it as complex, untested and unnecessary. These perceptions and mistrust can be further perpetuated by stereotypes and biases, leading to a lack of acceptance and adoption of the technology. To promote the widespread adoption of blockchain in the AFSC, it is crucial to establish trust and collaboration among stakeholders.

Moving forward, there is a clear need for new regulatory frameworks that specifically address blockchain technology's use in supply chains. Such frameworks would need to balance the need for data privacy and security with the potential benefits of T&T that blockchain provides. They would also need to accommodate the decentralised and cross-jurisdictional nature of blockchain, ensuring its potential can be fully realised in global supply chains.

2.3 Theories to explain the barriers and enablers to transparency and traceability in agri-food supply chains

Industrial network theory provides a mechanism for understanding the intricate dynamics of interpersonal and inter-organisational relationships between firms, especially in the supply chain context (Hakansson, 1982). The key concepts of this theory include actors, relationships and networks, which help understand the interactions between firms and the implications for developing the supply chain (Snehota and

Hakansson, 1995). The industrial network theory is particularly significant in illuminating how technological changes influence the strategic positioning of actors within these networks (Mandják *et al.*, 2017). Network behaviour is "the actors' activities in their direct and indirect business and non-business relationships that affect their strategic network positions". The significance of the theory is reflected in recent scholarly works, such as Kowalski *et al.* (2021), which underscores the pivotal role of trust in enhancing the effectiveness of technology within supply chains. Developing trust in relationships, as an imperative component to effectively reaping the benefits of technology implementations, represents an important concern of industrial network theory (Kowalski *et al.*, 2021). For example, Handoko *et al.* (2022) explore the role of social capital in knowledge exchange in supply chains, which increases trust and collaboration between the actors. Studies that have used industrial network theory in supply chain management examine the impact of network relationships on the coordination of supply chain activities (Saikouk *et al.*, 2021; Agrawal *et al.*, 2023; Song *et al.*, 2023). Similarly, reflecting the importance of interdependence in these networks, found that supply chain collaboration was moderated by information transparency and transaction dependence.

Signalling theory, on the other hand, provides a mechanism for understanding information transfer, especially in contexts impacted by information asymmetries such as supply chain management (Spence, 2002; Stiglitz, 2002; Connelly *et al.*, 2011). Originally conceptualised by Spence (2002), and later expanded upon by several researchers, including Stiglitz (2002) and Connelly *et al.* (2011), this theory posits that in environments with significant information disparities, specific actions or "signals" are leveraged to convey credible information. Managing an information asymmetry environment may require "signalling" to reduce information asymmetry between "signalers" and receivers. Rao *et al.* (1999) notably defined a "signal" as a deliberate action from the seller, aiming to provide credible insights into otherwise intangible product qualities. With the advent of technological support tools, for example, blockchain, such signals become more potent in mitigating information asymmetries, especially in AFSCs. T&T in AFSC aim to reduce information asymmetry and facilitate the exchange of "signals" between the actors of AFSCs using technological support, like blockchain.

The combination of industrial network theory and signalling theory in our study can offer a multi-faceted framework for exploring the challenges and opportunities of blockchain in AFSCs. Earlier studies have shown that the use of blockchain technology can serve as a robust signal of trust in supply chain management (e.g. Brookbanks and Parry, 2022; Ying *et al.*, 2023), and this can reduce the technological turbulence on the actors' behaviour and the actions of actors defining strategic network positions (Mandják *et al.*, 2017). This interplay between blockchain as a "signal" and the intricate Web of relationships in supply networks makes the dual-theoretical framework invaluable. In particular, the combined insights of both theories allow a deeper exploration into how blockchain can potentially dampen the disruptive effects of technological changes on network actors.

2.4 The gap – a need for a theoretical framework supporting transparency and traceability in agri-food supply chains

While it is clear that blockchain has the potential to offer numerous benefits (Ying *et al.*, 2023; Brookbanks and Parry, 2022), it is important to recognise that the technology is not a panacea. The majority of applications of blockchain technology have been in the financial sector, which happens to be where the technology originated. However, blockchain applications have extended beyond the financial sector, with the technology beginning to cause a significant change in various sectors. There is a limited understanding of the industrial implementation of blockchain technology outside the financial sector such as benefits for supply chain management and the extent to which the technology can (or has) transformed (ed) the industry (Queiroz *et al.*, 2019). Blockchain has also been tipped to disrupt the agriculture and food sector and provide transparency in the AFSC (Rogerson and Parry, 2020). Despite recognising blockchain technology as a potential driver for achieving transparency in AFSCs from a literature perspective (Markus and Buijs, 2022; Reyes *et al.*, 2022), there appears to be slow progress in its industrial/practical adoption. There is a lack of evidence as to why the technological support for T&T is slowly progressing in the sector. Hence, it is crucial to critically understand the roadblocks to support transparency for AFSC, which ultimately enhances transparency in the food supply chain.

3. Methodology

3.1 Research method

We adopted an exploratory qualitative approach using semi-structured interviews from industry experts. The choice of this methodology is justified as it allows for the provision of in-depth insights into the barriers and challenges to the adoption and implementation of blockchain technology for achieving T&T in AFSCs. The exploratory nature of the study necessitates a methodology that fosters flexibility and adaptability, enabling the researchers to probe deeper into the nuances and complexities of the research topic, ask follow-up questions and explore emerging themes. Qualitative approaches are particularly suitable for capturing rich, context-specific information and understanding the subjective experiences and perceptions of stakeholders (Bryman, 2016). Besides, surveys or quantitative approaches may not be as effective in capturing the complexities and nuances of barriers and challenges, whereas qualitative methods, such as semi-structured interviews, offer the flexibility needed to explore the multifaceted nature of the research questions (Creswell and Creswell, 2017). Many studies in the field of blockchain technology and supply chain management have adopted a similar research methodology of exploratory qualitative approaches using semi-structured interviews (e.g. Hew *et al.*, 2020; Markus and Buijs, 2022).

3.2 Research paradigm

Our research study adopts the interpretivism paradigm (Saunders *et al.*, 2009), which allows for exploring complex social phenomena, like technological support for transparency in AFSCs. By using a combination of data collected from primary and secondary sources, we can examine the factors that influence the adoption and implementation of blockchain by

aggregating and examining the subjective experiences of stakeholders and practitioners in the field. This approach allows for a more holistic understanding of the barriers that prevent the widespread adoption of blockchain technology in the industry. Furthermore, interpretivism allows for examining the social context and cultural factors that play a role in the technology adoption; this is crucial to understanding the dynamics of blockchain implementation in AFSCs (Martinsuo and Huemann, 2021).

3.3 Research context

The global food industry is faced with significant challenges, including food waste and undernourishment, as well as concerns about food safety and quality. These issues have been highlighted by recent food-borne illness outbreaks and scandals, which have exposed the vulnerabilities of current supply chain practices. Within the AFSC, supply chain managers often rely on manual processes susceptible to human error. Despite the potential of blockchain technology to address these challenges through improvements in traceability, transparency and efficiency, blockchain has limited implementation within AFSCs. This is supported by the literature, with studies such as Galati (2021), Markus and Buijs (2022), Zhao and Li (2023) and Zhong *et al.* (2023) highlighting the potential of blockchain in this context. However, further research is needed to examine the barriers to the effective implementation of blockchain in AFSCs.

3.4 Sampling method

To identify potential firms for interviews, we performed various forms of desktop research, such as business networking websites like LinkedIn and industry news sources, to identify the practitioners in AFSC who have experience in enabling T&T in their supply chains. Specifically, our industry contacts were explored to identify organisations that have already implemented blockchain technology. Due to the lack of industrial evidence for purposeful sampling, a snowball sampling strategy (Farquhar, 2012) was used, with interviewees being asked if they knew of any additional individuals or organisations that could provide valuable insight into implementing blockchain technology within the AFSC. Snowball sampling can be a useful way to research phenomena that are not discovered such as blockchain experiments in AFSC and might be difficult to identify otherwise. It enables researchers to access individuals or organisations having specialised knowledge or have unique experiences in a specific field (Berg, 2009). By using snowball sampling, we aimed to capture a comprehensive range of stakeholders involved in blockchain implementation within the AFSC. While the sample obtained through snowball sampling may not be representative of the entire population, it provides valuable insights and allows for an in-depth exploration of the experiences and perspectives of key actors in the field (Given, 2008). Interviewing experts in the field is an effective method of data collection, especially when exploring a nascent application area, for example, blockchain implementation in AFSCs (Markus and Buijs, 2022), Table A1.

3.5 Interview design

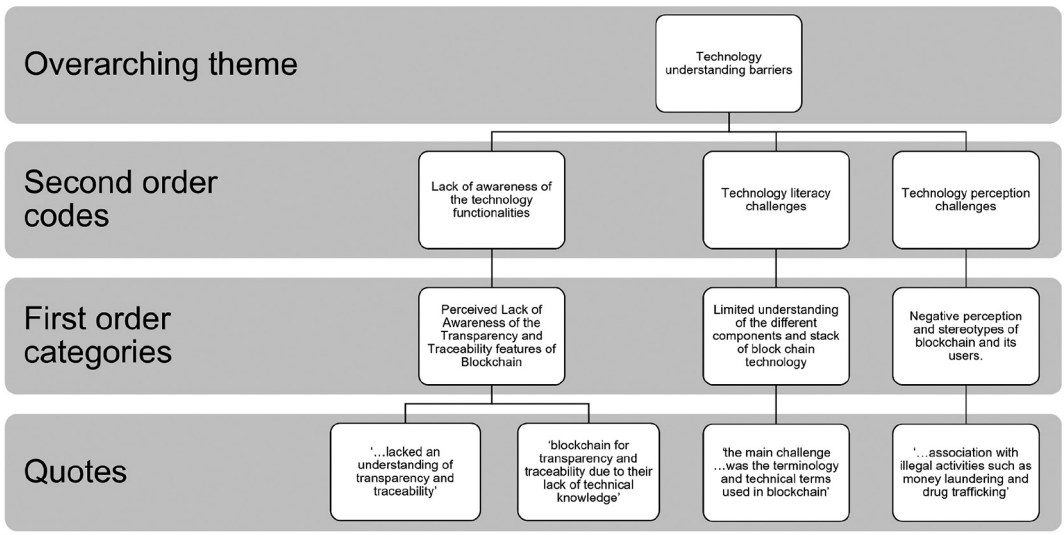
This study's primary data collection method was semi-structured interviews with open-ended questions (Martinsuo and Huemann, 2021; Patton, 2014). This approach was chosen to elicit detailed information about specific blockchain pilot implementation projects while also allowing for the collection of more general insights and causal inferences. Firstly, we analysed the literature review data and documents such as reports and online/news articles (Denzin, 2012). It allowed us to formulate questions for semi-structured interviews to understand better how the blockchain pilot projects are implemented. The interview protocol was designed to better understand their perception of the implementation of blockchain in AFSCs and what challenges were encountered within the respective implementations (please refer to Table A2). Our research strategy led us to approach a total of 113 organisations. Of these, 33 responses were received, allowing us to conduct 25 interviews with a sample of 15 industry experts (some of whom were interviewed two times) from key blockchain implementation projects globally. The interviews were structured to elicit information on the technology landscape within individual organisations, specifically focusing on the supply chain. The online interviews, which were conducted using Zoom and MS Teams, averaged 45 min in duration. The interviews were conducted online to maximise participation and reduce time and cost associated with travel. During the interviews, the problem(s) and challenge(s) that prompted the need for blockchain implementation were also explored, as well as how blockchain technology addressed these problem(s). Follow-up questions were asked to elaborate on more specific examples and additional detail as appropriate. The interviews were recorded, transcribed and reviewed to ensure accuracy and completeness and follow-up interviews were conducted as needed to address any mistakes or gaps.

3.6 Data analysis

The researchers began the data analysis by familiarising themselves with the data and developing initial codes from the interview transcripts. Thematic analysis is a widely used qualitative research method that allows for identifying, analysing and interpreting patterns within data (Braun and Clarke, 2006). In our study, we have chosen this method as it is particularly useful for exploring subjective experiences and understanding the meaning that individuals attach to these experiences (Joffe, 2011). Furthermore, thematic analysis allows for a flexible and iterative approach to data analysis, which is crucial in this study as we aim to explore a complex phenomenon having multiple perspectives. This process involved identifying descriptive themes and grouping them into interpretive themes (King and Horrocks, 2010), Figure 4.

The thematic analysis technique used in this study used an inductive logic approach. The themes emerged from the data itself through a process of open coding, allowing for a bottom–up exploration of the barriers and challenges identified by the participants during the semi-structured interviews. We applied a combination of both a priori and posteriori approaches. While we drew upon existing literature to inform our initial understanding of the barriers at different levels (i.e. micro, meso and macro), the specific categorisation and instantiation to our current data set were refined and validated through an iterative process of analysis and discussion among the research team. In simple terms, we ensured that the categorisation accurately represented the barriers identified in the data and aligned with the theoretical concepts and frameworks used in the study. Finally, we integrated two theories to enable a holistic framework that helped us to explain the phenomena

Figure 4 Summary of the coding approach adopted after King and Horrocks (2010)



*Note that for the other themes we can use the similar tree

Source: Authors' own work

observed in this research. From the network perspective we took the construct of supply chain structure and stakeholders relevant in supply chains. From the signalling theory, we inherited the need to share data to resolve information asymmetry: signal and receive, that help to resolve information asymmetry. We aligned these variables to develop a holistic framework. In the coding process, we agreed on, including new sub-categories as they appeared from the data. This approach was informed by empirical studies in existing literature relating to blockchain in food supply chains (Khan *et al.*, 2022; Tan *et al.*, 2022). Consequently, we confirmed theoretical saturation when the analysis no longer identified new codes (Tashakkori and Creswell, 2007; Braun and Clarke, 2006). Furthermore, triangulation based on the literature review was used to ensure the findings' validity, transparency and reliability and test the relationships between key concepts. We presented the final coding structure (quotations, first-order categories, second-order themes and overall themes) by adopting the Gioia (2013) framework.

3.7 System dynamics

System dynamics is "an approach to understanding the nonlinear behaviour of complex systems over time using stocks, flows, internal feedback loops, table functions and time delays" (Sterman *et al.*, 2015). We use causal loops to present the identified barriers and solutions at *micro*, *meso* and *macro* levels in the form of causal loop diagrams, discussing the interrelationships between them and suggestions for removing them.

4. Findings

Data shows the roadblocks to enabling technological support for T&T in AFSCs, such as blockchain, across the *micro* level of individuals – *technology understanding barriers*; the *meso* level of industrial firms – *technology adoption barriers*, *data governance barriers*, *data sharing barriers*; and the *macro* level of AFSCs – *national regulation of data*, *international regulation of data*, Figure 5.

4.1 Theme 1: Technology understanding barriers

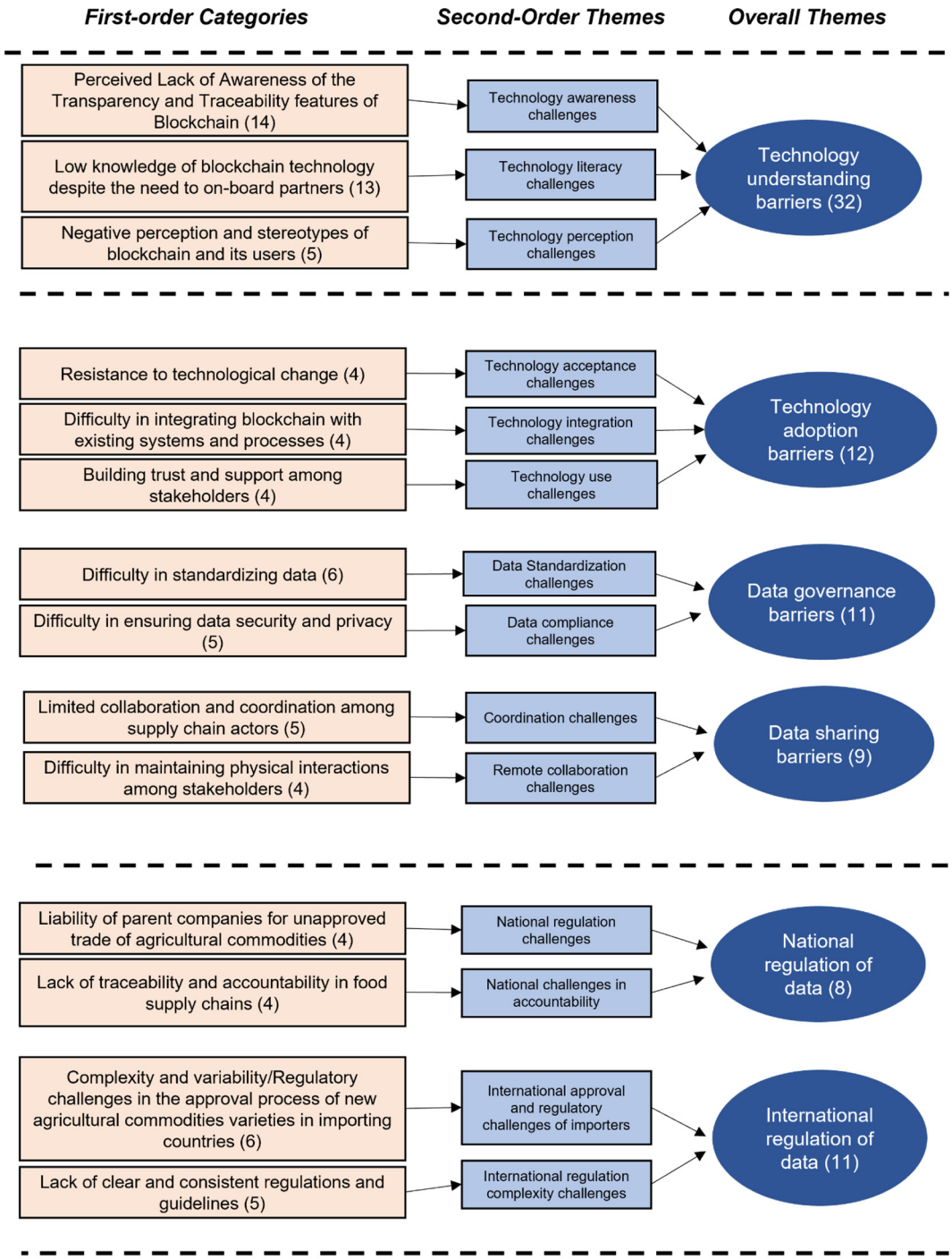
The first theme considers the *micro* level (i.e. an individual perspective of a human being). Here, we found challenges related to the misleading perception about blockchain technologies, the lack of technological awareness and digital literacy, resulting in challenges in technology understanding. Across the interviews, participants often mentioned the stereotypes and gossip around blockchain, which triggered scepticism regarding the technology. For example, IC5 said: *many of our partners* [colleagues] *were hesitant to adopt blockchain due to its association with illegal activities such as money laundering and drug trafficking*. This perception of blockchain as a tool for criminals excluded the possibility of perceiving its application as a new legitimate technology. Moreover, the negative stereotypes around blockchain users have made it hard for people to understand the potential benefits it can bring to them. IC6 agreed: *we had a lot of trouble getting buy-in from our suppliers, as they had a negative perception of blockchain and saw it as a tool for fraud and deception.* IC1 summarised: *when* [our colleagues] *think of blockchain, it appears what comes to mind is a teenager in their grandma's basement, eating crisps and hacking company servers. Until this thinking changes, we won't go anywhere.*

Most respondents revealed a very limited awareness of blockchain among their colleagues. *They have heard of it. However, they do not know what it is, how it works or its potential applications - IC7. This makes it difficult to engage employees in blockchain projects. It* impedes decision-makers from blockchain implementation at scale. For example, Participant IC10 pointed out:

> There are still many decision-makers in the supply chain who are not comfortable with blockchain technology and some of them even have a negative perception of the technology. They have many questions and concerns and need more education on the subject. Until they understand the benefits, it will be difficult to implement it at scale.

IC7 also mentioned the employees of sub-contractors: *We've come across suppliers* [employees] *who do not see the need for T&T in the supply chain, let alone understanding how blockchain technology can support it.*

Figure 5 Data structure



Source: Authors' own work

When asked about the explanation of low understanding, the subtheme of digital literacy emerged. For example, IC7 described that the need to understand technology resulted in employee educational programmes across the company:

> [. . .] when we first delved into the world of blockchain, one of the first things we did was to understand the different components and stack of the technology. We wanted to have a clear picture of how it works so that we could leverage it in our supply chain operations. It was a lot of work, but it was worth it in the end.

IC5 confirmed a *steep learning curve* while familiarising themselves with the technicalities of blockchain and highlighted *[. . .] there is a need for more education about the T&T features of blockchain technology*.

Across the interviews, we found a need for education and onboarding of partners as the critical issue due to the need to understand the potential benefits of blockchain technology. For example, IC11 noted:

> [. . .] we cannot just assume that everyone knows about blockchain and how it works. It is up to us to educate our partners and ensure they understand its potential for improving supply chain transparency and efficiency.

IC6 agreed:

> [. . .] many of our partners are still unfamiliar with blockchain technology and its capabilities. It's imperative that we invest in educating them so that they can see the value it can bring to their business operations.

One of the main challenges encountered during the implementation process, as highlighted by IC11, was *the need to educate and onboard partners and stakeholders on the use of blockchain*. Finally, IC14 added, *onboarding our partners is a critical step in adopting blockchain technology. Without their support and understanding, it will be challenging to realise its potential in the agri-food supply chain fully*.

In summary, the individual (micro) level is a critical success factor in implementing blockchain technology across AFSCs. Employees require support to resolve established stereotypes and phobias around blockchain, increase their knowledge of its application and understand the potential of blockchain technology to increase T&T across their supply chain.

4.2 Theme 2: Technology adoption barriers

The second theme from our study relates to barriers to adopting technology, which was at a *meso* level (i.e. at the firm perspective). For example, IC4 noted that *many partners and stakeholders were hesitant to adopt the technology as it was seen as a new and unfamiliar concept*. IC8 highlighted that:

> [. . .] many individuals did not see the need to change their current processes even if they were not as efficient or secure, as they did not fully grasp the long-term benefits.

Further, IC9 also touched upon the *fear of the unknown when it comes to technology change* and that *people need to be convinced that new solutions will make their job easier*. This was further echoed by IC10, who stated that some supply chain parties:

> [. . .] were too set in their ways to consider new technologies and often think, "if it ain't broke, do not fix it". This mentality is a challenge in today's rapidly changing technological landscape.

IC2 highlighted that [. . .] *the main barrier to technological change is not the technology itself, but rather, the challenges related to business processes and change management*. This observation is supported by the comments made by the other participants and highlights the importance of understanding one's business processes to manage the change towards new technologies effectively.

The interviewees reported facing integration challenges with existing systems and processes. For instance, IC5 highlighted that *we quickly realised that there were many challenges in integrating the technology with our current processes and information technology (IT) infrastructure*. As highlighted by IC15:

> We found that many of our partners were reluctant to share information and collaborate on the implementation of blockchain technology. This made it difficult to establish a cohesive and effective supply chain system.

This highlights the difficulties in integrating data, which takes time and extra budget. IC13 pointed out that *we had to completely revamp our IT systems to integrate blockchain technology properly, and it was a time-consuming and costly process*. This finding was also echoed by IC2, who shared that *integrating blockchain into our supply chain operations was a major challenge. We found that it was not as straightforward as we had initially thought and required significant time and resources to implement properly*.

4.3 Theme 3: Data governance barriers

The third theme is also related to the *meso* level (i.e. from the firm perspective). We found data governance challenges related to the standardisation of data, integration of data and keeping data secure, which shifted how firms may add this technology to their balance. Across the interviews, participants, for instance, IC1, mentioned that the lack of data standardisation in individual companies could lead to difficulties in implementing blockchain solutions, stating that*:*

> I have seen people trying to implement blockchain and they have not got a data standards [. . .][the problem is in] the lack of a data standard or whatever else it is.

IC11 pointed out that *there is a need for standardisation in data collection and recording processes to ensure that data is consistent and comparable across the supply chain*. IC8 noted, *The challenge is to have all participants in the supply chain use the same data standard*. Further, we identified the data security challenges, as participants reported the cases of the supply chain being vulnerable to malicious actors. Across the interviews, it was highlighted by many participants; for example, IC9 noted that "Another benefit of integrating blockchain with big data analytics is enhanced security. Since the decentralised nature of blockchain makes it difficult for data to be tampered with or altered, combining it with big data analytics can help to ensure the integrity of the data being analysed". The need for privacy mechanisms in public blockchains was emphasised by IC2, suggesting that*:*

> [. . .] you still have privacy issues that need to be resolved in public blockchains [and] this is an area that needs to be addressed to promote the wider adoption of blockchain in AFSC.

Finally, IC15 highlighted the importance of trust and commitment from the team, stating, *The key to our successful implementation of blockchain technology was the strong support and buy-in from all levels of our organisation. Without the trust and commitment of our management, we would not have been able to navigate the challenges and fully realise the benefits of the technology*.

4.4 Theme 4: Data sharing barriers

The fourth theme, a *meso level* barrier, captured the challenges associated with the coordination of firms and their remote collaboration. Across the interviews, it was highlighted that data sharing must be promoted to implement blockchain technology between firms effectively. For example, IC15 noted, *that many partners were reluctant to share information and collaborate on the implementation of blockchain technology, which made it difficult to establish a cohesive and effective supply chain*. IC4 agreed that the challenge is to align everyone's expectations and goals*: communication and coordination among supply chain actors* [is critically important], *as many of them* [actors], *have different ideas and goals for using blockchain technology*. IC6 also stated that getting *everyone on the same page was a big challenge in blockchain implementation*. This was because some partners were resistant to sharing information and working together. This sentiment was also echoed by IC11, who reported a *difficulty in getting all of their stakeholders to cooperate and collaborate on the blockchain project*. Lack of trust among partners was another *major roadblock in the implementation of blockchain technology*, as noted by IC13.

Moreover, more interaction between the firms happens remotely. For example, the social distancing modality during the COVID-19 pandemic was a prominent example, where the

only possible stakeholder collaboration between the firms was online. As remembered by IC2: *the pandemic . . . made it nearly impossible to meet with suppliers in person and discuss important matters face-to-face*. The reliance on digital communication and collaboration tools also led to operational challenges, as highlighted by IC7: *we struggled to maintain effective communication with our partners and stakeholders during the pandemic as we had to rely heavily on digital means. This led to delays and misunderstandings in our operations*. IC13 added that the lack of physical interactions also affected the ability to establish personal connections and trust with suppliers: *the lack of physical interactions during the pandemic made it difficult to establish personal connections and trust with our suppliers. This affected our ability to make important decisions and move forward with our supply chain operations*. In addition, IC11 mentioned that [use of] *digital communication and collaboration tools* [instead of physical contact] *made it harder to build trust and establish personal connections with our partners and stakeholders*. IC2 confirmed that the pandemic *hindered our ability to build trust and establish strong working relationships* [with other firms].

4.5 Theme 5: National regulation of data

The fifth theme is related to the *macro* level (i.e. the AFSC perspective). Across the interviews, we noticed that companies are held responsible for any black market transactions of their products, even if it occurs beyond their control or knowledge. For example, participant IC4 highlighted that *we are held liable for any unapproved trade of our products, even though it might happen beyond our control and knowledge. This creates a huge risk for our business.* IC6 agreed about a significant risk for our businesses *as a poultry producer, we are responsible for any unapproved trade of our chicken products, even though we might not be aware of the trade*. Similarly, IC9 added that:

> [. . .] one of our clients, a fish farmer, had a real issue relating to the liability for unapproved trade of their seafood products [. . .] this was a real issue for us. In effect, you cannot always control what happens to your products once they leave your farms.

IC13, operating within the livestock industry, also stressed the importance of managing the liability for unapproved trade of meat products, saying, [. . .] *livestock producers face a huge challenge when it comes to liability for trading their meat products beyond the second tier customers*.

The COVID-19 pandemic highlighted the need for a more robust and transparent supply chain system, supported by technological enablers, such as blockchain. For example, IC17 noted, *In light of the pandemic, our customers are more concerned than ever about the safety and origins of their food.* IC12 agreed that *we saw an increase in demand for traceable and transparent food products*. IC16 also agreed that *COVID-19 has shown us the importance of being able to trace the origin of food products.* Thus, national regulation of data represents a potential to support T&T AFSCs. IC4 summarises: *. . .sadly, there is the reality and risk that we can get into trouble if any of our products end up where they have not been approved, we all know that, and there is nothing we can do about it. You hear of fines daily in this industry, so that is the reality, and it is a real risk in the business*.

4.6 Theme 6: International technology regulation barriers

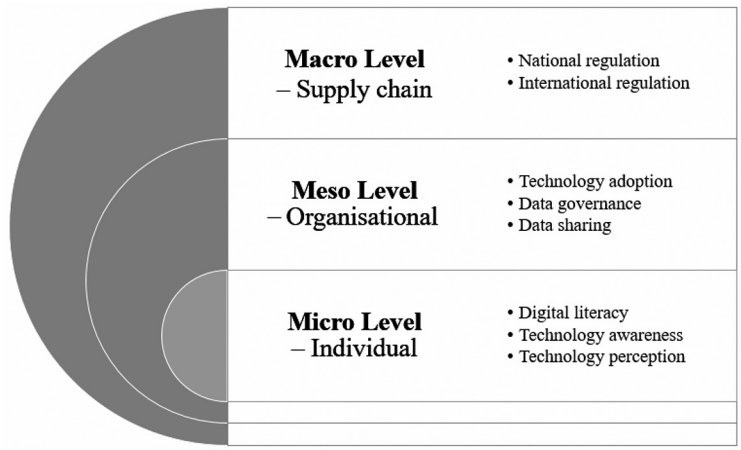
The sixth theme is related to the *macro* level (i.e. the AFSC perspective). Across the interviews, we noticed that significant international regulatory efforts in the global trade of agricultural commodities are needed to streamline long and cumbersome approval processes for new varieties in importing countries. The delays can have a significant impact on companies. For example, IC11 stated that these delays *can delay their introduction to the market and affect profitability*. IC12 agreed that this is a challenge which *can be both time-consuming and costly*. Achieving coherence in worldwide regulation is another important barrier. Data suggest that the existing regulations in the global trade of agricultural commodities are complex and variable. For example, IC13 stated that these challenges *make it difficult to ensure compliance and avoid liability for companies implementing blockchain* and *ensure data security*. IC14 noted its impact on different countries, *navigating the regulatory landscape for global trade of agricultural commodities was a major challenge for us. The rules and regulations vary greatly between producing and importing countries, making it difficult to ensure compliance.* Additionally, IC9 noted the lack of regulatory frameworks and standards for technologies supporting T&T: *many of our partners were hesitant to adopt blockchain due to the lack of legal and regulatory frameworks for the technology.* Thus, participants stressed the importance of addressing the international regulatory challenges for successful implementation of blockchain technology in agriculture. As IC11 summarised: *the regulatory challenges we face in the agriculture industry must be addressed soon; otherwise, companies will continue to struggle with implementing blockchain technology*.

5. Discussion

The dominant position in the literature supports blockchain's potential as a disruptive technology that can significantly impact the food supply sector by enhancing transparency, visibility and resilience (Deng *et al.*, 2022). The recent literature argues that enhanced product traceability is extremely beneficial to global supply chains (e.g. Zhou *et al.*, 2021; Garcia-Torres *et al.*, 2019). At the same time, the benefits of T&T might be accrued only when the barriers are removed. This study goes beyond the known meso-level barriers within organisations and focuses on the additional levels within AFSC: micro (individual) and macro (supply chain). In so doing, we extend the existing knowledge about technological, social and coordination barriers at two more levels (cf. Figure 3) and provide additional areas of improvement for T&T. Figure 6 interprets the barriers as the new areas of concern for developing technology for T&T.

Although our findings also confirm the existent technological barriers such as technology adoption (see also Zhao *et al.*, 2019; Agarwal *et al.*, 2022), system integration, data compliance and data sharing (see also Mangla *et al.*, 2022), we found technology understanding (micro-level) and technology regulation (macro-level) barriers not less important. For example, many employees are biased against blockchain due to a wrong technology perception and inability to learn fast (low digital literacy). Surprisingly, barriers at the micro-level are often out of the scope of research on why blockchain projects fail or do not progress at the expected speeds. Together with the studies, such as Markus and Buijs (2022) and Reyes *et al.* (2022), we acknowledge a need for better education and understanding of blockchain technology. People act as a major roadblock to using blockchain technology in food supply chains (Okorie *et al.*, 2022).

Figure 6 Strategic enablers to T&T at micro-meso-macro levels



Source: Authors' own work

As shared information, joint decision-making and collective learning can enable better coordination between supply chain parties in AFSCs (Kramer *et al.*, 2021; Compagnucci *et al.*, 2022), more data can be opened and shared among supply chain members. *Supplier development programmes* can raise awareness about the potential of the technology, can remove conspiracy theories and stereotypes and engage more employees in blockchain projects. In contrast to the prevailing attitude to supply chain partners as competitors (see also Li *et al.*, 2021), AFSC actors must see themselves as mutual partners seeking to achieve the shared (unified) goal – *of better food* (SDGs 2, 8, 10 and 12). More understanding and trust in blockchain technology among various stakeholders may further reinforce the spirit of eliminating food fraud and waste from the food supply chains by adopting technology for T&T.

Another potential barrier to the widespread adoption of blockchain technology in AFSCs is the regulatory effort needed at the national and international levels to convey the potential benefits of blockchain technology for organisations, particularly smaller ones (Janssen *et al.*, 2020; Feng *et al.*, 2020). We have confirmed the need for *a coherent regulation* to raise accountability along the AFSC that often crosses several countries (if not continents) and creates legislative collisions (Centobelli *et al.*, 2022). Although some studies claim that blockchain as technology makes supply chain transactions possible in a zero-trust environment (Powell *et al.*, 2023; Brookbanks and Parry, 2022), we claim that accountability is required from the regulators first, so that the SC actors can trust blockchain as a technology (Gualandris *et al.*, 2015; Saberi *et al.*, 2019; Rogerson and Parry, 2020; Khan *et al.*, 2022).

Further, exchanging best practices, sharing global warming concerns and *arranging a system of incentives* can raise the popularity of technologies for enabling T&T within AFSC firms.

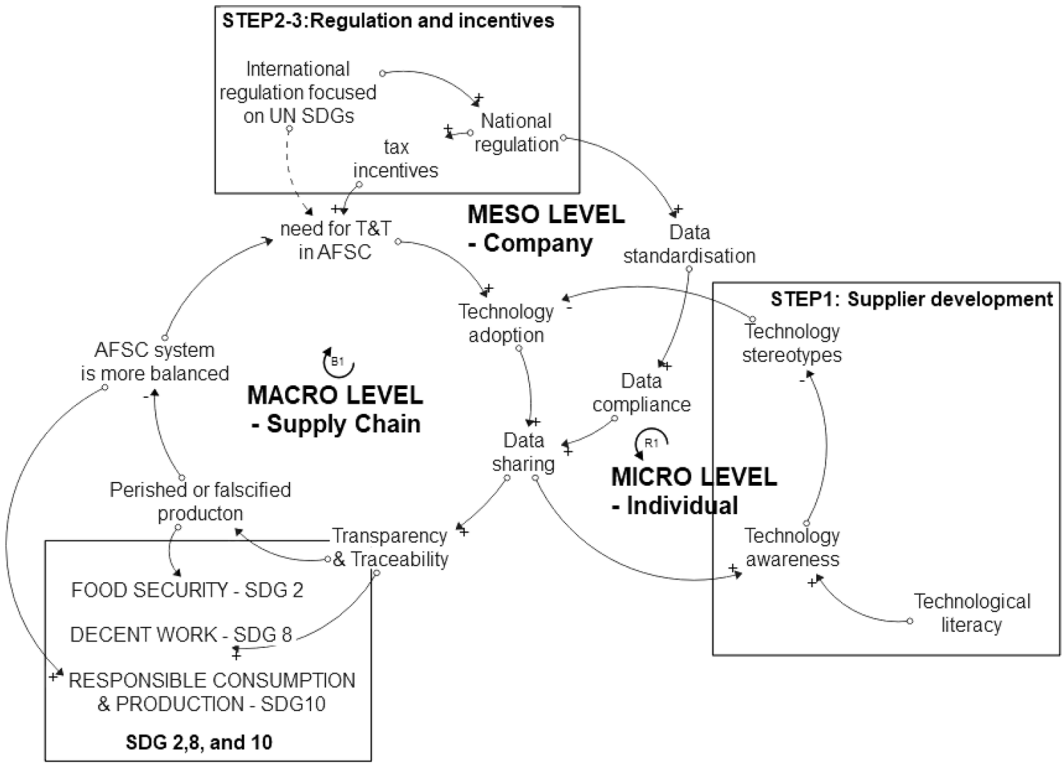
5.1 Theoretical contribution

The present study endeavours to explicate the behaviour of actors engaged in inter-organisational relationships in the context of T&T and its implications on their strategic network positions. Drawing upon the seminal works of industrial network theory (Hakansson, 1982) and signalling theory (Spence, 2002), we propose an integrated framework that endeavours to explain the underlying mechanisms of these relationships. The proposed framework posits that the transfer of information plays a crucial role in resolving information asymmetries, which are prevalent in AFSCs.

By integrating the insights derived from these two theories, the present study aims to provide a holistic examination of the challenges associated with T&T in AFSCs. This integration is expected to advance our understanding of the mechanisms that govern T&T in AFSCs and contribute to the ongoing efforts aimed at enhancing T&T in these complex organisational settings.

Figure 7 demonstrates three stages of a causal relationship towards barrier removal: *micro-level barriers* (e.g. lack of digital literacy and stereotypes of employees), which can be removed by raising digital literacy and technology awareness within supplier development programmes. The reinforcing loop (R1) shows how this impact reinforces with more technologies are adopted, and more data is shared – therefore, more employees recognise the benefits of T&T *macro-level* barriers (e.g. national legislation, international importing registration roadblocks), which can be avoided by developing a coherent regulation for AFSC. In addition, this can consider the UN SDGs, differences between the national regulations and the shared priorities along AFSC. This balancing loop (B1) implies that there is a certain level which AFSCs can target to be balanced enough (for example, when falsified or perished production will be eliminated), therefore, no more T&T supported by blockchain would be needed; and *meso-level barriers*, which enable more multi-sized firms to engage in data sharing, by incentivising, motivating and exchanging best practices for technological support between companies. It allows them to position supply chain members as collaborators for the shared goal (e.g. SDG) and reduce competitive threats along AFSC. Industrial network theory conveys the vital role of forming a consortium that facilitates the involvement of various stakeholders in addressing challenges at the macro level, ultimately leading to the establishment of relationships on coordination of supply chain activities. Signalling theory suggests a potential approach to reduce information asymmetry within micro and meso level, thereby fostering trust in supply chain stakeholder interactions. The research enhances our understanding of

Figure 7 Causal loop diagram explaining the elimination of barriers to T&T in AFSC



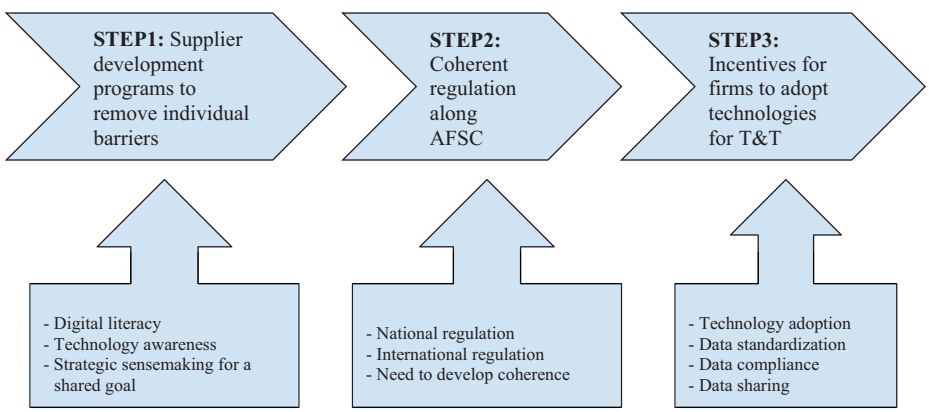
Source: Authors' own work

emerging technological implementation challenges from a socio-technical perspective by introducing an integrated theoretical framework that combines industrial network and signalling theories. This study contributes to the advancement of both industrial network and signalling literature, demonstrating their applicability within the specific agricultural context.

5.2 Managerial implications

While the technological implementation challenges are over-prioritised, the key issues for raising T&T in AFSC are the barriers across individual, firm and supply chain levels. Our study shows that the lack of significant adoption of blockchain is significantly impeded due to a lack of understanding about the technology and exacerbated by the existing stereotypes. It requires supplier development programmes to prepare employees for a new level of openness and data sharing provided by blockchain. The regulatory landscape for blockchain technology is still unclear, since AFSC cross countries and continents, which may be causing some hesitancy among potential adopters (see also Hrouga *et al.*, 2022). Additionally, trust in data-sharing and incentives to adopt technology for T&T is the key roadblock that is often omitted in the discussion. Based

Figure 8 Three-step framework for barrier removal



Source: Authors' own work

on the earlier causal loop diagram, we construct a decision-making framework for managers, so that the results of this study can be used by the firms in AFSC, Figure 8. The framework prescribes three steps towards T&T in AFSC: Supplier development, Coherent regulation and Incentives for T&T of AFSC firms.

6. Conclusion

Our findings explain the factors that hinder the increase of T&T by adopting blockchains in the AFSC industry such as technical understanding, adoption, data sharing, data governance and data regulation at the national and international levels. These findings inform the development of strategies for technological support for T&T in AFSCs by overcoming these barriers. The three-step framework, which includes supplier development, coherent regulation and incentives for firms, provides an original outlook on the enablers of T&T in AFSC and the potential to support achieving SDGs 2, 8, 10 and 12. The results of this study would provide valuable insights for companies and policymakers looking to improve the T&T of their AFSCs.

6.1 Limitations and future work

While this study provides valuable insights into the barriers and potential solutions in the implementation of blockchain technology for T&T in the AFSC, there are several limitations that should be addressed in future research. Firstly, our study could have considered the perspectives of other stakeholders involved in the supply chain, such as farmers, processors, distributors, retailers and consumers, which were not directly captured in this study. Their insights and experiences are crucial for a comprehensive understanding of the challenges and opportunities related to T&T implementation in the AFSC. Future research should aim to include a broader range of stakeholders to gain a more holistic view of the topic.

The decision to focus on blockchain technology as the primary tool for enhancing T&T in the AFSC stemmed from its unique features that align with the domain-specific challenges. Nonetheless, it is essential to highlight the potential of other emerging technologies that might complement these efforts. Future research should scrutinise the inherent constraints of blockchain in the AFSC. Given the preliminary stages of blockchain adoption, rigorous empirical studies are needed to ascertain its tangible impacts and limitations. Concerns such as the energy consumption, carbon footprint, scalability and security weaknesses of blockchain necessitate deeper exploration (Sternberg *et al.*, 2021). Additionally, understanding the influence of blockchain on supply chain resilience (Min, 2019) and the specific challenges SMEs encounter in its adoption will provide a more robust understanding of its role in the industry. Current literature suggests the integration of blockchain with real-time data collection mechanisms for advanced product tracking (Tan *et al.*, 2022; Ben-Daya *et al.*, 2019), pointing to the multidimensional nature of upcoming solutions.

T&T are imperative in confronting global food challenges and playing a pivotal role in achieving the UN SDG. Each technological advancements brings us closer to addressing global food challenges and making meaningful contributions to the UN SDGs. At present, blockchain technology represents a vital milestone, offering a robust mechanism to amplify T&T with its secure, transparent and tamper-proof transactional ledger. Yet, as technology advances, innovations such as the metaverse, augmented reality and real-time IoT sensors stand on the horizon, ready to reshape and enhance T&T in AFSCs. With these technologies converging and cooperating, we stand on the precipice of a transformative era for global food supply chains.

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Further reading

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Appendix

Table A1 Summary of participants

Participant	No. of interviews	Participant code	Location
Head of data science and innovation	2	IC1	United Kingdom
Co-founder and CEO	1	IC2	Canada
Co-founder and CEO	2	IC3	Australia
Co-founder	2	IC4	Australia
Open innovation lead	1	IC5	Singapore
CEO and founder	2	IC6	Canada
CEO and founder	2	IC7	Canada
Head of innovation	2	IC8	Italy
Software development lead	1	IC9	USA
CEO and co-founder	1	IC10	South Africa
Consultant	1	IC11	India
Procurement lead	1	IC12	United Kingdom
Head of innovation	3	IC13	United Kingdom
Procurement team member	2	IC14	Australia
Data analyst	2	IC15	New Zealand

Table A2 List of questions for the identification of benefits and barriers

S.no	Question	Question type
1	Can you provide some background on the technology (relating to supply chain) landscape in your organisation with specifics, if possible?	Open-ended
2	What problem(s) or challenge(s) prompted the need for the blockchain implementation(s)?	Open-ended
3	How did blockchain solve this/these problem(s)? Any specifics would be appreciated (e.g. smart contracts, etc.)	Open-ended
4	What were the specific benefits (e.g. effect in financial, customer service, traceability, increased throughput rate, etc.) of implementing this technology?	Open-ended
5	From your experience, how can Blockchain technology be implemented in the supply chain of companies today? What were some notable challenges in this implementation? (BP maturity vs IT maturity)	Open-ended
6	What are the benefits and challenges of blockchain integration with big data analytics (BDA)?	Open-ended
7	Can you describe the process flow for the blockchain implementation (if described to me, I can create the figure to represent this). If there is already a graphic that represents this, then it would be appreciated if it could be shared with me?	Open-ended
8	What would you consider the main challenges that are associated with implementation and to identify the main strategies used by organisations to overcome the difficulties?	Open-ended
9	Can you discuss the possible blockchain utilisation in the green supply chain/sustainable supply chain field? How can blockchain enhance the tracking and visibility of green suppliers?	Open-ended
10	What are the limitations of this technology and what is preventing its widespread adoption?	Open-ended

Note: BP = Business process

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