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Uncovering the potential of blockchain in the agri-food supply chain: An interdisciplinary case study

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A R T I C L E I N F O

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A B S T R A C T

This paper explores how Blockchain technology (BCT) can be integrated in the agri-food supply chain (ASC) and how BCT-based networks are formed. To do this, the paper describes a BCT solution, designed to enhance traceability, and analyses its adoption in two small firms. Adopting an interdisciplinary approach and the Actor-Network Theory (ANT), the findings have revealed that BCT improves how data is collected and has changed how firms interact with stakeholders and customers. Firms have enhanced their reputations and started targeting new domestic and international markets. Technical and economic challenges were found when persuading actors to participate in the BCT-based network.

1. Introduction

Blockchain technology (BCT) could offer a transformative solution for industries by acting on their supply chain. BCT provides a decentralized system without third-party intervention (Nakamoto, 2008) and makes information publicly available, ensuring integrity and immutability of data (Zhao et al., 2016). Due to these characteristics, BCT can ensure traceability, which is defined as the ability to trace transactions and products from the source to the consumer (Pólvora et al., 2020).

Based on its potential for traceability, BCT is predicted to add the most value to agri-food supply chains (ASCs) (González-Puetate et al., 2022; Morella et al., 2021; Saurabh and Dey, 2021; Wang et al., 2019a) by encouraging fraud prevention, guaranteeing regulatory compliance and, by improving the quality of the information stored (Guido et al., 2020). Above all, BCT could help to establish a trust relationship between consumers and producers and enable customers to make informed decisions about the products they purchase and firms to support (Bumblauskas et al., 2020). On the other hand, ASCs are increasingly suffering from multifaceted transparency, integration and traceability issues (Vern et al., 2022).

The literature has stressed the importance of exploring how to extend the deployment of BCT far beyond the field of crypto-currencies (Nanayakkara et al., 2019; Pólvora et al., 2020). While the agri-food sector has called for technologies which enable traceability along the supply chain (Barata et al., 2021), the degree of integration of BCT in the ASC still remains unclear because it is a relatively new area of study (Kumar et al., 2022; Vern et al., 2022). Moreover, "killer applications" have yet to be invented (Behnke and

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Janssen, 2019). As yet, few academic publications have focused on BCT in the ASC (Demestichas et al., 2020; Motta et al., 2020). In particular, there is a lack of knowledge about BCTs potential impact, both negative and positive, on ASCs. The perceived benefits and challenges for firms should also be addressed (Liu et al., 2020; Wang et al., 2019a). Existing research has still not paid much attention to the formation of BCT-based networks and the coordination of stakeholders (Liu et al., 2020; Pólvora et al., 2020; Saurabh and Dey, 2021). Indeed, there is little of knowledge about how companies could adopt BCT so as to improve customer engagement (Boukis, 2019; Gielens and Steenkamp, 2019; Scholz and Duffy, 2018).

To contribute to the debate, the study of innovation in supply chain management has sought interdisciplinary approaches (Barata et al., 2021; Sabri et al., 2018) specifically as regards BCT (Queiroz et al., 2019), which should be investigated through collaboration among researchers from different disciplines (Rane and Narvel, 2019). The purpose of this paper is to advance such research. First, to explore how BCT can be integrated into the ASC and what the perceived benefits and challenges for firms are. Second, the paper focuses on the formation of a BCT-based network and the engagement of stakeholders. To do this, the study applies the Actor-Network Theory (ANT) (Callon, 1984; Latour, 1991). The ANT offers a theoretical framework to capture the context, the motivations and the relationships occurring within the ASC from an interdisciplinary perspective, by considering both human and non-human entities (Elbanna, 2012; Roba et al., 2017). Thus, the paper addresses the following research questions:

1) How do focal actors build consensus for the adoption of BCT in the ASC?

2) What are the socio-economic and technological interests of the actors involved in the adoption of BCT within the ASC?

3) In what way is BCT disrupting relationships between actors in the ASC?

We started from a complex case study (Yin, 2018) describing a novel BCT solution, namely Trusty, which acts as a traceability platform that captures data from the ASC. We investigated its adoption in two small agri-food firms. The firms are part of traditional Made in Italy sectors where reputation, brand awareness and customer value are becoming essential drivers for competitiveness (Bravi et al., 2018). To analyse the design and the implementation of the BCT solution, we put together the views of academics, from both applied economics and information engineering, along with practitioners, and with the perspectives of company experts. Adopting both an interdisciplinary approach and the ANT approach, enabled the paper to reveal the potential of BCT integration in the ASC as it matched the solutions proposed to meet the technological, legal, economic and managerial challenges identified in the literature. This paper also offers implications which might well be of interest to academics, policy makers and to experts operating in ASCs.

This paper is structured as follows: Section 2 illustrates the theoretical framework on BCT, ASCs and traceability; Section 3 describes the methodological approach; results are presented in Section 4 and the discussion follows in Section 5. Conclusions, implications, limitations and future avenues of research are then presented.

2. Theoretical framework

2.1. Uncovering the potential of blockchain technology for industries: from Bitcoin to supply chain management

To be transformational, a technology should impact on the life of people in a meaningful way. This seems to be the case for BCT, which is now recognized as one of the most promising technologies (Fernández-Caramés and Fraga-Lamas, 2019) and most disruptive innovations of the Fourth Industrial Revolution (Si et al., 2020).

When it was introduced in 2008, BCT provided a distributed ledger in which every computer participating in the transaction of a certain coin kept a copy of the history of its transactions. The technology made sure that no party storing this history could tamper with it without being detected (Nakamoto, 2008; Narayanan et al., 2016). Since then, this distributed cryptographic system has offered a new means of dealing with industry needs and supply chain management (Zhao et al., 2016). An increasing number of studies have proposed BCT-based solutions for tracing transactions and items along the supply chain (Chang et al., 2019). Through its traceability mechanisms, BCT could become a source of change in today's conventional ways of extracting and delivering value by acting as a new means for achieving trust among partners and stakeholders (Pólvora et al., 2020).

Based on interviews with supply chain experts, Wang et al. (2019b) argued that traceability through BCT can enable information sharing and build trust among stakeholders along the supply chain. Similar conclusions were argued by Nakasumi (2017) who proposed a BCT-based solution to address knowledge sharing problems among the companies in a supply chain so as to ensure responsiveness to market conditions and improve overall supply chain efficiency. Within this line of research, based on a case study on B2B relationships, Korpela et al. (2017) found that BCT can also accelerate the digitalization of supply chain networks in a cost-effective manner. Indeed, the integration of BCT with other Industry (I4.0) technologies, such as the Internet of Things (IoT), is expected to boost traceability applications (The European Union Blockchain Observatory & Forum, 2020; Pólvora et al., 2020). In this regard, Helo and Shamsuzzoha (2020) described a pilot study where BCT architecture tracks and traces data in supply chains using IoT. In their architecture, IoT provides data from sensors attached to items, while BCT ensures secured data transactions between stakeholders.

All the above-mentioned features are increasingly relevant and important for the ASC where, as is described in the next section, multiple stakeholders, especially customers, are pressuring for traceability along the supply chain.

2.2. The transformational impact of BCT for traceability in the agri-food supply chain

Among the potential applications of BCT in supply chain management, ASC is emerging as one of the most promising areas for traceability (Bünger, 2017; Kshetri, 2018; Staples et al., 2017). From a legal standpoint, based on the European Union General Food Law EC 178/2002, food traceability is the capability of tracking and tracing food in all phases of production, processing, and sales. Traceability in ASCs is becoming more and more complex since ASCs are getting longer with expanding globalization and increasingly

Table 1
Selection of reviewed use cases on BCT for ASC traceability.

Application	Features	Implications	Open challenges	References
IBM Food Trust™ for Walmart's pork and mango supply chain	Permissioned platform based on Hyperledger blockchain	• More control over brands and businesses • Deeper learning capacities	• Ensure value for all participants • Leadership to coordinate stakeholders • Going beyond pilot projects • Solving previous vulnerabilities of broken supply chains • Overlapping and conflicting demands from national regulators around the world • Formation of BCT-based network and the coordination of stakeholders	Galvez et al. (2018);IBM (2020, 2017),Kamath (2018),Köhler and Pizzol (2020),Polansek (2019), Redman (2016)
WWF pilot for a sea-food supply chain	Built on the Ethereum blockchain combining RFDI and QR codes	• Better product control • Better business decisions • Meeting ethical and sustainable standards	• Reliance on paper-based processes • Incentivize supply chain actors to participate in the process • Authenticity of data • Transaction time • Unknown costs	Cook (2018),Köhler and Pizzol (2020)
EZ Lab for Wine supply chain	Blockchain based on Ethereum combining RFID and QR codes	• Helps the customer to learn about the wine processes	• Implementation in small food companies • Paper-based processes • Lack of financial resources from farmers to support the new system	EZLab (2017), EZLab (2018a) (2018b),Motta et al. (2020), The European Union Blockchain Observatory & Forum (2019b)
TE-Food	Both public and private blockchain are used. Tokens are used to reward customers	• Addressing power imbalances between producers in emerging economies • Fairer distribution of value • Poverty reduction	• Pilot based project	Köhler and Pizzol (2020), Motta et al. (2020),TE-Food (2017),TE-Food and LAUREL (2017)
Fair Chai along MoyeeCoffee	Blockchain linked to tokens. ID and digital wallets are created for the farmer	• Creates a fair and more honest supply chain. • Gives small businesses more power	• Pilot based project • Additional technologies are needed to really ensure trust • Doubts on removing human intervention	MoyeeCoffee (2018), Potma (2018), Wang et al. (2019a)
Bytable Inc.for eggs	Private Blockchain integrated with software and hardware solutions	• Possibility to further explore customer interaction with blockchain traceability data	• Need for updated technologies to ensure standardization • Lacking interfaces or standards regarding food traceability	Bumblauskas et al. (2020)
AgriBlockIoT	BCT can rely on Ethereum or Hyperledger Sawtooh	• Using IoT to collect data along the chain	• Selecting the right blockchain based on languages and customization • Assessing the suitability of the framework in the case of real IoT devices and gateways • Lack of clear data governance • Heterogeneity of the involved actors, stakeholders and business models, their different levels of confidentiality and coordination	Caro et al. (2018), Demestichas et al. (2020), Zhao et al. (2019)
originChain for imported products	BCT offering on-chain vs off-chain solutions	• Suitability of the solutions for many industrial projects	• Applying BCT in existing systems makes the architecture more complex	Wang et al. (2019a);Xu et al. (2019)

(*continued on next page*)

Table 1 (*continued*)

Application	Features	Implications	Open challenges	References
			• Implementation of additional components to make BCT interact with existing databases	
GEBN Blockchain Business Network for grain	Blockchain consortium	• Reduction of dispute among business partners • Additional valuation of products	• Collaboration required by companies in the ASC	Lucena et al. (2018)
Green Blockchain	Traceability system based on Algorand Blockchain, which uses the Pure Proof-of-Stake mechanism of consensus	• Low energy consumption • Costs savings	• Developing a fully decentralized application (DAPPS) integrated with smart contracts • Scaling the system architecture, design, and interactions inside the whole supply chain	Varavallo et al. (2022)
Agri-SCM-BIoT	The Agri-SCM-BIoT (Agriculture Supply Chain Management using Blockchain and Internet of Things) uses multiple blockchains to meet the requirements of the agriculture supply chain business	• System storage and performance enhancement • Privacy and security enhancement • Cross-chain communication between heterogeneous blockchain platforms • IoT device authentication and data authentication and integrity	• Collaboration between several stakeholders and diverse parties • Developing a trustworthy blockchain-based cross-chain SCM system.	Bhat et al. (2021)
F2F application – European Food Supply Chain	The proposed F2F application relies on the Hyperledger Sawtooth platform	• Sensorial traceability • Right mix of authorizations and public visibility of the data • Elimination of centralization • Increase in trust between members participating in the supply	• Low maturity of the Sawtooth platform • Lack of application and scalability	Baralla et al. (2019)

Source: Authors' elaboration.

intense competition (Behnke and Janssen, 2019; Xiong et al., 2020).

The increasing complexity of ASCs has radically widened the distance between consumers and producers (Lan et al., 2017). Moreover, consumer confidence in the ASC has been heavily undermined due to the threat of food scandals (Bernard et al., 2002; Tian, 2017; Xiu and Klein, 2010) and this steady decline in the level of trust is negatively affecting companies' reputations (Edelman, 2017; Gallup, 2012). Furthermore, customers have become considerably more wary, and are demanding more information (Guido et al., 2020) about food safety, sustainability and origin (Demestichas et al., 2020; Lan et al., 2017). In particular, empirical studies have recently found that consumers consider food origin as the most important information to be traced (Petrescu et al., 2022; Walaszczyk and Galińska, 2020). This means that agri-food companies should increase transparency for consumers (Köhler and Pizzol, 2020). To this end, firms need to trace products well and quickly identify issues along the ASC to improve supply chain management.

Nevertheless, most ASCs are bereft of traceability (Hastig and Sodhi, 2019) and are little digitalized (Manyika et al., 2015). The majority of the existing traceability systems are both centralized and outdated in terms of data sharing (Demestichas et al., 2020). Supply chains often rely on time consuming paper-based processes, which may lack transparency due to inconsistent, missing, or even fraudulent data. A major issue is also the lack of interoperability of data structures between actors and, hence, limited information on product traceability (OECD, 2019a). As a result, data are subject to fraud, corruption or error, which can lead to food illnesses, health emergencies, and financial losses (Aung and Chang, 2014).

More recently, scholars and practitioners have emphasized that BCT could be a disruptive force that will add value to ASCs, by ensuring product traceability (Wang et al., 2019a). Implementing traceability can improve the quality of stored information and enable actors to be informed, in real-time, about what is happening along the ASC (Guido et al., 2020; Tian, 2017). BCT would also support fraud detection and counterfeiting prevention (Business Reporter, 2018; Tan et al., 2018) based on transparent, reliable, and auditable data (The European Union Blockchain Observatory and Forum, 2019). Moreover, there could or would be cost savings due to the reduction of surveillance of goods (Ko et al., 2018).

The implementation of ASC traceability, by means of BCT, would also help establish a relationship of trust between consumers and producers by guaranteeing transparency on the origin of their food (Bumblauskas et al., 2020). From the firms' perspectives the technology could enable companies to analyse consumers at the individual level and to take better informed production and marketing decisions (Tripoli and Schmidhuber, 2018). Hence, BCT could support firms when expanding their advertising campaigns and improving their customer targeting capabilities by enhancing service responsiveness, legal compliance and ethical principles (Boukis, 2019; Ertemel, 2018; European Parliament, 2020b; Rejeb et al., 2020). From the consumers' perspective, having access to traceable and transparent ASCs, BCT guarantees that they will have reliable data about how food is both produced and distributed. Thus, BCT enables consumers to make informed choices about which products and companies to support (Bumblauskas et al., 2020) by addressing concerns about the safety, quality, authenticity and environmental friendliness of products (Ge et al., 2017).

Although BCT-based traceability is able to provide a wide range of advantages for both companies and consumers, it must be admitted that a variety of technical, legal, managerial and economic challenges are hindering the adoption of the technology within the ASC.

2.3. Challenges of using blockchain for ASC traceability

A blockchain is a distributed ledger, composed of consecutive blocks of data that include details of all transactions and other operations supported by the infrastructure itself. Each block is hashed and connected to the next one, providing a chain of unchangeable and tamper-proof records (Peck et al., 2017; Salah et al., 2019). All blockchain infrastructures support the immutable storage of data, which is the basis for both data notarization and certification applications such as those aimed at documenting, tracing, and certifying the steps of a productive process in the supply chain. Furthermore, some blockchain infrastructures, like Ethereum, also make it possible to execute algorithms, which serve to extend the fields of application of BCT (Pólvora et al., 2020; Toyoda et al., 2017).

To investigate the deployment of BCT in ASCs, we performed several searches in both Google Scholar and Scopus. We included the following key words: "Blockchain", "Agri-food supply chain" and "Actor-network". The search returned more than 2000 results. We restricted the analysis to the most cited use cases regarding BCT and traceability in the ASC. Table 1 below shows a selection of the use cases resulting from the search and reports the name of the BCT-based applications in the ASC, their features and implications, and open challenges.

From a general standpoint, the implementation of ASC traceability by means of BCT provides a reliable framework for tracking data on food safety, origin and protocol regulations across various distributors, processors and retailers (Demestichas et al., 2020). Sharing a public ledger of immutable transactions enables stakeholders of the ASC to keep track of transactions with no central record-keeping. The use cases of BCT reviewed have shown that its adoption has not only made it possible to improve business processes and decisions but has also disrupted the traditional supply chain. In fact, the implementation of BCT has resulted in a fairer distribution of bargaining power between actors in the ASC. In terms of customer management, BCT has made it possible to disclose additional information to customers on products and processes and, the information disclosed has also highlighted the importance of studying how the customer interacts with the information uploaded on the BCT (Bumblauskas et al., 2020).

However, the use cases studied have also shown that there are several open challenges which concern the technical, legal, and economic and managerial domains. Drawing on the above use cases reviewed, Table 2 summarizes our elaboration of the most recurrent challenges that hinder the wider application of BCT in ASCs and also proposes a set of applicable solutions.

As regards the technical domain, the first challenge is posed by the "digital twin consistency" issue. Indeed, what is traced and certified through the blockchain is a digital twin of the real world, but the extent to which the digital twin truly reflects the real world is both hard to guarantee and hard to verify. For example, data concerning the sowing and cultivation of a specific agricultural product may be manually entered into the certification and tracing infrastructure. However, there is no guarantee that these data have not already been falsified or altered beforehand. One way of overcoming this weakness is to design tamper-proof IoT devices that can notarize data directly into the blockchain (Grecuccio et al., 2020). Moreover, the implementation of BCT raises another crucial issue concerning the standardization of technical interoperability. To date, there has been little research regarding this burgeoning challenge. On the one hand, there have been several traceability projects based on a variety of BCT solutions, such as that on Ethereum (Kim et al., 2018), Hyperledger (Caro et al., 2018), and IOTA (Suhail et al., 2020). On the other, these BCT-based solutions are non-interoperable. As yet, little effort has been made to standardize inter-BCT data interoperability and, furthermore, the reviewed applications mainly refer to pilot projects for which long-term costs are still unknown (Cook, 2018). Most of the applications require additional, costly, software and hardware to ensure the accuracy of the data uploaded. Best practices for testing different solutions are needed to find, and share, the optimal technical combinations that can ensure both accuracy and financial sustainability.

Second, regulations concerning BCT traceability are still far from ready to be systematically enacted within the supply chain (Kshetri, 2018). In particular, the terminology used when regulating BCT is non-uniform, which seriously limits both the development of an appropriate legal framework and the design of policies: any such terms should be explained, clarified, and then standardized. Furthermore, there are various overlapping, and conflicting, demands from national regulators around the world, often concerning allergens, trace elements, pesticides, food fraud and market substitution. There is also a lack of regulations in place regarding the reduction of energy consumption in BCT. To address these issues, collaboration between governments and stakeholders involved in use cases should be encouraged (Kamilaris et al., 2019; OECD, 2019b). White papers can also be a useful tool for summarizing research outcomes and positions on complex issues, such as BCT, and for proposing a set of recommendations for empowering regulators and engaging stakeholders.

Third, the state of economic and managerial research is, as yet, largely at the experimental stage (Wang et al., 2019a) and the

Table 2
BCT open challenges and suggested solutions.

Domains	Open challenges	Proposed solutions
Technical domain	• Digital twin consistency: adherence of the digital twin to the real world is hard to ensure and verify. • Standardization of technological interoperability: Lack of standards for traceability platform interoperability.	• Designing tamper-proof IoT devices able to notarize data directly into the blockchain. • Data harmonization among other, diverse, good practices to improve interoperability.
Legal domain	• Few regulations and discussions on BCT traceability and BCT energy consumption.	• White paper proposals for the empowerment of regulatory bodies and stakeholder engagement approaches.
Economic and managerial domain	• Formation of the BCT-based network • Understanding perceived benefits and challenges for both companies and customers.	• Fostering awareness and knowledge, among stakeholders and customers, about BCT and its economic, social and environmental implications in the ASC.

Source: Authors' elaboration.

potential impacts of BCT in the supply chain are still unclear (Köhler and Pizzol, 2020; Pólvora et al., 2020; Wang et al., 2019b). There is a lack of use cases evaluating the effects of introducing BCT (Holotiuk et al., 2018; Liu et al., 2020; Stranieri et al., 2021), especially regarding customer experience (Boukis, 2019; Gielens and Steenkamp, 2019; Kamilaris et al., 2019; Scholz and Duffy, 2018). It is worth noting that most stakeholders are not ready for a paradigm shift towards BCT because of a lack of awareness and of knowledge about BCT and its value for all ASC participants and customers (Ge et al., 2017; Kamath, 2018; Liu et al., 2020; Stranieri et al., 2021; Verhoeven et al., 2018). There is also widespread scepticism among ASCs actors about adopting BCT: in fact, many supply chain actors still rely on paper-based processes. Overall, ASC companies often do not know how to make an optimal investment decision in BCT and, mostly, how to form a BCT-based network and how to coordinate partners and stakeholders (Liu et al., 2020).

Because both several actors and heterogeneous interests are at stake, the study of BCT specifically for ASC is emerging as an interdisciplinary field of research (Karlsen et al., 2013) for which, as the following section illustrates, the ANT could provide a theoretical framework of reference.

2.4. The actor-network approach for introducing blockchain in agri-food supply chain

The ANT is a suitable theoretical framework for investigating BCT adoption in supply chains and the formation of a BCT-based network. The ANT makes it easier to examining the complex relationships and motivations of the actors who are part of a network (Elbanna, 2012; Sage et al., 2011). These premises are critical when analysing supply chain management which is recognized as being a complex network of businesses that are responsible for customer satisfaction, through their production and consumption activities (Lu et al., 2012).

Each supply chain requires an accurate investigation of the context, the actors, and the activities performed (Roba et al., 2017). Furthermore, each actor plays a socio-economic role in a supply chain, one which will impact on their production and marketing activities (Osei-Amponsah and Visser, 2016).

The actions and roles of different supply chain actors in the BCT-based network can be mapped through the theoretical lenses of the ANT. Table 3 shows four stages through which actors within a network could be analysed:

Among the actors involved are the focal actors, those that convince other actors to achieve a specific goal (Venturini, 2010). According to the ANT, actors can be human or non-human, as technologies are also included in the analysis. By considering BCT as a non-human actor, scholars have recognized the value of the ANT for interpreting the socio-economic domain that is involved in the introduction of BCT itself (Darcy et al., 2018). The ANT has been applied specifically to the ASC to support agricultural practitioners when formulating strategies and decisions that could increase brand awareness among customers. Mapping, based on the ANT, can also facilitate expansion of both the type of customers targeted and of distribution channels for selected agricultural products (Tang et al., 2018). Thus, the ANT could offer a "toolbox", to help unravel the complexity of implementing BCT in ASC and assist with interpreting BCT potential (Molling et al., 2020).

3. Methodology

This paper has two purposes. First, it seeks to contribute to the literature by addressing the lack of knowledge about the integration of BCT in ASCs and its potential impact, both negative and positive, on firms. The perceived benefits and challenges for firms are also addressed. Second, this paper seeks to advance the existing research that has not paid much attention to the formation of BCT-based networks and the coordination of stakeholders, including the engagement of customers.

We have investigated the adoption of BCT in the area of food traceability by presenting a BCT-based solution whose implementation is examined through the cases of two small Italian firms in the agri-food industry. The BCT solution is called Trusty, which is a novel traceability platform that captures data from the ASC.

The case study methodology was suitable since the case involved is exemplary (Yin, 2018) as it provides an explicative example in which BCT has been adopted not only as a tool for improving traceability within the ASC, but also as a means for enhancing customer engagement. Since this technology is still in its initial stages of development, case study research can generate valuable insights

Table 3
ANT stages.

Stages	Description
1) Problematization	• Identification of the needs, of the key and the focal actors, and of an obligatory passage point (OPP) wherein all the different interests converge
2) Interessment	• Focal actors negotiate the roles and decide how to involve all the other actors, into the BCT-based network and how to balance bargaining power
3) Enrolment	• The planning of the previous stage is turned into action
4) Mobilization	• Focal actors ensure acceptance of roles and decisions. Focal actors become the voice of the BCT-based network

Source: Authors' elaboration based on Callon (1984) through theory-based or practical oriented studies (Treiblmaier, 2019).

The ANT provides a suitable theoretical and methodological framework for establishing which data to collect when investigating digital technologies and their impact on supply chain management (Molling et al., 2020; Wehrle et al., 2021). Moreover, the ANT enables us to focus on both the stage of technology design and on adoption (Kaghan et al., 2001). Based on the ANT, we have identified the actors, focal actors, and their motivations and activities, classifying them according to the four stages suggested by Callon (1984): problematisation, interessment, enrolment and mobilization. We then, by applying a simplified version of ANT, as suggested by Islam et al. (2019), mapped the actors taking part in the BCT-based network by classifying them into technological, social and economic domains. Drawing on Yin (2018), data for this case study was gathered from several sources (see Table 4). Data collection was carried out as follows:

- *Step 1.* Selection of case study Trusty. Experts from the Department of Information Engineering of the Polytechnic University of Marche (Italy), who have experience in developing BCT prototypes and in providing consultancy for use cases in multiple sectors, have screened the most innovative BCT solutions for the ASC at the national level. This screening focused on solutions tailored for small firms, which are those who have most need to increase their visibility within the ASC. Trusty was selected as being the most suitable case study to investigate.
- *Step 2.* Initial meetings with the developers of Trusty were held: with the founders of Apio, an innovative Italian start-up; and with the Blockchain Department of the Var Group, a leading Italian group in the field of value-added IT solutions for business segments. These interviews sought to identify the actors, focal actors, motivations and the use cases that should, or could, be included from their portfolios of clients (May 2020).
- *Step 3.* Secondary material on the functioning of Trusty, provided by Apio, was analysed (May 2020).
- *Step 4.* Two rounds of interviews, with the entrepreneurs of the small companies selected, were held (June – July 2020).
- *Step 5.* Follow-up interviews were conducted with Apio founders and the Var Group Blockchain Department (September 2020).
- *Step 6.* Follow-up interviews were conducted with Apio founders, and the small companies selected (March 2022).
- *Step 7.* Triangulation of the data was carried out to construct the case study (Gibbert et al., 2008).

4. Results

Following the ANT, first, we classified the developers of Trusty as the focal actors of the BCT-based network. In presenting the focal actors, we explain, in Section 4.1, the *problematisation stage*, i.e. which needs the developers had identified among Italian firms with reference to their ASC, and how the BCT-based solution provided a reliable answer. In explaining the BCT solution we relied on the indications of Treiblmaier (2019) presenting, in detail, both its architecture and the additional non-human entities involved, including software and I4.0 technologies. In Section 4.2 – the *interessment stage* - we specify how the focal actors managed to bring together all the interests at stake by proposing a differentiated business model in which customer engagement acted as an incentive for adopting BCT among small firms. In Sections 4.3 and 4.4 – respectively the *enrolment stage* and the *mobilisation stage* - the use cases are illustrated by considering the introduction of BCT based on the specific needs of two small Italian companies.

4.1. Problematization stage: focal actors, needs and BCT-architecture

In 2018 Apio, an innovative Italian start-up, and the Var Group, a leading Italian group in the field of value-added IT solutions for business segment, started working on Trusty, which is a traceability solution, based on BCT, for the ASC. The companies acted as focal actors by recognizing major issues that have been, and are, impacting the Made in Italy industry, such as food counterfeiting and the, so-called, "Italian sounding" illusion. The latter consists of the production and distribution of food with names, colours and symbols that evoke Italian identity. Based on recent data, the value of fake "Made in Italy" products in the agri-food industry has registered an increase of 70% over the past 10 years, reaching a total value of 100 billion Euro in 2019.[1] Because of this, Apio and the Var Group started to design Trusty to capture data from the ASC, so as to provide an easy, secure way for firms of different sizes to share knowledge along the supply-chain.

In the first few months of 2019, Apio and the Var Group became the first worldwide Trusted Partner of the IBM Food Trust, which is the most important BCT platform for actors in the food industry. This platform offers improved visibility throughout the ASC, as it forms a collaborative network of stakeholders (i.e., farmers, processors, suppliers, distributors, and retailers). The IBM Food Trust provides several modules, on subscription, which offer a distinctive supply chain solution for members based on their technological, managerial and social needs. In particular, the *Trace Module* provided by the IBM Food Trust ensures full disclosure regarding the provenance and ingredients of products travelling through the entire supply chain, by scanning a QR code that can be linked to the public page of the product.

By using Trusty, traceability, events can be retrieved either from the IBM Food Trust or from other BCT platforms, such as Bitcoin and Ethereum. Disclosure of data is possible since Trusty is a Global Standards (GS1)-compliant solution and offers a standard for identifying the location of origin/production based on Global Location Numbers (GLN). The codes can trace the plant, or farm, where production takes place, and identify the products, packaging and pallets through a Global Trade Item Number (GTIN). Then, Quick

[1] https://www.coldiretti.it/economia/falso-made-italy-sale-100-mld-70–10-anni

Table 4
Summary of empirical data.

Data source	Type and quantity of collected data
Technical documentation	• White paper of Apio on BCT for ASC • Trusty brochure (light version) • Technical presentation of Trusty (extensive version) • 2 Technical reports of Use Case 1 • 2 Technical reports of Use Case 2
Semi-structured Interviews	• Apio founders (4 interviews of 60 min each) • Var Group S.p.A. - Blockchain department (2 interviews of 60 min each) • Client Use Case 1 (3 interviews of 60 min each) • Client Use Case 2 (3 interviews of 60 min each)

Source: Authors' elaboration.

Response (QR) codes are printed on the label of the product and can also be applied to batches or serial numbers.

Trusty also enables food producers to upload descriptions, pictures, and videos of the company, and of its facilities and products. Drawing on consumer interactions with the public pages, Trusty is structured as a tool that collects relevant information on customers, such as, how many people have interacted with the brand, and on which content has been most appreciated for its purchasing and product appeal. This additional data can be used by food producers both to improve customer engagement and to create new marketing campaigns all based on transparent and secure supply-chains. It should be noted that this partnership with the Var Group provided Apio with the necessary co-marketing and co-selling activities and, also, supported pre-sales and post-sales activities.

In developing Trusty, the focal actors also took into account the other, non-human entities (software and I4.0 technologies), in the BCT solution considering them as additional tools able to deal with further issues occurring within the ASC. In this sense, Trusty was designed as a service cloud platform, that includes an integration layer with I4.0 technologies and, also, with Enterprise Resource Planning (ERP) software, Customer Relationship Management (CRM) software and with Software Configuration Management (SCM). This integration is necessary in order to avoid:

- duplicating information. Data would be duplicated since they are entered from both the existing software used by the company (e.g. ERP, CRM, SCM) and from the blockchain.
- Human errors. An operator may make mistakes when entering data.
- Data tampering. An operator could change information before data-entry.

Such integration enables both automation and acceleration of data entry processes with respect to each production batch and to the company registration procedures (on boarding), which consist of a declaration of the company's facilities and data. Through integration with I4.0, Trusty also permits secure exchanges of information with the whole supply chain, thus ensuring transparency with all stakeholders.

The integration process is carried out in four steps: 1) Knowledge of the company, including the analysis of economic and social needs, data systems, factories, products, and traceability events. 2) Assessment of the interface and data model used by the company. 3) Product and batch data integration through two methods. The first is Indirect integration, which consists of the creation of software micro-services that receive data as input from the company model and, then, build a data model compliant with the platform. The second is Direct integration, based on the use of external software that can easily integrate Trusty's functionalities and automate data-entry processes. 4) Data timestamping through BCT (e. g. Bitcoin, Ethereum, or IBM Food Trust).

Thus, as shown in Fig. 1, with its cloud architecture and components, Trusty also facilitates blockchain integration between existing blockchain solutions and the company's own software. This integration offers specific solutions for the following challenges:

- *Interoperability between different Blockchains*. It is possible to integrate several BCT-based solutions through the Blockchain Integration Layer which means companies are not tied to one single solution (e.g. Bitcoin, Ethereum, or IBM Food Trust).
- *Integration of external systems*. It is possible to use diverse communication channels (Hypertext Transfer Protocol HTTPs, Message Queuing Telemetry Transport MQTT, Secure File Transfer Protocol, SFTP) through the Integration Layer and Representational State Transfer Application Programming Interface (REST API) architecture and methodology, and so be able to integrate any enterprise's software as described in step 3. This integration creates a public product page that can be viewed by customers through the QR code. Using the QR code, customer analytics are then included in the Trusty Dashboard. Furthermore, thanks to integration with the GS1 Electronic Product Code Information Services (EPCIS) Standard, it is possible to make systems interoperate seamlessly with each other.

4.2. Interessment stage: converging the interests in a differentiated business model

After identifying the needs of Made in Italy companies in the agri-food industry, Apio and the Var Group considered how to involve businesses along the ASC into a BCT-based network. Defining incentives was a central part of the business model proposed. Trusty is the only free-use platform on the market that acts as a traceability platform using BCT to secure and certify information. Contrary to

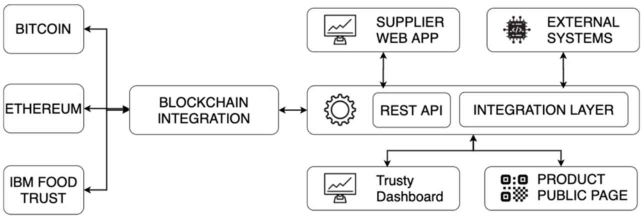

Fig. 1. Trusty architecture and components.
Source: Authors' elaboration.

leveraging on a pay-to-use approach for final customers, the company introduced a "freemium approach". This means that the platform will always be free for newcomers, making it easier to expand Apio's database and to increase awareness of BCT potential, especially among SMEs. The free-use platform for food producers has several innovative features:

- A dashboard that enables food producers to manage information associated with products (e.g., pictures, videos, and descriptions).
- Timestamping through Public Blockchain (Bitcoin).
- A public page with product pictures, descriptions and traceability information. The page can be accessed through a QR-Code scan.

There are also three premium functionalities that can be unlocked by paying a fee. They range from 1) a Base Plan (which enables the client to remove Trusty's logo from the public page and to unlock analytics on products and batches), 2) an SME Plan (that integrates an external software, such as REST-API, for bulk upload and automation of data entry) and, 3) an Enterprise Plan. This latter functionality makes it possible to activate sensors and, also, offers other suppliers in the supply-chain an opportunity to declare information. Food producers invite their suppliers to join and then share a data-entry interface with them to receive information.

An advisory service, that is mainly used by Large Retail Organizations and Large Food Producers, is also available. It is based on a monthly fee that varies according to the number of suppliers and batches handled. This option offers the opportunity to create a customised plan. In this case, a detailed analysis is conducted starting from the company's objectives, the list of products and suppliers to include, and a selection of interfaces to use for uploading data and communicating with customers.

Based on this analysis, a final document is elaborated to assess all the company's activities, specifying timings and budget. The project may include:

- Co-marketing activities, that enable the company to share information about the BCT projects they are involved in.
- Customised integration, such as integration with I4.0, ERP, CRM and SCM systems.
- Customised product pages: by creating customized pages and aligning online communication with the guidelines of the company's brand.

Thus, the focal actors structured an innovative business model by considering the specific needs of SMEs, which are mainly concerned with increasing customer engagement, and the needs of large firms ready, and willing, to go through the process of "onboarding".

In fact, engagement with different partners and stakeholders proved to be crucial for overcoming the lack of awareness of BCT potentialities among SMEs and both winning their trust and convincing them to adopt a seemingly complex solution. Here, local universities were important actors: cooperation was established with the Polytechnic University of Marche which involved both the Department of Information Engineering and the Department of Mathematical Sciences for the technical competencies required to develop BCT prototypes. This academic actor served as a facilitator to win trust in the local (regional) area and, thus was able to engage extensive, and critical, supply-chains, agrarian consortiums, and other potential customers. There is also ongoing collaboration with the University of Macerata, a Social Sciences and Humanities (SSHs) based university. As empirically shown by previous research (Compagnucci et al., 2021) such cooperation with academic actors is fundamental for addressing economic, ethical and legal challenges. Furthermore, public-private partnerships with universities have often represented a preliminary condition for further involvement in interdisciplinary and applied projects, set up at the regional, national and even the European level.

4.3. Enrolment stage: the use cases

This Section demonstrates how, through two use cases, the focal actors were able to convince and guide SMEs when adopting Trusty by introducing BCT as a tool for improving their customer management. Section 4.4 – *mobilization stage* – will illustrate the technological, economic and managerial changes that Trusty introduced in the two firms.

The SMEs involved were two Italian companies, with different levels of digitalization, but with the same need to ensure information symmetry, transparency and visibility for their ASC as a means for improving both supply chain management and customer engagement.

The first firm is "Colli del Garda" which is based in Lombardy, in the North of Italy. The company operates in the food industry where it produces hams and cured meats. The vision of the company is based on combining traditional breeding techniques with novel tools that can guarantee both the high quality and the traceability, of its meat products. The company's activities aim to ensure the wellbeing of the animals involved, responsible use of antibiotics, and the adoption of BCT along the ASC. Managing the supply chain from the birth of the animal to the final product packaging is one of the distinctive features of the company and a source of competitive advantage for them. When the pigs are ready, the company sends them to a well-known slaughterhouse cooperative where the firm itself is a partner. The meat is then sent both to local medium-size factories, carefully selected by the company, and to some in the nearby region of Friuli-Venezia Giulia, well-known for its curing facilities. The monthly production is 150 raw hams and about 700 kg of cooked products (i.e. cooked ham or pancetta), strictly D.O.P. (Protected Designation of Origin).

The second firm, Pasta Mancini, is based in Marche Region (central Italy) and it makes pasta. Pasta Mancini oversees its pasta production starting from the cultivation of the raw material (grain) and follows the entire production chain, step by step. The company manages its land as a "careful farmer", one who also pays attention to safeguarding resources throughout the production process. This is why the company has adopted the Good Agricultural Practices (GAP) as a set of rules to manage agricultural activities so as to reduce environmental impact.

The vision of the company is based on having a comprehensive understanding of the agricultural system to achieve economic, social, and environmental sustainability. Pasta Mancini applies an extra-price which is justified by the processing methods and the high quality of the ingredients. Consumers of Pasta Mancini are mainly chefs and premium consumers. The former are particularly interested in selecting raw materials of excellent quality as a strategy to raise the level of their final services. Thus, this type of consumer focuses on the product, its origins and characteristics told as a unique story of values "from farm to fork". Here, traceability and secure information play a strategic role as a tool for affecting customer choices. Unlike the majority of customers, Pasta Mancini premium consumers are those who are willing to, and can, pay extra in order to have products they can trust. Table 5 summarizes the company profiles.

The two companies were contacted by the focal actors in different ways. Colli del Garda was already a client of the Var Group while Pasta Mancini was involved through a European project, called Blockchers, that aimed to support the adoption of Distributed ledger technologies (DLT) in SMEs. Once the companies had shown interest in the technology, face to face meetings were held to explain the advantages and functioning of Trusty. After these initial meetings, a detailed phase of analysis followed which looked both at the objectives that could be reached by using BCT and at the products that were to be traced.

It should be considered that before the introduction of BCT, the two companies had different levels of knowledge of digital technologies for data management. Colli del Garda had a low level of digitalization. For this company, Trusty acted as a driver to accelerate the adoption of digital tools and has led to investments in Enterprise Resource Planning (ERP) management, which previously had not been considered by the company. Due to its low level of digital maturity, Colli del Garda was initially somewhat resistant to investing in BCT and data-entry automation because of the investment costs this would incur. Nevertheless, the company needed to improve its traceability, visibility, and control processes and, at the same time, deliver its message of quality and innovation to customers. The only way to do so was through an immutable digital register that could be shared by the different stakeholders in the supply chain, and which would include all the information about traceability and production.

On the other hand, Pasta Mancini had already begun a process of digitalization before Trusty, experimenting with advanced data-entry automation techniques for its internal management system. However, even here, there was still some resistance to trying out BCT solutions, which were seen as being unnecessary, since: *"The pasta factory already does everything internally and follows the entire supply chain"* (Pasta Mancini).

Before adopting BCT neither company had public documentation for each batch of their product. Data exchange along the supply chain was entirely paper based, and there was no information sharing with consumers. However, provenance and traceability data, as they were to realize through regular meetings with Apio, are strategic assets for companies that produce quality food and need to engage customers.

4.4. Mobilization stage: the introduction of Trusty

The adoption of Trusty in these two small agri-food firms has resulted in significant changes from both the technical and the economic-managerial point of view.

As regards the technical aspects, Colli del Garda has implemented Trusty through simple integration with its data-exchange files. This integration has led to simplification of the data-entry process and a reduction in the amount of information required from ASC stakeholders. The solution adopted is based on the IBM Food Trust. The company decided to integrate Trusty with IBM Food Trust technologies to create a new communication channel with customers. In fact, by relying on the IBM Food Trust blockchain, Colli del Garda has won more confidence from consumers, mainly thanks to the solidity of the overall solution, which latter has also reduced the

Table 5
Companies' profile.

	Colli del Garda	Pasta Mancini
Industry – sector	Meat	Pasta
Number of employees	4	35
Year of foundation	1985	2010
Company main activity	Production of meat	Production of pasta
Website	https://collidelgarda.it/	https://www.pastamancini.com/en/

Source: Authors' elaboration.

risks associated with counterfeiting. In this case, the purpose for which this technology is being used is not to control or check the source of the data, rather it is to prevent other actors from manipulating the information produced retroactively by each supply chain participant.

As regards economic and managerial effects, with an investment of just under 5000€, the firm is expected to receive additional revenues from increased brand awareness. Indeed, the company has been able to transform its brand into a unique experience for users, adjusting its offer to meet specific demands, but without worrying about having to manage an IT infrastructure (e.g. domain name, website, cloud infrastructures etc.). BCT has also become part of the Colli del Garda vision as presented on the company's website, where a specific section has been added to explain the value of BCT for the ASC. Moreover, the BCT-based solution adopted by the company has been described as a best practice by both IBM and the Var Group. This increased brand awareness has led Colli del Garda to consider entering new international markets, such as the German one, where the BCT-based solution has been presented during sectoral exhibitions and Trade Fairs. New opportunities have also emerged in the domestic market. Indeed, the company is taking part in creating a consortium specialising in traced products.

Regarding Pasta Mancini, the Trusty project is still in the implementation stage. It is based on automating the data-entry processes by integrating Trusty with their existing Manufacturing Execution System (MES). Technically, the project will enable timestamps of traceability events on a public BCT (Open Timestamp on Bitcoin) and it is now at an advanced stage.[2] Trusty guarantees reliable data about how Pasta Mancini produces and distributes food and, also, addresses consumer concerns about the safety, quality and authenticity of the raw materials used and about the environmental and social friendliness of the whole supply chain. BCT is being used to enable consumers and partners to verify traceability information and be sure that it remains immutable after the packaging phase.

Pasta Mancini transforms wheat into pasta, and it therefore wants to share information, photos and documents about every batch of pasta: *"Through Trusty, we want to track the wheat fields, and automate Data Entry and QR-Code printing on products through the Blockchain and Internet of Things"* (Pasta Mancini). Trusty, through micro-services, communicates with the Manufacturing Execution System (MES) to automate the data-entry process. Trusty also communicates with the printing machine, through API, to automate the QR-Code printing process. The integration between Trusty and the printing machine, already used by the company, was a critical step for the project. The challenge was to make sure that the two systems could communicate correctly. Thanks to this integration, each pack of pasta has a unique code linked to its batch. In this way consumers, by scanning the code, can see the information about the specific pack they have in their hands. In only 10 months, there have been 1225 scans of the QR code with an average engagement of 40 s. The results show that users scanning the code are mainly located in Italy (70%), while abroad the main results are recorded in the USA (10%), France (3%) and Japan (2%), followed by smaller percentages in Germany, Spain and Belgium.

The initial investment has been already repaid through public funds and, even in this case, brand awareness increased, as proved by articles and interviews that have been published citing the company.[3] Moreover, the company has been invited, as an example of a best practice, to conferences discussing the use of blockchain in the ASC. The visibility gained is expected to continue boosting the sales networks of the company.

Nevertheless, a common challenge identified by the firms was that of convincing suppliers to upload their data onto the BCT-network since they were not compelled to do so. Thus, incentives had to be offered in terms of a premium price on the goods traced and involving suppliers in the increased brand visibility that Trusty makes it possible to achieve. This was done by showing customers the entire supply chain, including suppliers.

Table 6 provides a summary of the benefits and challenges perceived by the two firms.

Overall, in both cases Trusty was introduced as a means of improving customer engagement. The increasing complexity of their ASCs was making it difficult for the two companies to keep pace with global competitors, maintain customers, and acquire new markets. Before the introduction of Trusty, both companies had acknowledged that an overall reduction in the level of trust among customers was affecting their firm's reputation. After implementing Trusty, the two firms have been able to safeguard their trust relationship with their loyal customers by increasing transparency. At the same time, the firms have also been exploiting new opportunities in domestic and international markets thanks to increased brand awareness. In fact, Trusty not only guarantees transparency for customers, but it is also a bidirectional tool for Pasta Mancini and Colli del Garda themselves. In the case of Pasta Mancini, the BCT-based solution offers them valuable information including: the number of customers who have interacted with the brand, the most appreciated contents, the features which drive purchasing, and feedback on product and packaging appeal. The introduction of a BCT-based QR Code has enabled Pasta Mancini to collect and analyse a considerable amount of data which can be used to change both the production process and customer relationships, by introducing innovative loyalty programs.

In the case of Colli Del Garda, Trusty has facilitated improvements both in overall internal transparency and in the quality of both processing methods and of products. Furthermore, the BCT-based solution and the IBM Food Trust are providing new communication channels which heighten consumer experience. This is possible because Trusty guarantees the digitalisation of real-time and up-to-date communication with both consumers and ASC stakeholders.

Furthermore, the two firms have become ambassadors to other SMEs, helping them to understand, and trust, the benefits that can be achieved by adopting BCT.

[2] To date, the following stages have been completed: (I) analysis of the company's data model; (II) creation of the company (and associated users) on the platform; (III) data-entry for facilities; (IV) data-entry for products.

[3] https://www.agrifood.tech/blockchain/pasta-mancini-filiera-certificata-con-la-blockchain-di-trusty/; https://www.italiaatavola.net/alimenti/farina-pasta-riso/2021/2/9/pasta-mancini-filiera-trasparente-grazie-alla-blockchain-di-apio/73962/; https://www.ilgiorno.it/economia/un-qr-code-racconta-l-identikit-della-pasta-1.6051834

Table 6
Perceived benefits and challenges in the use cases.

	Colli del Garda	Pasta Mancini
Blockchain solution	IBM Food Trust	Bitcoin
Benefits	• Introduction of the ERP system. • Simplification of the data-entry process and reduction in the amount of information required by ASC stakeholders. • Cost savings from subsidized loans and credit rates • Increased brand awareness among customers • New opportunities in both domestic and international markets	• Automation of the data-entry processes. • Payment of investment through an EU project on blockchain • Increased brand awareness among premium customers
Challenges	• No previous awareness on blockchain potential • Low level of initial digitalization • Convincing suppliers to upload their data	• No previous awareness on blockchain potential • Integration of Trusty into the company printing machine • Convincing suppliers to upload their data

Source: Authors' elaboration.

5. Discussion

This case study of Trusty provides a detailed analysis, and understanding, of how the focal actors have been able to deal with the emerging challenges of two agri-food firms in Made in Italy, by proposing a novel BCT-based solution able to converge their differentiated needs (*problematisation stage* and *interessment stage)*. The presentation of the two use cases describes how Trusty improved the collection and communication of data in the ASC, especially for customers *(enrolment stage* and *mobilisation stage)*.

Adopting the ANT, according to the model proposed by Islam et al. (2019), we have captured the heterogeneity of the actors involved in the BCT-based network and classified their features within technological, social and economic domains. This classification promotes understanding of the role played by each actor, both the human and the non-human, into the formation of a BCT-based network (Table 7).

The focal actors, here the ICT providers, were able to offer novel BCT solutions by using their technical competences and hardware/software applications and by acting as initiators and facilitators of the BCT-based network. The business model proposed is also a source of profit for the providers, who expect to have returns from the fees paid by companies that opt to use the additional features of Trusty.

The focal actors in the design and diffusion of Trusty, have also benefitted from the contribution made by local universities, which have acted as facilitators and providers of technical, managerial and legal competences. These interdisciplinary competences support the building of BCT-based networks.

These findings are consistent with a study by Compagnucci and Spigarelli (2020), according to which universities are increasingly fulfilling their Third Mission (TM) which has been broadly portrayed as the opening of academia towards the socio-economic environment (Vorley and Nelles 2009). Along with education and research, universities also play a crucial role in local development by engaging private and public stakeholders, by transferring knowledge to the market and by fostering innovative solutions. To do this, universities adopt an interdisciplinary and multi-stakeholder approach which strengthens the impact of their research outcomes, thereby also improving the social, cultural and environmental development of local communities.

From a general point of view, the universities involved in such case studies contribute to overcoming the so-called "European Paradox" by filling the gap between knowledge production and knowledge transfer and contributing to the commercial success of innovation. More specifically, here the Polytechnic University of Marche and the University of Macerata acted as trusted partners in the territory by assuming the role of mediator between the focal actors and the agri-food businesses. The Universities, in their turn, benefited from this collaboration by applying for research projects at the European level, which gave them access to additional funding for this purpose.

Looking into Trusty, it became clear that different blockchain infrastructures, each with their own rules and foundation, should be examined. A different economic value is generated depending on the specific kind of blockchain used. As a source of competitive advantage, Trusty can be integrated easily with other softwares and I4.0 technologies, which have their own rules and principles. When lacking software or I4.0 technologies, the agri-food firms are offered the opportunity to decide whether to invest in these applications, and so capture additional advantages from using Trusty, or simply to improve their existing process used for collecting data.

The two agri-food firms considered, which are typical SMEs from Made in Italy sectors, introduced Trusty to build trust in their ASC, especially for customers. This was possible by encouraging suppliers to take part to the BCT-based network by sharing gains in brand awareness and introducing premiums for the goods traced. Customers are the main reason why the companies introduced Trusty and, indeed, they are crucial actors in a BCT-based network. In fact, customers by paying a premium price contributed to the success of the BCT solution and to supporting brands that offer transparency throughout the ASC. Furthermore, by scanning the QR code, consumers, in their turn, provided important information for enhancing the marketing strategies of the company.

Looking at the overall BCT-based network formation, it is clear that focal actors are needed to create awareness of the potential of BCT assisted by the support of actors from other sectors who can offer different knowledge bases/expertise. Their role is also important in keeping the network stable in the future. This could be possible by introducing further incentives and features that companies could adopt in their BCT-based solution, such as additional marketing, and I4.0 applications.

Table 7
The formation of the BCT-based network.

	Domain		
Actor type	Technology	Social	Economic and managerial
Provider	• Hardware, web-based applications	• ICT based companies	• Profit • Data
Universities	• BCT prototypes • Security protocols	• The Third Mission of the University: universities transfer knowledge to non-academic environments to improve the social, cultural, economic and environmental development of local communities	• Project grants
Trusty	• Blockchain architecture	• Rules and ideological foundations	• Fees based on the blockchain platform used
I.40 technologies	• Integration layer with BCT	• Rules and ideological foundations	• Investment costs
Agri-food firms	• Software and/or I4.0 used for data collection	• Made in Italy SMEs	• Revenues from customer segmentation and brand awareness • Saving on costs
Suppliers	• Software and/or I4.0 used for data collection	• Made in Italy companies	• Premium on traced goods • Brand awareness
Customers	• QR code, mobile phone, electronic devices, website company	• Individuals, consumer associations	• Price of item purchased • Validators of companies using BCT-based solutions • Supporting the need for transparency throughout ASCs

Source: Authors' elaboration based on Islam et al. (2019).

Based on the results presented in Section 4, we conceptualized the interdisciplinary contribution of BCT to the ASC by connecting the solutions provided to meet the technological, legal and economic—managerial challenges, identified in the literature (Table 8).

From a technological perspective, the introduction of Trusty, guided by the ICT firms and local universities, acted as a driver to introduce new, or to improve existing, data collection tools, including software and I4.0 technologies. This resulted in improving the way in which data was being collected and communicated within the ASC. The small business involved, not only had to become familiar with BCT but also had to revise their existing procedures used to collect and communicate data throughout the ASC. The adoption of BCT solutions for data notarization and traceability, as well as their interfacing with existing information systems, offers an important stimulus for a critical review of existing technical solutions. In this study, this appeared to encourage the two companies to rethink design choices, from both technical and organizational points of view. Thus, contrary to Wang et al. (2019a); Xu et al. (2019) where the need to include additional components for the functioning of BCT is perceived as a barrier, in these two use cases it became an opportunity for enhancing both data collection and a BCT-based network.

As for the economic and managerial domain, Trusty created the foundations for a trusted environment where information became publicly available throughout the ASC. More specifically, in the two use cases, traceability acted as a tool to establish a trust relationship between consumers and producers, increasing brand awareness and opening up new opportunities in both domestic and international markets. Based on the data analysed by the ICT providers, which was gathered from customer scanning of the QR code, the agri-food firms were subsequently able to obtain advantages from the marketing perspective which, in its turn, allowed them to improve customer engagement.

6. Conclusions and implications

This paper has sought to investigate how BCT can impact supply chain management in the agri-food sector and how a BCT-based network can be formed. To this end, we have presented Trusty, an innovative BCT solution for the ASC, and examined its implementation in two small agri-food firms.

From an economic-managerial standpoint, BCT has enabled the two firms involved to improve both visibility and control by simplifying the data-entry process and, by reducing the amount of information required. One interesting finding lies in the potential of BCT for improving customer engagement. On the one hand, BCT implementation can disrupt how companies interact with their customers by developing a fruitful, bidirectional relationship with each consumer. On the other, BCT can both provide valuable, strategic data on customers and can create a new digitalised channel for communication, based on real-time, constantly updated, interactions with both consumers and ASC stakeholders.

Looking specifically into the technological impacts, the case study shows how BCT could be implemented by companies with different levels of digitization and size. However, to be successful the introduction of BCT, especially in small firms, requires support in understanding which BCT solution to adopt and how to integrate it with existing software and I4.0 technologies. The introduction of this new disruptive technology into business processes has both stimulated and fostered a process of critical review and renewal within the technological choices of both companies. Above all, the BCT-network formation shows that focal actors and interdisciplinary competences are needed to initiate, and support, the stability of the network.

In terms of policy implications, the cases highlight the fact that sectors requiring focused attention on trust in industries such as those in the Made in Italy sector could benefit, to a high degree, from BCT solutions, by improving the transparency of product information and thus eventually reducing the risks associated with counterfeiting and fraud. BCT can also be considered as a driver for undertaking further processes of digitalization, which are still lacking in many SMEs. If this aim is to be achieved, national and regional institutions should be supporting the development and adoption of BCT solutions, acting through financial and organizational measures, promoting both the tools used to favour collaboration between firms and academia and/or other institutions, and those adopted to support the implementation of innovation.

7. Limitations and future avenues of research

As regards the limitations of this study, the paper is based on a sample of only two cases of firms adopting BCT-based solutions in the agri-food sector. Thus, caution is needed when generalizing the results in other contexts. Therefore, future research directions should focus on more use cases so as to better understand both the potential and the constraints of trinomial ASC-BCT-customer

Table 8
The potential of BCT in ASC.

Areas	Contribution to BCT challenges
Technical area *Legal area* *Economic and managerial area*	• Improved data collection and communication among ASC stakeholders through BCT and I4.0 integration. • Development of use cases that can increase discussion on BCT traceability based on empirical evidence. • Formation of the BCT-based networks under the coordination of the focal actor. • Increased brand awareness for BCT adoptees. • Early adoptees become ambassadors for BCT among other firms. • Improved customer engagement based on a bidirectional relationship that provides valuable data. • New opportunities in both domestic and international markets

Source: Authors' elaboration.

engagement. With respect to the latter, the transition towards a consumer-centric paradigm that is triggered by BCT also deserves more attention. A wider, longer term analysis, could provide further knowledge regarding the role customers play in the stability of a BCT-based network. It would also be interesting to further explore and assess the economic impacts of BCT. Furthermore, econometric analysis would make it possible to compare SME implementation and non-implementation of BCT-based solutions in the long term.

CRediT authorship contribution statement

Lorenzo Compagnucci: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Dominique Lepore:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Francesca Spigarelli:** Supervision, Project administration, Writing – original draft, Writing – review & editing. **Emanuele Frontoni:** Conceptualization, Writing – original draft, Writing – review & editing. **Marco Baldi:** Conceptualization, Writing – original draft, Writing – review & editing. **Lorenzo Di Berardino:** Resources, Investigation, Writing – original draft, Writing – review & editing.

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