Impacts of blockchain technology in agrifood: exploring the interplay between transactions and firms' strategic resources

Mirta Casati, Claudio Soregaroli and Gregorio Linus Frizzi
Department of Agricultural and Food Economics, Università Cattolica del Sacro Cuore – Campus di Piacenza e Cremona, Piacenza, Italy, and
Stefanella Stranieri
Department of Environmental Science and Policy, Università degli Studi di Milano, Milan, Italy

Abstract

Purpose – Despite the growing interest in blockchain technology (BCT) applications in the agri-food industry, evidence of their economic and strategic implications remains scarce. This study aims to contribute to filling this gap by jointly investigating how BCT adoption affects transactional relationships, and how it contributes to the firm's strategic resources.

Design/methodology/approach – An explanatory case study is conducted based on a theoretical framework grounded on transaction cost economics and the resource-based-dynamic capabilities view. Six BCT implementations by agri-food firms are studied. Data were collected through semi-structured interviews and analysed using thematic analysis.

Findings – Findings reveal that BCT benefits depend on how companies integrate technology across their supply chains. In fact, the results suggest that overall transaction efficiency within the supply chain is enhanced only for those firms prioritising stakeholder engagement during technology implementation and leveraging existing trust relationships with economic agents. Moreover, the results suggest that BCT is not yet perceived as a strategic resource, but rather that it has the potential to enhance firms' operational-adaptive, absorptive and innovative capabilities. When all supply chain actors clearly understand blockchain's functionality and value, the development of these capabilities becomes more pronounced.

Practical implications – The study identifies two BCT adoption configurations. One primarily focuses on enhancing supply chain efficiency and transparency (dynamic BCT), while the other uses BCT mainly for marketing purposes (static BCT). These configurations lead to varied possibilities for leveraging BCT's potential advantages. Furthermore, they show how a mismatch between a strategic approach and its chosen configuration could work against any positive impact and lead to disillusionment with the BCT. Thus, managers should assess carefully the impact of such different configuration choices on performance.

Originality/value – To the best of the authors' knowledge, this is the first study to attempt to analyse the economic implications of adopting BCT in the food sector from both a firm and supply chain perspective. Additionally, it shows how interpreting these impacts is contingent on the diverse modalities for embedding BCT into existing supply chains.

Keyword New technology

Paper type Research paper

1. Introduction

As the demand for food quality and safety is increasing, along with a growing emphasis on the sustainability of agri-food products and processes, there is a pressing need for enhanced transparency within agri-food supply chains (Bastian and Zentes, 2013). Currently, in several countries, product-related information for food supply chains relies on traceability systems that refer to different normative requirements in terms of procedures and types of products covered by both domestic and imported origins. According to Charlebois *et al.* (2014), the so-called "one step forward one step backward" approach provided by EU Regulation 178/2002 is the most effective existing traceability system, even if it has been demonstrated to be inefficient at determining the distribution of liability among the agents of the food supply chain and at retrieving complete information on a product for consumers (Feng *et al.*, 2020; Stranieri *et al.*, 2016). Moreover, it incurs high costs due to its reliance on external third parties for monitoring (Ge *et al.*, 2017).

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Besides the challenges of existing systems for the transparency of supply chains, an increasing consumer demand for information on quality attributes of food products pushes firms to implement reliable systems for managing and monitoring the labelled information on their food products. Blockchain technology (BCT) could help overcome the limitations of current traceability systems and provide informative supply chains able to answer consumer needs and demonstrate the sustainability of business practices (Hughes *et al.*, 2019). Indeed, BCT can deliver faster and more punctual traceability, and be used to create sustainable and reliable business models in the food industry (George *et al.*, 2019; Christidis and Devetsikiotis, 2016; Yiannas, 2018; Esteki *et al.*, 2019; Komulainen and Nätti, 2023). Among its most important benefits, it has the potential to improve information sharing among transacting parties (Manski, 2017; Min, 2019), food integrity (Tian, 2017), food security (Kamilaris *et al.*, 2019), food safety and quality (Creydt and Fischer, 2019; George *et al.*, 2019) Moreover, the high level of data reliability offered by BCT aids in the management of transparency and liability risks along the agri-food supply chain (Pournader *et al.*, 2020; Zhao *et al.*, 2019).

However, the potentially positive role of BCT to manage the information associated to food quality attributes efficiently also poses some challenges. There exist many voluntary traceability systems in addition to the mandatory one in the EU with different levels of complexity in terms of breadth (i.e. amount of traceable information), depth (i.e. number of sectors involved in the traceability system) and precision (i.e. the tracking unit dimension) of the information traced within the supply chain. The chosen level of complexity varies according to the type of food product (Olsen *et al.*, 2019), the firm's incentives to reduce opportunistic behaviour (Stranieri *et al.*, 2017) and the desired flexibility in the modification of transactions. This final point is particularly relevant for the food sector where respect for the conditions of transactions often comes up against the impossibility of accurately predicting the amount of raw material production due to external environmental factors, such as climatic conditions or other extreme events (Hawlitschek *et al.*, 2018). Other current issues common to BCT across sectors include the lack of privacy (Biswas *et al.*, 2017), the lack of standardised protocols and global regulations and the waste (in/out) problem and the need for trust in third parties that are often outside the supply chain (Babich and Hilary, 2019).

To date, several startups have developed solutions in the agri-food sector based on BCT (Böhme *et al.*, 2015). Most of these initiatives aim to ensure food integrity and to manage environmental issues within the supply chains efficiently (Kamilaris *et al.*, 2019). However, while there has been much discussion regarding the technical performances of BCT adoption in agri-food supply chains (see Stranieri *et al.*, 2021), there is still scarce empirical evidence on its economic and strategic implications. Aside from implications regarding accounting and the market value of firms (Sharma *et al.*, 2023), the economic literature has recognised that BCT can have implications in two main dimensions: in terms of supply chain governance and efficiency (Lumineau *et al.*, 2021; Davidson *et al.*, 2018) and in terms of firms strategic resources that could ultimately lead to a "sustained competitive advantage" (Kant, 2021; Nandi *et al.*, 2020). In this study, we aim to investigate the implications of BCT on these dual dimensions by addressing the following two research questions:

RQ1. How does the adoption of BCT impact the transactional relationships within the agri-food supply chain?

RQ2. How does BCT, once adopted, constitute a strategic resource and promote dynamic capabilities?

The combined examination of the two dimensions offers a valuable opportunity to uncover the intricate interplay between a supply chain perspective and a firm-focused one when evaluating the implications of introducing BCT. This is because the adoption of BCT has the potential to not only enhance transaction efficiency within the supply chain but also to establish relationships between supply chain partners and activate internal processes that could bring new strategic resources, thereby bolstering firms' competitive advantage (Sheel and Nath, 2019).

The theoretical underpinnings of this research are grounded in transaction cost economics (TCE) and the resource-based view (RBV), coupled with the dynamic capabilities view (DCV). TCE offers the possibility to understand which transaction-related dimensions are impacted by the implementation of BCT and the consequent effect on supply chain efficiency. RBV and DCV offer a conceptual framework to explore whether firms treat BCT as a strategic resource, one with the potential to foster a sustained competitive advantage. The two theories were suggested as complementary for the study of BCT by Treiblmaier (2018), who advocated their utility, with the evidence they could bring from empirical studies, in supporting a middle-range theory development in supply chain management (SCM).

However, as we discuss in Section 2, there is a limited number of empirical studies that approached the BCT phenomenon using the two theoretical lenses jointly. Among these, Stranieri *et al.* (2021) is the only study that, to our knowledge, focused on agri-food supply chains. Our study extends their exploratory approach to new agri-food supply chain contexts by introducing literature-based theoretical propositions. To validate these, we analysed six Italian agri-food supply chains and conducted semi-structured interviews with their managers and two BCT experts, as suggested also by Astarita *et al.* (2019). The interviews were transcribed and analysed through thematic content analysis.

Our findings contribute to the literature by revealing that BCT adoption alone does not guarantee improved transparency and reduced transaction uncertainties in supply chains. Rather, we argue that BCT benefits depend on *how* companies integrate technology along their supply chains. In fact, our results suggest that overall transaction efficiency within the supply chain was enhanced only for those firms prioritising stakeholder engagement during technology implementation and leveraging existing trust relationships with economic agents. Moreover, the results suggest that BCT is not yet perceived as a strategic resource, even if it has the potential to enhance firms' operational-adaptive, absorptive and innovative capabilities. When all supply chain actors clearly understand blockchain's functionality and potential, the development of these capabilities becomes more pronounced. Overall, we find that there are different ways in which firms can choose to implement BCT, with a first Configuration (*dynamic BCT*) suitable for improving product traceability and transparency and a second Configuration (*static BCT*) suitable for customer engagement and marketing purposes.

To evaluate the most appropriate BCT Configuration, companies should assess their strategic objectives and align the chosen Configuration accordingly. This approach ensures that the positive impact of BCT can be optimised.

The paper is organised as follows: in Section 2 we provide a background of previous studies investigating BCT using either TCE or RBV-DCV or jointly. The conceptual framework and the theoretical propositions are described in Section 3. Section 4 outlines the methodology and case studies. The results are presented in Section 5 and then discussed in Section 6. Finally, Section 7 provides a conclusion.

2. Background

As regard TCE, there are several mechanisms through which BCT can potentially reduce transaction costs. Schmidt and Wagner (2019) extensively illustrated these from a theoretical perspective, providing a discussion for each of the TCE assumptions and constructs, such as bounded rationality, opportunistic behaviour, behavioural uncertainty, environmental uncertainty and asset specificity. Other theoretical studies provide a specific focus linked to some of the TCE constructs, for example, on opportunistic behaviour (Saberi *et al.*, 2019) or environmental uncertainty (Notheisen and Weinhardt, 2018). Empirical investigations mostly follow an exploratory setting and a qualitative case study approach (e.g. Rauniyar *et al.*, 2023; Bhatia *et al.*, 2023; Chen *et al.*, 2022; Abdollahi *et al.*, 2023). These studies generally confirm Schmidt and Wagner (2019) propositions suggesting how the intrinsic characteristics of BCT have the potential to reduce behavioural and environmental uncertainties, thereby lowering transaction costs. Other studies adopting the TCE lenses look at specific aspects of supply chains. For example, easy access and reliable data from BCT are expected to simplify performance and risk assessments favouring financing in commodity markets (Bhatia *et al.*, 2023) or in the highly asymmetric information context of startups (Ahluwalia *et al.*, 2020). Smart contracts have also been scrutinised under the TCE lenses, as their deterministic nature and automatisms could reduce transaction costs (Chen *et al.*, 2022; Eenmaa-Dimitrieva and Schmidt-Kessen, 2019; Halaburda *et al.*, 2019). However, these contracts could require relatively high design costs (Chen *et al.*, 2022) and could generate new types of transaction costs because of the limited adaptation while the transaction is executed and ex post via legal wrangles (Vatiero, 2022).

RBV and DCV offer a broader understanding of the role of resources and capabilities of firms while adopting and managing BCT, which can be seen as a potential strategic resource for the firm driving sustained competitive advantage (Kant, 2021). On the empirical side, a large body of literature uses exploratory and case study approaches. For example, Nandi *et al.* (2020) provided a content analysis of news articles from case studies under RBV lenses highlighting how BCT improved supply chain performance thanks to the operational capabilities of information sharing and co-ordination. Narratives from expert interviews by Pattanayak *et al.* (2024) highlight how improved supply chain performance originates from trust-building mechanisms generated by BCT which generate relational and dynamic capabilities. BCT appears to positively influence alternative forms of dynamic capabilities in various case studies and surveys (Meier *et al.*, 2023; Abdollahi *et al.*, 2023; Rauniyar *et al.*, 2022; Sheel and Nath, 2019). Dynamic capabilities have also been tested as mediators in quantitative settings: ex ante they can mediate and reduce resistance to BCT adoption (Dwivedi *et al.*, 2023), while ex post they can positively mediate the effects of BCT on firm performance (Latan *et al.*, 2024; Chin *et al.*, 2022). Finally, other works move beyond the single supply chain level, providing theoretical reasons on how a national BCT-based strategy could foster economic development through dynamic capabilities (Kwok and Treiblmaier, 2023) and how capabilities supported by BCT can promote supply chain resilience in vulnerable areas (Belhadi *et al.*, 2024).

Focusing on agri-food supply chains, the empirical evidence of the economic impacts of BCT using TCE or RBV-DCV is somewhat scarce. From a TCE perspective, it is possible to observe some contradictory results. Roeck *et al.* (2020) and Compagnucci *et al.* (2022) emphasised the positive effects of BCT in reducing transaction costs and improving visibility and control within food supply chains, thereby fostering a sense of consumer trust. In contrast, Brookbanks and Parry (2022) and Caldarelli *et al.* (2020) failed to find evidence of heightened trust or a significant influence on vertical relationships within wine and dairy supply chains. From an RBV and DCV standpoint, in the wine industry, Silvestri *et al.* (2023) discuss the generation of a trust-based competitive advantage, with BCT enabling the development of distinctive capabilities through the reconfiguration of organisational processes and routines. Compagnucci *et al.* (2022) show how BCT engagement mechanisms improved reputation and ability to operate in new food markets for two small and medium-sized enterprises (SMEs) in Italy.

The empirical evidence from the literature investigating TCE and RBV-DCV approaches jointly is even scarcer. It is possible to retrieve only a few qualitative studies. Abdollahi *et al.* (2023) adopt a multi-theoretical perspective, including TCE and RBV among other theories, to assess the role of BCT in generating value for the firm. Their findings highlight how BCT can mitigate risks and reduce transaction costs while at the same time increasing innovativeness thanks to improved capabilities. Pattanayak *et al.* (2024) identify trust as a pivotal concept linking TCE and DCV constructs. They found that reduced uncertainties and opportunistic behaviour originating from BCT improved trust levels. This led to better relational capabilities thanks to a greater willingness to collaborate and to the development of higher-order dynamic capabilities. Stranieri *et al.* (2021) is the only study that, to our knowledge, provides empirical evidence for both theoretical approaches in the context of agri-food supply chains. The study explores the performance of three BCT food supply chains of a leading EU retailer. Even if TCE and RBV were not directly used in their conceptual model, the two theories emerged organically as new and connected themes from the content analysis conducted. Their results revealed a possible impact of BCT in improving the management of vertical relationships, by reducing behavioural uncertainty and increasing human asset specificity. In a parallel way, the management of tighter relationships of economic agents, the training of personnel and the learning by doing in managing new data led to an improvement in firms' resources and capabilities. As these results are specific to a captive supply chain run by a large retailer, the authors call for a systematic validation of these new themes in other food supply chains and contexts.

3. Theoretical propositions

3.1 Transaction cost economics and blockchain technology

3.1.1 Asset specificity and blockchain technology

Asset specificity is a measure of how specific investments are to a particular transaction (Williamson, 1985). The more specific an investment is, the more the parties involved in the transaction operate under dependency. This can lead to higher transaction costs, as the parties may be less willing to co-operate or renegotiate the terms of the transaction (Williamson, 1985). BCT adoption has been shown to increase asset specificity due to the cost of technological and operational investments needed for its implementation (Stranieri *et al.*, 2021). There are two main stages in the BCT adoption process: full implementation and post-implementation (Vu *et al.*, 2021). Asset-specific investments are required in both stages. During the full implementation stage, firms are obliged to invest in both human and physical assets – that is, they need to train personnel, but also to purchase software and use platforms that support BCT. These costs can be considerable (Saberi *et al.*, 2019). However, costs are also incurred during the post-implementation stage: firms need to master and exploit the technology (Wong *et al.*, 2020) and they need to ensure that the members of their supply chain co-operate actively to ensure
the benefits of the new technology in the medium and long term. These costs can also be significant. Nevertheless, the literature does not clearly assess the importance of these investments nor how they vary along the stages of BCT adoption (Agi and Jha, 2022; Vu *et al.*, 2021):

Proposition 1. Human and physical idiosyncratic investments are required to implement and maintain BCT in agri-food supply chains, leading to an increase in asset specificity level.

3.1.2 Behavioural uncertainty and blockchain technology

Although much explanatory power has been attributed to asset specificity, the bilateral dependency embedded in highly specific transactions does not posit a problem unless combined with the risk of maladaptation arising from a high level of uncertainty associated with a transaction (Williamson, 2005; Stranieri *et al.*, 2017). Uncertainty, which arises when the contingencies surrounding an exchange are highly unpredictable, can come in two forms: behavioural and environmental.

Behavioural uncertainty, which stems from bounded rationality and opportunism, is the inability of agents to verify and monitor the ex post contingencies of a transaction (Williamson,1985). Within the food domain, behavioural uncertainty is primarily related to the information asymmetry that occurs between the transacting parties within supply chains. A decrease in transaction uncertainty leads to a reduction in costs because of the reduced risk of opportunism. Blockchain adoption makes it possible to remove intermediary parties and create faster, more agile and more transparent supply chains because the technology acts as a secure form of contractual agreements (Cole *et al.*, 2019). Thanks to the crypto-enforced execution of agreed contracts through consensus and transparency, BCT could eliminate the need for trust (Schmidt and Wagner, 2019). Consensus and transparency, together with the data immutability and the information flow, can improve monitoring. Furthermore, in a blockchain, everyone is accountable for their actions, creating a more reliable environment wherein opportunism is discouraged and expectations of behavioural uncertainty are reduced (Rauniyar *et al.*, 2023; Chen *et al.*, 2022; Schmidt and Wagner, 2019; Saberi *et al.*, 2019):

Proposition 2. Blockchain adoption in an agri-food supply chain reduces behavioural uncertainty because it limits opportunistic behaviour.

3.1.3 Environmental uncertainty and blockchain technology.

BCT can also affect environmental uncertainty, which relates to sudden and unexpected changes in the economic environment which, in turn, may lead to an increased risk of maladaptation among supply chain agents (Williamson, 1985). Environmental uncertainty and transaction-related risks lead to increased difficulty in the drawing up of agreements (Gurcaylilar-Yenidogan and Windsperger, 2014). Such risks are defined as "transaction-external" risks, as they are exogenous to the behaviour of transacting parties but have a strong influence on the management of conditions established in the agreements (Sydow *et al.*, 2013; Wever *et al.*, 2012). Different types of transaction-external risks have been found to influence the execution of transactions within agri-food supply chains. Variations in agricultural raw material and product prices, the complexity related to frequent changes in legislative frameworks and changes in consumer preferences affect the ease of accomplishing transaction conditions and achieving transaction efficiency (Stranieri *et al.*, 2021).

The extent to which supply chain partners can exchange information with each other plays a crucial role in shrinking environmental uncertainty. In fact, environmental uncertainty requires rapid and responsive decisions to the aforementioned sudden market changes. To achieve this, supply chain partners need to process information promptly and accurately (Krishnan *et al.*, 2016). One of the most crucial features of BCT is its ability to increase the frequency of information exchange throughout a supply chain (Wan *et al.*, 2020). In fact, data entry into the blockchain occurs in real time, with all participants offered direct and immediate access. Given that the frequency level is related to the time interval between one transaction and another (Hobbs, 1996), this technology ensures faster information exchange, improving supply chain transparency in terms of timing, quantity and precision of the information exchanged. Once the blockchain is adopted, all the information is shared on a platform and accepted by all participants, who keep track of the state of play without the need for external intervention. The deeper the level of information sharing, the better the market efficiency and the less severe the problem of asymmetric information (Notheisen and Weinhardt, 2018). Thus, better monitoring and transparency of supply chains can improve decision-making and optimise processes, ultimately meaning that BCT can help mitigate environmental uncertainty and aid firms adapt to changing economic conditions (Rauniyar *et al.*, 2023; Ahluwalia *et al.*, 2020; Schmidt and Wagner, 2019):

Proposition 3. Blockchain adoption in an agri-food supply chain decreases the risk of maladaptation from environmental uncertainty.

3.2 Resource-based, dynamic capabilities views and blockchain technology

3.2.1 Valuable, rare, inimitable and non-substitutable characteristics and blockchain technology

To understand whether BCT has valuable, rare, inimitable and non-substitutable (VRIN) characteristics, that is those of a strategic resource, i.e. VRIN (Barney, 1991), it is important to distinguish between the different steps in the process of technology adoption. The implementation phase, when the technology software is installed and firms learn how to use it, should be distinguished from the post-implementation phase, where activities are carried out to integrate and make the technology functional (Vu *et al.*, 2021).

In the implementation phase, BCT can be viewed as just an information technology (IT) product – as a piece of software. This in itself would not be sufficient to give firms the competitive edge needed to gain a sustained advantage (Sheel and Nath, 2019). Indeed, IT goods, such as software packages, can be easily imitated or acquired by other companies. As a result, a firm must combine advanced IT technology with other assets and capabilities to achieve a sustained competitive advantage (Nandi *et al.*, 2020). For this reason, researchers tend to agree that the actual benefits of blockchain adoption lie in the long term (Roeck *et al.*, 2020). In the post-implementation phase, blockchain can be considered a VRIN resource (Kant, 2021). It is valuable because it can help firms improve traceability, transparency and security in their supply chains. Exploiting these benefits to the full is rare because few firms have the resources and capabilities to implement and use blockchain effectively. Moreover, in this longer-term sense, BCT is inimitable because its network effects make it difficult for other firms to replicate. Moreover, it is non-substitutable because there is no other technology that can offer at that stage the same benefits as blockchain. However, it is important to note that there is little empirical evidence regarding the latter phase within agri-food supply chains. In fact, most blockchain projects have a short lifespan, with several companies discontinuing its implementation because they do not see the benefits:

Proposition 4. The blockchain post-implementation phase has VRIN characteristics.

3.2.2 Dynamic capabilities and blockchain technology

RBV theory does not consider how to leverage resources to sustain a competitive advantage in an emerging economy and a rapidly changing environment (Teece *et al.*, 1997; Kim *et al.*, 2015; Stranieri *et al.*, 2021). Dynamic capabilities help firms move beyond VRIN resources by allowing them to constantly integrate, reconfigure, renew, recreate and reconstruct their resources and capabilities in response to the changing environment (Wang and Ahmed, 2007). This enables firms to adjust their strategy and maintain a sustained competitive advantage (Kim *et al.*, 2015; Martinéz *et al.*, 2019; Nandi *et al.*, 2020).

The literature has highlighted the crucial role of dynamic capabilities, particularly in organisations navigating innovative environments (de Araújo *et al.*, 2018). These capabilities play a pivotal role in facilitating innovation management (Ceptureanu and Ceptureanu, 2019), enhancing research and development efforts (Biedenbach and Müller, 2012) and supporting the growth of early-stage digital startups (Griva *et al.*, 2021). BCT has demonstrated its ability to enhance firms' operational dynamic capabilities (Nandi *et al.*, 2020). In fact, in the post-implementation phase, BCT empowers firms to develop new capabilities by modifying their supply chain operations, which, in turn, facilitates the dynamic adaptation of rules and routines. More precisely, BCT holds the potential to influence three critical components of operational dynamic capabilities: adaptive, absorptive and innovative.

First, BCT enhances firms' adaptive capabilities, defined as the ability to assess and exploit new market opportunities (Wang and Ahmed, 2007), by assisting them to promptly adapt to sudden shifts in the external environment (Sheel and Nath, 2019). This is because it provides real-time information, which enables better tracking and tracing of the steps along the supply chain (Nandi *et al.*, 2020). This improved sharing of information, in turn, can ensure companies respond more rapidly to changes in the competitive environment (Kshetri, 2017).

Second, BCT can positively impact a firm's absorptive capability, defined as the ability to recognise the value of external knowledge and then apply said knowledge for commercial ends (Cohen and Levinthal, 1990). BCT can improve the flow of information between upstream and downstream supply agents, which can then increase the quality and quantity of the information exchanged (Nandi *et al.*, 2020). Better information regarding supply chain activities leads to more informed data-driven decisions that improve performance (Liu *et al.*, 2021). Moreover, BCT allows companies to obtain information about consumers through the quick response (QR) codes placed on product packages (Compagnucci *et al.*, 2022). When consumers scan a QR code, companies obtain helpful information for marketing and planning purposes, such as the geographical location of the product. This enables firms to acquire and potentially exploit new knowledge, by giving them a better understanding of consumer needs and preferences.

Finally, BCT can enhance a firm's innovative capability (Rauniyar *et al.*, 2022) which is the capacity to develop new products or open new markets in such a way as to align innovative orientation with innovative behaviours and processes (Wang and Ahmed, 2004). BCT can foster innovation capabilities through the companies' increased ability to develop new ideas and projects thanks to enhanced data availability (Nayal *et al.*, 2021; Rauniyar *et al.*, 2022). For example, once firms have implemented and learned how to exploit BCT, they can supplement it with other cutting-edge technologies or use it to fund innovations in their technological infrastructure and stakeholder relationships (Abdollahi *et al.*, 2023). Such innovation creates value and helps firms to establish a sustained competitive advantage:

Proposition 5. Blockchain adoption in agri-food supply chains can leverage a firm's adaptive, absorptive and innovative capabilities.

4. Methodology

4.1 Case study description

To explore the impact of BCT adoption on agri-food supply chains, we chose an explanatory case study approach (Yin, 2014). This method is valuable for testing propositions against existing theories and distinguishing between competing explanations (Welch *et al.*, 2011).

The unit of analysis for this case study is the Italian agri-food firms that have adopted BCT. Given the lack of any official report detailing which and how many firms have adopted BCT, to select the firms, we relied on online searches using an Italian editorial portal entirely dedicated to innovation in agri-food supply chains to find which firms had adopted BCT [1].

From the search results, we excluded firms with projects that were only in the pilot or announcement phase, focusing on firms whose projects were up and running as of June 2022. In addition, we specifically targeted SMEs since these are representative of the Italian agri-food sector, which includes over 42% of microenterprises with less than nine employees and another 39% of medium-small enterprises (1–50 employees) (ISMEA, 2020). In total, we identified 12 firms, a number consistent with the fact that, according to newspaper articles, in Italy, there were approximately 93 ongoing BCT project announcements, but only 24% materialised in concrete applications (dell'Orefice, 2021).

We contacted each firm through LinkedIn, phone and email. Of these, six companies, represented by their owners and managers, agreed to participate in the case study (Table 1). The meetings were held through videoconferencing between July and October 2022 and lasted an average of 45 min. Five of the companies had a short supply chain, defined as a supply chain involving a limited number of economic operators, committed to co-operation, local economic development and close geographical and social relations between producers, processors and consumers (Regulation 1305/2013). By contrast, the sixth company, the London Dry Gin, had an external distiller and bottler located in London.

To find out more about the operating context, we also conducted videoconferencing interviews with a BCT service provider and a BCT expert. It is worth noting, however, that we did not use the content of these interviews to test propositions directly but rather to enhance the overall quality of our discussion. The blockchain experts were selected on the participating companies' suggestions – for instance, the service provider worked with two of the firms involved in our case study. To maintain impartiality and avoid any preconceptions, the names of participating companies/managers were not disclosed to the interviewees.

4.2 Data collection

We collected data through semi-structured interviews, adopting a conversational and flexible style and a fixed list of questions as a starting point, before veering off into new lines of questioning that could occur naturally during the conversation (O'Leary, 2004). This flexible approach enabled us to cover important content through a pre-defined set of questions while also obtaining personalised data by asking additional questions related to topics arising during the interview. The flexibility of semi-structured interviews also makes them well suited to answering "how" and "why" questions, which enable interviewers to delve deeper into specific topics of interest.

The interviews were conducted by a researcher with scientific expertise in the areas under investigation. The researcher received training on the purpose of the investigation, the interview protocol and the structure to follow during the interviews. Additionally, a pilot study was conducted beforehand to test the comprehensibility of the questions and to make any necessary adjustments. The pilot study was conducted with two agri-food companies that had each implemented a pilot BCT project but then decided not to continue.

We designed two questionnaires to address a range of issues with our respondents. Table 2 presents the specific questions posed to the companies and to the blockchain service providers and experts. Questionnaire-1 for the companies, was tailored to the investigation of the TCE and RBV-DCV propositions. We carefully followed the structure of questions shown in Table 2 during all the interviews, only making minor modifications when required by the conversations to gain more insight for the research. Questionnaire-2 was directed towards the blockchain service provider and the blockchain expert. These interviews aimed to validate both the perceptions and opinions of the firms involved and to gain further insights into the blockchain-based platforms available to the agri-food industry. Besides aspects deriving from our theoretical framework, for these interviews, we added questions related to technical aspects and the general operating context. We asked each interviewee permission to record their interview, as recordings were necessary for data analysis.

4.3 Data analysis

A deductive thematic analysis (TA) approach was used to analyse the data collected. TA is a method used in qualitative research to systematically identify, analyse, organise, describe and report on themes discovered within a data set (e.g. Golicic and Sebastiao, 2011; Poniman *et al.*, 2015). It operates on a top-down principle, searching for previously identified theoretical patterns within the data (Mayring, 2014; Clarke *et al.*, 2015; Nowell *et al.*, 2017).

This methodology consists of two main steps. Firstly, a deductive phase to identify themes based on existing theoretical frameworks. Once these themes have been defined, a set of codes is constructed. These codes help us to systematically extract the theoretical constructs from the

Table 1 Participants in the case study

Case study participant	Geographical location	Participants characteristics	Time	Role of the interviewee
Expert in BCT		This expert is a leading professional working in one of the major tech companies in Italy, providing technology advice for digital advancement to companies	42 min	Tech strategist
Expert in BCT service provision		This expert works for an Italian start-up specialising in providing BCT solutions to companies operating in the food, fashion, cosmetics and pharmaceutical industries	45 min	Chief operating officer and co-founder and finance manager
Cold cuts	Northeast Italy	The company is a family business founded in 1850, characterised by a quasi-integrated short supply chain focusing on slaughtering and processing pork meat. The company does not breed pork, but it does purchase animals from a network of local breeders. The company does not distribute to large retailers. The company introduced BCT for six charcuterie products	43 min	Owner
Carnaroli rice	Northwest Italy	The company is a family business founded in 2017 with a quasi-integrated short supply chain. The company controls the supply chain from the field to the final product but purchases seeds, fertilisers and packaging externally. The company's preferred distribution channel is Ho.Re.Ca. The company implemented BCT on "Carnaroli Classico" rice	27 min	Owner
Organic rice	Northwest Italy	The company was founded in 1933. The company has a quasi-integrated supply chain as it co-operates with a network of selected local farmers who supply paddy rice, which the company then stores, packages and distributes. The company introduced BCT to trace the organic rice supply chain	31 min	Owner
London dry gin	Central Italy	This company is a family business founded in 2015 and produces London Dry Gin made from the traditional distillation of nine homegrown botanicals. Their distillation and bottling process is carried out externally with a long-term partner. Their core value is "Made in Italy" culture and tradition. The company introduced BCT for a non-alcoholic and an alcoholic distillate	33 min	Owner
Organic olive oil	South Italy	This company is a family business founded in 1864 that specialises in the production of organic extra virgin olive oil. The company has a fully integrated supply chain. The company's preferred selling channels are online, Ho.re.Ca. and speciality stores. The company introduced BCT to trace the organic olive oil supply chain	30 min	Owner
Flour and semolina	South Italy	The company was founded in 2012. The company has a quasi-integrated supply chain and co-operates with a network of selected local farmers who supply wheat that the company mills. The company's preferred selling channels are Ho.re.Ca, large-scale distribution and specialised retail stores. The company introduced blockchain for a specific short wheat supply chain, monitoring every step from sowing to the final product	46 min	Owner

Source: Authors' own work

collected material. Secondly, the empirical material is summarised in line with each code, analysed and interpreted (Mayring, 2014).

In Table 3, we summarise the coding structure used to conduct the TA, which was developed through the following steps:

- *Transcription*: we transcribed the recorded interviews and organised the transcript following the structure of the questions used. We organised the content of each interview in structured text in a worksheet of Microsoft Excel categorising each interview's content by themes. At this stage, we made a preliminary selection of the text according to the relevance of the answers, discarding the interviewees' suppositions, hypotheses and technical examples.
- *Defining themes*: we developed a set of themes based on the theoretical dimensions characterising the propositions to be tested in the case study.
- *Coding guidelines*: we operationalised each theme identified in Step 2 with one or more codes. Each code was identified by a label, with a brief definition for rapid identification. Finally, we defined coding rules i.e. what should be mentioned in the text to be classified under a certain code.
- *Coding*: we examined each transcribed sentence from the interviews numerous times, tagging relevant data with phrases that captured the nub of our search and then – following the coding rules identified in Step 3 – we divided the text into different codes to characterise the overarching theme identified in Step 2.

Analysis: Finally, we assessed whether and if so to what extent blockchain adoption impacted the theoretical TCE and RBV-DCV determinants. To this end, we indicated whether there was an impact, whether the BCT used had a certain characteristic and whether the interviewee did not mention a specific determinant or did not have a well-formed opinion.

Table 2 Semi-structured interview questions and propositions

Question	Propositions
Questionnaire-1	
Did the adoption of blockchain require specific investments in personnel?	Proposition 1
Did the adoption of blockchain require specific investments technology/software?	Proposition 1
How did the adoption of blockchain affect the relationship with your suppliers/distributors?	Proposition 2
How did the adoption of blockchain affect the trust relationship with your suppliers/distributors?	Proposition 2
How has blockchain changed the acquisition and exchange of information?	Propositions 3–5
How did the blockchain introduction affect your supply chain?	Propositions 3–5
How can blockchain lead to advantages over competitors?	Proposition 4
How did blockchain introduction affect your corporate reputation or brand value?	Proposition 4
How blockchain can be strategic for your company?	Proposition 4
How blockchain can help you to meet consumer needs?	Proposition 5
How did the implementation of blockchain deepen the knowledge about your supply chain?	Proposition 5
How does blockchain introduction affect the development of new ideas?	Proposition 5
How did blockchain introduction affect the development of new products or services?	Proposition 5
Questionnaire-2	
Does blockchain adoption represent a significant investment for agri-food small and medium companies?	Proposition 1
How does BCT adoption influence the companies' relationship with their suppliers and distributors?	Proposition 2
Do you consider blockchain an useful tool to respond to the changing market conditions?	Proposition 3
How blockchain can be strategic for a company?	Proposition 3
Is there a relationship between blockchain and corporate reputation and brand value?	Proposition 4
Is there a relationship between blockchain and consumer needs?	Proposition 5
Do you think blockchain can deepen a firm's knowledge along the supply chain?	Proposition 5
Do you think blockchain adoption could bring technological innovations along the supply chain?	Proposition 5

Source: Authors' own work

5. Empirical findings

The interviews with companies and experts show that the firms involved in the case study exploited different technology configurations. Flour and Semolina and Carnaroli Rice firms, both using the same BCT service provider, have opted for a dynamic integration of BCT in their daily operations and IT systems, actively involving their supply chain partners and fostering collaboration (from now on Configuration 1). In contrast, London Dry Gin, Organic Rice, Organic Olive Oil and Cold Cuts firms have not directly involved their supply chains with the BCT platform nor directly integrated IT systems, mentioning that they exploited BCT more for marketing and communication purposes than for improving information traceability along the supply chain (Configuration 2). Notably, the Organic Rice company mentioned that they continue to transport traceability documents through conventional means and that they do not involve their supply chain partners directly in the BCT platform. In addition, the Cold Cuts and London Dry Gin firms emphasise that BCT plays a role in building tailored communications to consumers rather than improving information sharing along the supply chain, mentioning that "*we have not linked BCT to the supply chain, BCT is just a service we offer to the end consumer*". According to the experts involved in the case study, this division in BCT adoption mirrors the current agri-food landscape. Mainly driven by concerns with privacy and customisation, the majority of agri-food firms opt for private blockchain platforms, such as Hyperledger Sawtooth, that operate in modular templates (i.e. data management platforms) – which can vary in terms of customisation and the level of supply chain partner engagement – into which firms input their traceability information.

Configuration 1 involves a high degree of customisation as BCT is integrated directly with existing corporate databases, which can result in automatic data retrieval and seamless updates to the BCT database. Depending on the level of participation in the ecosystem, this process may involve integrating data from the entire supply chain or only part of it. This database integration ensures that the platform data is constantly and dynamically updated. Regarding the need to integrate BCT with existing technologies, costs can vary significantly depending on the sophistication of the company's IT system and the sophistication of its supply chain partners. The greater the number of partners, the lower their level of technological sophistication and the higher the cost of adapting and customising the technology to meet their different requirements. According to the BCT experts, service providers can charge fees ranging from €10,000 to as much as €400,000 for the implementation year, followed by subsequent maintenance years with an annual fee of approximately 15% of the initial price. On the other side, Configuration 2 involves creating a static snapshot of the supply chain, where data are recorded on a BCT database that is not customisable. According to the BCT experts, this option comes at a relatively low cost, ranging from around €4,000 to €10,000. The price range varies according to the number of products involved and the breadth of traceability data since it does not involve direct involvement of supply chain partners. Since it is static, the information uploaded on the BCT will not change unless manually updated.

It must be remarked that the above fees do not constitute the whole implementation and maintenance costs of BCT for a

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Table 3 Coding structure used for the thematic analysis

Theme	Code label	Code definition	Coding rules
Asset specificity	Human	Investments in training	Mention of training of the personnel through internal communication or meetings
	Physical	Investments in technical development and consulting	Mention of various implementation costs (software/hardware implementation, maintenance, transaction costs, etc.)
	Physical	Investment in new machinery	Mention of new machinery needed to support blockchain-traced products
Uncertainty	Behavioural	Increase of credibility	Improvement in the credibility of the firms along the supply chain
	Behavioural	Decrease in opportunistic behaviour	Improvement in the trust relationship and greater responsibility of the supplier
	Environmental	More information available	More information helps companies to foresee unpredictable changes
	Environmental	Traceability improvement	Critical tool for addressing issues such as food safety and food complaints
Frequency	Frequency	Information exchange improvement	More precise, visible and available information
	Frequency	Reduction of information asymmetry	Better distribution of information, both upstream and downstream
VRIN resource	Valuable	Increased in perceived product quality	The increase in perceived product quality improves firm reliability
	Valuable	Blockchain as a technology is valuable	Mention that it allows an organisation to both exploit opportunities and counter threats
	Valuable	Blockchain enables firms to differentiate	Mention that firms differentiate themselves from others due to technology adoption
	Valuable	Blockchain gives value to the brand	Mention that blockchain gives value to the brand just by having it
	Inimitable	Blockchain as a technology is inimitable	Mention that blockchain is difficult to acquire and replicate
	Rare	Blockchain as a technology is rare	Mention that only a few competitors have it
	Non-substitutable	Blockchain technology is unique	Mention of unique and non-replicable features that the adoption of BCT brings
Dynamic capabilities	Adaptive	Product differentiation	Enables firm to create new products or adapt old ones to dynamic markets
	Adaptive	Improvement of market scanning	Better response to external opportunities, anticipation of market trend and consumer needs
	Absorptive	Assimilation of new information	Improvement in the ability to receive and process external information
	Absorptive	Improvement of existing process	Flexible technology to be integrated into the company's existing processes
	Innovative	Strategic innovative orientation	Development of innovative processes and adoption of innovative behaviour

Notes: Further details of the coding process can be found in the Excel document in the supplementary material section
Source: Authors' own work

company; other aspects such as design, negotiation with partners, internal training and reconfiguration should also be considered. As highlighted by Agi and Jha (2022), an overall assessment of blockchain implementation costs is currently lacking and represents a gap in the BCT literature.

Figure 1 illustrates the relationship between the characteristics associated with BCT across different firms and the dimensions of TCE, RBV and DCV, as discussed below for the different propositions.

5.1 Asset specificity – *Proposition 1*

The type of BCT configuration chosen by the investigated company is closely linked to the level of asset specificity involved. For Configuration 1, the Flour and Semolina company stated that the adoption of BCT necessitated specific and substantial investments, highlighting "*significant*" costs associated with both workforce and software implementation. Carnaroli Rice, on the other hand, although adopting the first type of configuration, benefited from their previous traceability experience and a high pre-existing level of technological sophistication. This made them an ideal partner for the BCT service provider that decided to partner with the company to test their service in a pilot scheme. For this reason, Carnaroli Rice mentioned a minimal initial investment fee 2,000 euros and limited internal reconfiguration costs thanks to an already existing structured traceability setup.

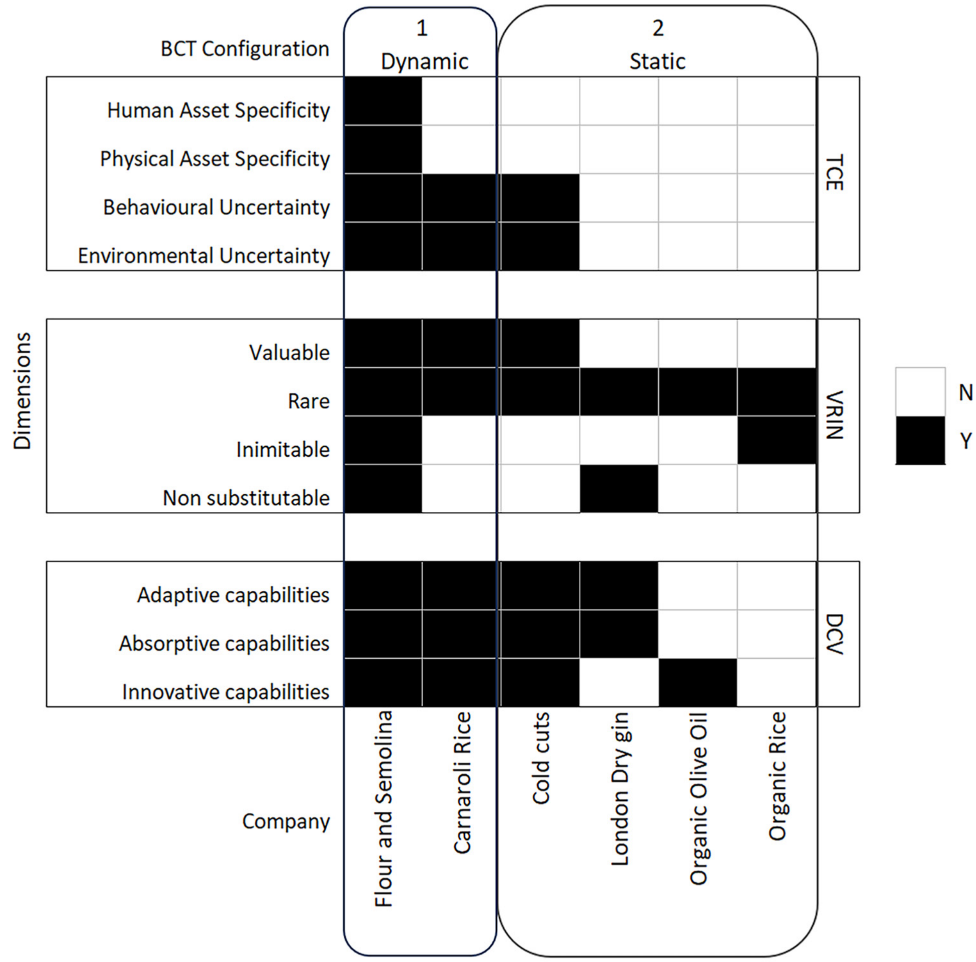
As expected, companies adopting Configuration 2 found that the human and physical investments required for blockchain adoption, such as software or consultancy services, were not particularly onerous during the implementation and post-implementation phases. For example, the Cold Cuts company remarked that "*one of the big advantages of blockchain is that it is very competitive on the price side*". Moreover, the Organic Olive Oil company, highlighted how human-related idiosyncratic investments were not overly burdensome in terms of personnel training time: "*We can estimate the time invested as three working days*".

Overall, support for Proposition 1 is company specific. The collected data show how this depends upon the configuration choices and the company's prior level of technological sophistication.

5.2 Behavioural uncertainty – *Proposition 2*

Proposition 2, which considered the effectiveness of blockchain adoption in reducing behavioural uncertainty, yielded responses that are again linked to the chosen configuration. The two companies adopting Configuration 1, Carnaroli Rice and Flour and Semolina, supported the proposition, emphasising the significant role that BCT can play in

Figure 1 Impact of BCT adoption on the determinants investigated across the case study participants



Notes: In the figure, a black/white cell indicates that the firm met/did not meet our proposition (Y/N)
Source: Author's elaboration

reducing behavioural uncertainty along the supply chain. For example, the Carnaroli Rice company highlighted the fact that BCT provides added value to their products, particularly in terms of "*transparency and trust*" from the perspective of their distributors. They also noted that BCT enables their company not only to demonstrate the quality of their products but also the quality of their production processes, while Flour and Semolina commented on how BCT enhances trust and stability along the entire chain and helps build loyalty among partners.

On the other hand, the Organic Olive Oil, Organic Rice and London Dry Gin companies did not recognise the potential of BCT to reduce behavioural uncertainty. They failed to observe any significant impact on trust levels among their supply chain partners, including suppliers and distributors, nor did they perceive any reduction in the risk of opportunistic behaviour. This is likely determined by the implicit design of Configuration 2. Nevertheless, Cold Cuts do report a positive reputational effect from BCT involvement which incentivised business relationships and resulted in a decrease in behavioural uncertainty.

5.3 Environmental uncertainty – *Proposition 3*

As in the previous proposition, our findings indicate the importance of BCT effects according to the type of configuration. For Configuration 1, BCT adoption can mitigate environmental uncertainty by enhancing the quality and quantity of information exchange among supply chain partners. The Carnaroli Rice company highlighted the benefits of BCT in addressing stringent food safety requirements. They emphasised that improved traceability enables better product tracking and potentially faster product recalls. Flour and Semolina, meanwhile, noted that BCT streamlines the process of information retrieval in the event of food safety threats: "*Even in the case of a recall, blockchain allows us to trace the product back to the field, enabling us to measure residues on flour. Such a task would be extremely challenging, if not impossible, with a paper-based traceability system*".

Within the second configuration, the Organic Olive Oil, Organic Rice and London Dry Gin companies did not observe any impact of blockchain adoption on environmental uncertainty. However, the Cold Cuts company reinforced its market-oriented approach emphasising how, though not improving food safety performance, BCT did enable them to adapt quickly to market needs through improved communication with consumers, which indirectly contributed to mitigating demand volatilities.

5.4 The post-implementation phase has valuable, rare, inimitable and non-substitutable characteristics – *Proposition 4*

Our findings offer something of a challenge to Proposition 4, as demonstrated by the fact that only one firm, the Flour and Semolina company, recognises the post-implementation phase of blockchain as having VRIN characteristics, making it a strategic resource that could lead to a competitive advantage.

As regard "value", not every company recognises this VRIN attribute of blockchain. Within Configuration 1, Flour and Semolina highlights its positive impact on innovation in operations, market differentiation and brand perception. Carnaroli Rice highlights how BCT has given them a competitive edge over less structured and agile competitors. However, when Configuration 2 is considered, the London Dry Gin, Organic Rice and Organic Olive Oil companies do not currently see blockchain as particularly valuable. Organic Olive Oil notes that the market has yet to recognise BCT as bestowing a significant advantage except for the marketing field. London Dry Gin views BCT as a complementary service to their product but not as a primary driver of brand value. The Organic Rice company sees no direct connection between BCT and reputation or brand value, while also pointing out that even buyers and large retailers remain unaware of or uninterested in BCT. A different perception is provided by the Cold Cuts company: consistently with its external market focus, they link blockchain to corporate reputation, showcasing their willingness to embrace innovation.

Moving to "rareness", all the interviewed companies agree that fully implementing a blockchain project in the agri-food industry is still uncommon, considering that a blockchain project rarely progresses beyond the pilot phase. Indicative of this is the fact that the Flour and Semolina company proudly identifies itself as being "*the first mill in Italy to adopt blockchain*", while the Organic Olive Oil company expresses a similar sentiment.

In terms of "inimitability", BCT configurations do not appear to have much effect on driving perceptions. The Flour and Semolina company notes that implementing BCT is not only challenging but also costly for SMEs, making it difficult for companies to acquire and sustain it over the long term. The Organic Rice company says that it has experienced difficulties in replicating the technology for other products due to the complex data collection processes involved. They state, "*We wanted to expand the technology to other products, but it is challenging due to the data collection processes required*". In contrast, the remaining companies perceive BCT imitability as a relatively simple process.

Regarding "non-substitutability", two companies attributed to the blockchain unique and non-replicable features related to the process of information collection. BCT configurations become relevant in distinguishing their perceptions: Flour and Semolina emphasises the non-substitutability of BCT, observing that "*no other technologies provide the same level of detailed information that blockchain offers*". Their perspective is an internal one, where BCT allows them to build a unique way of managing information; London Dry Gin highlights that only with BCT can they efficiently obtain data directly from consumers by using QR codes. This clearly highlights their market-oriented perspective in approaching BCT.

5.5 Blockchain as a leverage for dynamic capabilities – *Proposition 5*

Three companies (Flour and Semolina, Carnaroli Rice and Cold Cuts) report that blockchain adoption had a positive impact on their overall set of capabilities. However, for the remaining companies, the results were mixed, with only the Organic Rice company not experiencing any improvement in this area. The adopted BCT configurations do not seem to segment specific outcomes concerning dynamic capabilities.

Turning to adaptive capabilities, Flour and Semolina and Carnaroli Rice view BCT as a "*versatile*" tool that facilitates adaptation to future market evolutions, particularly in the context of customer demand for increased transparency in the post-pandemic world. BCT not only addresses the need for market transparency, but it also offers potential for adaptive marketing. As highlighted by the Cold Cuts company, businesses can dynamically change and customise the information they provide to customers by using QR codes. The Organic Rice company holds a different opinion, however, stating that BCT does not have any adaptive capabilities. They believe that it is not a useful tool for responding to emerging market challenges, not just because many end-customers are still unfamiliar with it, but also because it is virtually irrelevant to their decision-making processes. The Organic Olive Oil company shares a similar sentiment, stating "*Unfortunately, we are a little too far ahead before we get to the market, so we need another 4–5 years to make the market understand what blockchain is*".

Regarding absorptive capabilities, Carnaroli Rice stated that BCT enhances their understanding of their supply chain's traceability, enabling them to integrate features of the supply chain more effectively into their everyday activities. Similarly, Flour and Semolina noted that BCT improves their knowledge of the supply chain and enhances business processes. Furthermore, both the Cold Cuts and the London Dry Gin companies highlighted a unique feature of BCT: its ability to collect data from end-customers without incurring "*exorbitant*" costs from big market research firms. However, two firms reported no impact on their absorptive capabilities. Organic Olive Oil attributed the strengths of their data collection and utilisation not to BCT but to their Agriculture 4.0 technologies, while the Organic Rice company claimed that BCT adoption did not affect their knowledge of processes or information retrieval.

Moving onto innovative capabilities, what emerged from most companies is that blockchain could help build innovative services and digital tools but that it may not directly influence product innovation. For instance, Flour and Semolina and the Carnaroli Rice companies are optimistic about blockchain's potential to promote innovation, as it enables them to improve "*technological knowledge and know-how*". The Organic Olive Oil and Cold Cuts companies claimed that blockchain might facilitate the

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development of new digital products and innovative marketing tools. On the other hand, the Organic Rice and the London Dry Gin companies are sceptical and see BCT as just a service, at least for the time being.

6. Discussion

6.1 Theoretical implications

From *RQ1* and the TCE perspective, the findings presented in the previous section do not fully confirm our theoretical propositions, which assume that the characteristics of BCT should result in increased asset specificity and reduced behavioural and environmental uncertainties. Indeed, the prevailing academic perception that BCT serves to enhance traceability, transparency and trust is confirmed only if BCT technology is adopted under a specific configuration (i.e. Configuration 1). In this configuration, the establishment and operation of a collaborative BCT network may require time and energy investments involving supply chain partners. However, it is likely to yield substantial benefits, including reduced transaction costs. Conversely, a system requiring low asset-specific investments in BCT might lead to foregone benefits in terms of improved relationships along the supply chain. This suggests that the extent to which BCT impacts transaction costs is not a matter of whether companies adopt the technology but rather *how* they adopt it.

Our findings align with prior research (Brookbanks and Parry, 2022; Commandré *et al.*, 2021) that says that if a firm fails to integrate BCT across its entire supply chain, establishing an ecosystem of trust, the potential benefits of reducing transaction costs are hindered or even non-existent. Not all firms fully grasp the true advantage of BCT, which lies in its collaborative and distributed nature (Casino *et al.*, 2019): only if companies embrace BCT with an inclusive approach and are willing to integrate it throughout the supply chain, can they unlock its full potential (Dwivedi *et al.*, 2023).

Our findings align with the existing literature, suggesting that without the establishment of a collaborative network, a BCT-based platform offers no additional benefits *vis-à-vis* legally required traceability (Casino *et al.*, 2019). Moreover, in line with the existing literature (van Hoeck, 2019), our case study shows that, while it is relatively easy to start a BCT pilot project, the implementation of the technology across an entire supply chain is a multifaceted endeavour that requires considerable investment financial and otherwise. At this stage of technology development in agri-food, where only a few projects have progressed beyond the pilot stage (Morkunas *et al.*, 2019) and few have involved all their partners in the BCT system, predicting the impact of BCT adoption on supply chain relationships remains challenging.

Considering *RQ2* from an RBV-DCV perspective, our study reveals that companies that acknowledge the uncertainty-reduction benefits of BCT also recognise it as generating some VRIN characteristics. Flour and Semolina identified BCT as having the full set of VRIN characteristics, clearly stating that the main advantage of BCT is embedded in improved firm processes. The Carnaroli Rice and the Cold Cuts companies perceive BCT to be both valuable and rare. In this case, both companies attributed these two attributes to marketing and product differentiation of the blockchain. For these companies, blockchain can be perceived as leading to a sustained long-term or a transient competitive advantage, in line with existing literature (Kant, 2021).

The three above-mentioned companies are also the only ones where results indicate BCT's potential to enhance their entire set of operational capabilities – adaptive, absorptive and innovative. Consistent with previous literature, BCT is perceived to enhance a firm's ability to compete in a dynamic market (Sheel and Nath, 2019), meet the market's growing demand for transparency and enable firms to retrieve more data both from within the supply chain (Nandi *et al.*, 2020) or from useful consumer information such as geolocation through QR code scanning. Finally, as suggested in the literature (Rauniyar *et al.*, 2022), the results confirm that BCT has the potential to significantly enhance innovative capabilities in the development of digital services.

However, the case study participants also highlighted both demand and supply contingencies that can either support or impede the potential of BCT to leverage operational capabilities. On the demand side, consumer willingness for increased transparency alone is insufficient to enhance adaptive and absorptive capabilities. Indeed, it must be accompanied by a proper understanding and effective utilisation of the BCT. For example, if consumers do not engage in QR code scanning, the maximum benefit of this feature will not be realised. This highlights the potential risk for those companies that adopt BCTs for marketing purposes only; the danger is if the market and consumers are not ready to use the innovation, the investment could well be unsuccessful. On the supply side, companies expressed concern about the resistance of the agri-food industry to innovation on the part of farmers. BCT experts noted this concern, pointing to a low level of technological knowledge in the Italian agri-food industry. This highlights the complexity of engaging farmers in a BCT platform when their technological sophistication is low.

6.2 Implications for supply chain management literature

In discussing the implications for the SCM literature, we shall start by building upon the considerations of Cole *et al.* (2019) in this journal. The authors highlight how BCT challenges existing SCM theories. Their work emphasises the need to discern which theoretical frameworks are most suitable for understanding BCT's impact on SCM, and to explore how these existing theories might be adapted or expanded. Specifically, Cole *et al.* (2019) suggest that theories grounded on the necessity of strong, trust-based relationships may become less relevant in explaining how supply chains are built and managed. For example, they argue how the social capital theory might diminish interpretive power in explaining supply chain performances, as BCT reduces the importance of trust and collaborative relationships. From this viewpoint, the social capital, which is formed by the relationships within a network, would be less necessary in a BCT context to deliver sustained competitive advantage. Our results do not support a move in this direction, at least at the present stage of the development of the technology. Companies still need trusted and knowledgeable partners to adopt the technology regardless of the chosen Configuration. Therefore, social capital in the supply chain network would act as a catalyst of adoption not only because it would predict superior supply chain performances (Bernardes, 2010), but also because it would lessen the need for human asset specificity and, with time, it would favour an improvement in operational capabilities. This reasoning is consistent with the findings of Pattanayak *et al.* (2024) and underlines the importance of interlinkages across theories such as social capital, TCE and RBV in designing further interpretative frameworks.

Cole *et al.* (2019) also supposed a "renaissance" of TCE as a result of market transactions where BCT would eliminate intermediaries and create more agile and transparent supply chains with reduced space for opportunistic behaviour. Such a "trustless" environment seems to predict a market operationalised using spot transactions. However, our results indicate that agri-food firms aiming to enhance product traceability and transparency will still need a business model based on long-term relationships and collaborative practices. Essentially, for the investigated SMEs, the identity of the suppliers or customers will not be irrelevant under a BCT system. It is evident that while BCT can eradicate elements of trust within a transaction, it cannot *per se* deliver an ecosystem of trust within a comprehensive set of network relationships. Therefore, looking at an ordinary transaction using TCE as a stand-alone approach could be misleading when interpreting the impact of BCT.

The provided results also address some of the research questions proposed by Treiblmaier (2018) in its methodological study, when applying TCE and RBV to investigate the impact of BCT within a supply chain. For TCE, we address questions such as the explanation of the conditions that foster or impede BCT-induced changes or the prediction of the type of transaction costs involved. We show that changes depend not only on the type of firm but also on the strategic approach that guides BCT implementation, as will be better illustrated in the next section. For RBV, we provide insights concerning the analysis of BCT for internal strategic resources and explanations about the conditions fostering BCT-induced changes in the supply chain. By providing evidence from TCE and RBV-DCV together, our study contributes to the development of middle-range theories for SCM that Treiblmaier (2018) advocates as necessary to provide incremental and replicable research knowledge on the BCT phenomenon.

Our investigation into BCT in the agri-food sector also contributes to the broader literature concerning digital transformation and SCM. BCT streamlines processes and introduces a higher level of data accuracy and immediacy, which are key components of the digital transformation. This is based on four pillars, as proposed by Frank *et al.* (2019):

1 Smart supply chains, which consider all of the digital technologies that increase information flows along the chain;
2 Smart manufacturing, which includes digital technologies that improve manufacturing systems, production planning and control;
3 Smart products and services, which include physical products and services, complemented by IoT, cloud and AI technologies; and
4 Smart working, which considers all of the digital tools that enhance the activities of employees.

Meindl *et al.* (2021) conducted a systematic review of the literature about digital transformation and Industry 4.0 and identified as a first and major priority area for future research the study of interlinkages between smart supply chain and smart working. The results provided in this study follow this direction and provide insights into the underlying conditions that allow BCT to reshape supply chain dynamics by reducing transaction costs, enhancing transparency and fostering capabilities. At the same time, the specific "smart" characteristics of BCT could pave the way for investigations from different theoretical perspectives. For example, the introduction of smart contracts has the potential to mitigate information asymmetry and discrepancies in contracts, prompting an exploration of their implications with the Principal-Agent Theory (Treiblmaier, 2018).

6.3 Implications for practice

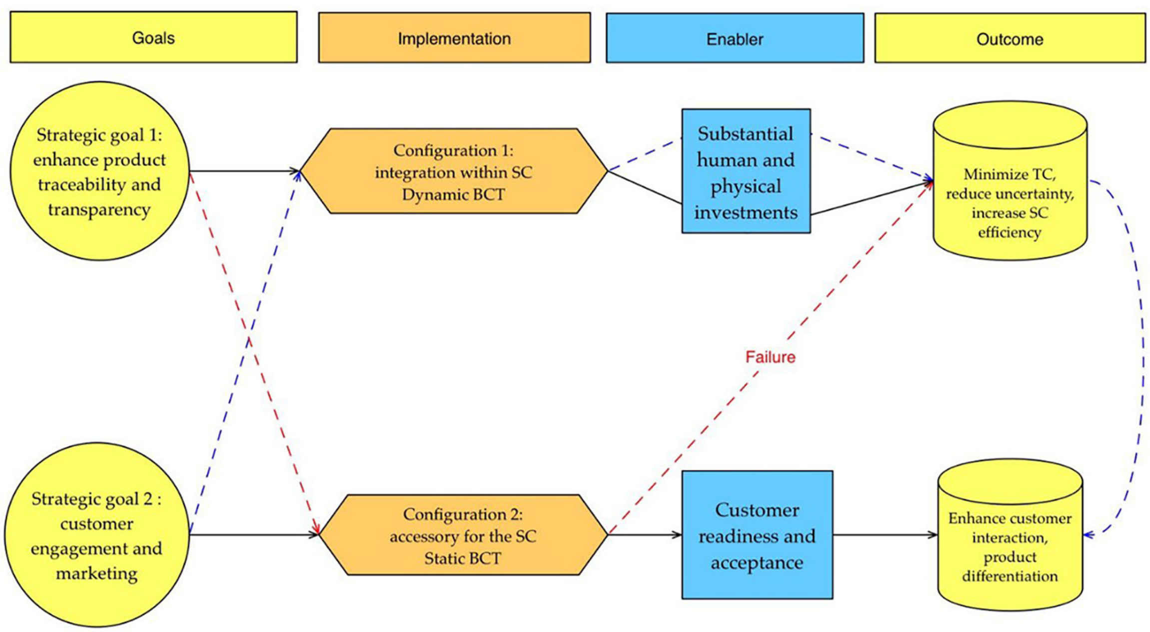
Based on our findings and the existing literature, it can be concluded that the potentially positive effects and economic advantages of BCT in supply chains depend both on the reasons for its adoption (the "why") and the manner of its implementation (the "how"). Managers must identify the specific supply chain challenges they aim to address – the "why" (Markus and Buijs, 2022) – and evaluate how the supply chain environment supports the full exploitation of BCT's potential – the "how" (van Hoek, 2019).

The case study results have shown that different configurations of BCT (the "how") led to different impacts on transactional relationships and strategic resources, and that firms perceived these impacts as positive when the way they adopted the technology was aligned with the "why" – the strategic motivations that led them to implement BCT. Flour and Semolina and Carnaroli Rice wanted to improve the traceability and transparency of their products. As a result, they implemented BCT in Configuration 1, actively involving their supply chain partners. The Cold Cuts and London Dry Gin firms prioritised marketing and consumer engagement as their primary strategic focus. They chose Configuration 2, bypassing extensive partner engagement and collaborative network building. Despite choosing different configurations, all four firms expressed satisfaction with their choices and felt their technological expectations had been met. In contrast, when the configuration does not mirror a company's strategic objectives or when there are no clear strategic goals for the BCT to realise, the technology falls short of its potential. The Organic Rice company stated their intention to adopt BCT to improve transparency and information flow. This suggests that Configuration 1 would suit their needs better. However, they failed to actively involve their supply chain partners. This lower level of involvement ensured lower asset-specific investment, but also led to disappointment as the technology did not meet their expectations and did not have the expected impact on the supply chain. Thus, they became critical and disillusioned with its overall effectiveness. On the other hand, the Organic Olive Oil company lacked a clear strategy when it adopted BCT. The company opted for Configuration 2, which implies lower engagement costs and development efforts. However, without a clear and identifiable customer response, this resulted in little clarity regarding the potential benefits of BCT and little confidence in its future developments. Negative early experiences with the technology could delay or deter future consideration and adoption of BCT. This hesitation could result in missed opportunities, especially when compared to firms that either had positive initial experiences with BCT or did not encounter such early setbacks. In light of these considerations, firms would be wise to adopt a more holistic approach towards BCT implementation. This involves considering BCT not just as a tool for immediate marketing gains but as a strategic asset that can bring long-term benefits across various dimensions of the supply chain. In this way, firms can avoid the pitfalls of a narrow, short-term focus and position themselves instead to fully leverage the transformative potential of BCT for enduring competitive advantage and supply chain resilience.

We summarise these findings in the following practical recommendations for use, which are also illustrated in Figure 2.

- Configuration 1 – dynamic BCT – is an option well suited for firms seeking to improve product traceability and transparency and involves a high degree of customisation and ecosystem participation. This requires a significant commitment from supply chain stakeholders, a significant investment in human resources and the seamless integration of BCT into daily operations. This approach is particularly effective for supply chains producing high-value products or facing challenges such as security threats, sustainability concerns, counterfeiting and quality risks (Cole *et al.*, 2019). It requires a business model that emphasises long-term relationships and collaborative practices.
- Configuration 2 – static BCT – this option is well suited to firms seeking to improve customer engagement and use it for marketing purposes and capitalise on BCT's ability to enhance customer interactions through absorptive and adaptive capabilities and marketing strategies through product differentiation. However, it is important to acknowledge that such a configuration does not lead to the establishment of a collaborative BCT platform, limiting the potential for greater transparency. The level of customer readiness before implementing this

Figure 2 Mastering BCT adoption effectively aligning strategic goals with realised outcomes



Notes: The figure provides a visual representation of the relationship between the company's strategic objectives and their achievement through specific BCT configurations. On the left-hand side, yellow circles represent the company's strategic objectives, each of which corresponds to specific yellow cylinders on the right-hand side of the figure. To achieve Strategic Goal 1, the direct path (solid black line) is to adopt BCT through Configuration 1. Successful adoption relies on enabling factors (light blue quadrants), which are significant investments in human and physical resources. To achieve Strategic Goal 2, the direct path (solid black line) involves adopting BCT through Configuration 2. Successful adoption relies on enabling factors (light blue quadrants) that are consumer readiness and acceptance of the technology. A mismatch between the company's objectives and the chosen BCT configuration leads to different outcomes. If a firm pursues Strategic Goal 1 but adopts Configuration 2, following the red dashed path, the adoption is considered a failure, resulting in no match of the desired outcome. Conversely, if the firm pursues Strategic Goal 2 but adopts Configuration 1, following the blue dashed path, there is still a potential path to achieving Strategic Goal 2, albeit indirectly. In this case, success would require the fulfilment of both enabling factors – making substantial investments and securing consumer acceptance
Source: Author's elaboration

configuration must be considered, as customer acceptance and adoption will play a significant role in its success.

These considerations become important for how firms organise their business models around BCT. Configuration 1 resembles a holistic view in implementing BCT within the supply chain. This is coherent with a BCT-based open business model, where resource sharing, complementarities and identification of mutual benefits are essential for its success (Berglund and Sandström, 2013). In this model, relationships between firms lay the groundwork for the creation of an ecosystem where value is jointly created. As Komulainen and Nätti (2023) observe, in such a collaborative network firms should focus on creating a coherent industrial strategy, develop standards and best practices. However, its cost structure is challenging when involving all supply chain partners in-depth. Firms, therefore, should carefully evaluate the breadth of product lines to be implemented in a blockchain platform. This approach is in line with TCE principles, as complex and wide supply chains can make stakeholder involvement and required investments demanding and costly (Ahmed *et al.*, 2022). At the same time, selecting specific product lines inevitably leads to hybrid or dual models-with and without BCT-running in a company at one and the same time. This raises compatibility issues, impacts operational activities and ultimately increases costs (Komulainen and Nätti, 2023). However, over time the transactional efficiencies gained from BCT can reduce operational costs along the supply chain. Moreover, the developed capabilities can help to extend BCT to new product lines and progressively involve more supply chain actors. This is inherent to the value proposition of this business model which is centred on the improved transactions and resource use among supply chain partners that can eventually lead to a more flexible and dynamic network.

In contrast to Configuration 1, Configuration 2 demands a less technology-intensive and stakeholder training-heavy cost structure. Marketing strategy is the starting point in preparing the business model. With BCT, consumers are incentivised to engage with the brand directly. This disrupts the traditional role of intermediaries such as social media platforms (Tan *et al.*, 2021). Consequently, a larger proportion of expenditure is allocated to marketing and building customer-awareness. The business model follows a value proposition where BCT is leveraged to capitalise on the unique benefits provided by BCT, such as enhanced traceability or innovative customer engagement. For example, customer engagement and experience could be achieved through storytelling about product origins and quality. The effective use of BCT by end consumers is critical in this model. Therefore, firms must focus on raising consumer awareness about BCT and informing them about the technology while simultaneously enhancing their post-purchase experience (Tan *et al.*, 2021). However, the above tasks could be particularly challenging in terms of financial resources, especially for SMEs.

In conclusion, our results highlight the importance of BCT in developing capabilities to absorb, adapt and innovate. The information that is almost automatically produced in BCT product lines would not be useful *per se*, unless processed and transformed into knowledge for the firm. In fact, according to RBV reasoning, to gain a competitive advantage it is important to complement technological innovation with the firm's other resources, such as human skills (Teece, 1986). This can produce an integrative knowledge, that is, a knowledge that "enables organizations to coordinate activities within a vertical chain or across vertical chains, to obtain market feedback from customers about products and to obtain feedback either from within vertical chains or from external markets regarding technology" (Helfat and Raubitschek, 2000, p. 964). BCT can introduce a system of learning within the firm, where the processing of real-time data transforms into knowledge thanks to employees learning by doing and customers learning by using. As for other Industry 4.0 technologies, new job positions could emerge or gain importance, exemplified by the Data Analyst position. As outlined by Delke *et al.* (2023), this role extends beyond mere data analysis skills. It encompasses the ability to contribute significantly to new project initiatives and strategic development, supporting the alignment of technological advances with organisational goals and strategies. Additionally, BCT impacts other skills, such as interdepartmental communication and negotiation skills to engage stakeholders along the supply chain, as previously discussed by Epelbaum and Martinez (2014) for the traceability systems in the food sector. Moreover, in terms of evaluation, BCT leverages the ability to critically analyse the effectiveness of BCT in meeting business objectives and to make informed decisions based on this analysis. However, as the case study shows, the full potential of BCT can only be achieved if the implementation of blockchain is framed within a clear strategic overview.

7. Conclusions

This study has investigated the impact of BCT adoption on the economic relationship within the agri-food supply chain from two perspectives: TCE and RBV-DCV.

Our empirical findings revealed the existence of two different types of BCT Configurations by the firms participating in the case study: the first Configuration involves a dynamic integration of BCT into the firm's daily operations and IT systems, with the active involvement of supply chain partners (Configuration 1-*Dynamic* BCT) and is suitable for firms aiming to improve traceability and transparency in the supply chain. The second Configuration (Configuration 2-*Static* BCT) does not require the direct involvement of supply chain partners or integration with IT systems, and is used by companies for marketing and communication purposes, as it provides a static snapshot of the supply chain that can then be communicated to the consumer via a QR code.

Results showed that the choice of Configuration, and thus *how* BCT is adopted, influences the impact of the technology on the agri-food supply chains, particularly from a TCE perspective. In fact, the case study revealed that agri-food companies can only reap the benefits of BCT, such as reduced uncertainty and increased transparency, if they adopt Configuration 1, integrating the technology into their daily operations and actively involving supply chain partners in its implementation and maintenance. This collaborative approach creates a network of trust that effectively reduces transaction costs, yet it has had less of an impact from an RBV-DCV perspective. In fact, we found that both Configurations led to the development of dynamic capabilities, albeit through different channels. This effect is more pronounced when all actors in the supply chain have a clear understanding of blockchain's functionality and value. Moreover, we found that BCT is not yet perceived as a strategic resource by most of the companies involved in the case study, regardless of the type of Configuration. Overall, the findings suggest that to fully realise the potential of BCT, companies should align the type of Configuration with their strategic objectives, whether it is improving traceability or marketing, to realise its full potential.

This study also contributes to the existing literature by empirically exploring the implications of BCT adoption for firms in the agri-food sector. Given that BCT is still in its early stages of adoption in sectors that can greatly benefit from this technology, such as agri-food, our qualitative investigation provides an in-depth analysis of the phenomenon. However, the generalisability of our findings is limited by our sampling strategy focused on short and local supply chains as well as SMEs. Despite this, the qualitative case study approach proves invaluable in investigating new technologies like BCT. By using robust qualitative methods, we ensure that our findings are insightful and potentially replicable in diverse contexts. Moreover, although the application of quantitative methodologies remains a challenge in sectors where BCT is still in its infancy, the expanding adoption of BCT within agri-food supply chains, coupled with insights from qualitative research, lays a solid foundation for developing testable hypotheses. This process facilitates the creation of theoretical constructs that are well-suited for empirical examination in future quantitative studies. Such a methodical approach is instrumental in advancing our understanding of the impact of BCT and its potential in these evolving sectors.

To enhance external validity, future research could replicate our investigation across different geographical areas, various agri-food supply chains and a broader range of firm sizes. This would enable researchers to reveal more intricate power dynamics and practical challenges that could arise in longer and geographically dispersed supply chains. Moreover, the perspectives of the many stakeholders, together with the opinions from a larger set of owners and managers of companies promoting BCT in their supply chains, may provide diverse insights into the experiences of all the actors along the supply chain. Furthermore, longitudinal analysis collecting empirical data on the evolving impact of BCT over time would provide deeper insights into the formation of sustained competitive advantage and the implications of failed attempts. On top of this, our results highlight the importance of establishing a comprehensive understanding of the different types of BCT configurations available and adopted in the market. Future studies should assess the awareness and perceptions of BCT of all supply chain actors and consumers to maximise its benefits. This broader perspective would help exploit BCT's advantages to the full in the agri-food sector studied in this work and beyond.

Note

1 www.agrifood.tech/tag/agroalimentare/

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Further reading

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Supplementary material

The supplementary material for this article can be found online.

Corresponding author

Claudio Soregaroli can be contacted at: claudio.soregaroli@unicatt.it