UNIVERSITÀ DEGLI STUDI DI MACERATA

CORSO DI DOTTORATO DI RICERCA IN
DIRITTO E INNOVAZIONE

CICLO XXXVI

TITOLO DELLA TESI
ENABLING FIRMS IN THE MARCHE REGION TO UNDERSTAND BLOCKCHAIN FOR SUPPLY CHAIN TRACEABILITY THROUGH A TRIPLE HELIX APPROACH

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ANNO 2024

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INTRODUCTION

This Thesis is the result of an "Innovative PhD" programme at the University of Macerata. The programme was financed by the Regional Operational Programme for the Marche region in Italy, with funds from the European Social Fund 2014-2020 funding period. The PhD dissertation is in Applied Economics and has the objective of understanding how blockchain technology (BCT) can help firms in the Marche Region to be more competitive in domestic and international markets. The PhD programme was conducted in collaboration with the Cluster Marche Manufacturing, a public-private partnership composed of universities, research institutes, and local companies that collaborate to collect and study the needs of manufacturing firms[1]. The programme also included nine months of internship in firms in the Marche region and twelve months of mobility abroad, which were useful for gathering insights for the research on BCT. Part of the mobility abroad was done within the TRUST "digital TuRn in EUrope: Strengthening relational reliance through Technology" project, which is a Horizon 2020 – MSCA (Marie Skłodowska-Curie Actions) – RISE (Research and Innovation Staff Exchange) program aimed at understanding the role of trust in the implementation of BCT and suggesting actual means of development[2].

The Thesis is focused on the role of BCT which is a database technology created by Satoshi Nakamoto (2008) to allow everyone to exchange value through the Internet without intermediaries. Blockchains enable this by making the data they store almost immutable and accessible to stakeholders (i.e., people interested in accessing that data) at any time. Since the record of a transaction of value stored on a blockchain cannot be changed and is visible to everyone even after several years, no trusted intermediaries

1 Cluster Marche Manufacturing, https://www.marche-manufacturing.it/
2 TRUST project, https://trust-rise.eu/

like banks are needed to carry out the transaction and ensure its safekeeping and retrievability.

Since strings of text can be written inside transactions that are stored on blockchains (Bianchini & Kwon, 2020), this database technology has recently been studied for its potential applications aside from cryptocurrency for managing data from firms' and institutions' processes (Y. Sun et al., 2022). Since 2015, when applications of BCT besides cryptocurrency were first proposed (Swan, 2015), BCT has been in search of applications as a "solution in search of a problem" to solve (Schweizer et al., 2018). BCT has been proposed as a means to bring transparency to business processes (Casino, Dasaklis, et al., 2019) such as supply chain management (Kopyto et al., 2020), product traceability (Violino et al., 2020), accounting (Bellucci et al., 2022), manufacturing (Z. Song & Zhu, 2021), and marketing (Antoniadis et al., 2019). Evidence from academic research conducted so far, although conceptual more than empirical (Rogerson & Parry, 2020), found that firms can store the data about their processes on a blockchain to make them tamper-proof and visible to interested parties, thus enabling data transparency (Casino, Dasaklis, et al., 2019) which helps firms reduce information asymmetries with stakeholders (Chan et al., 2019) and build trust with them (Longo et al., 2019). A study by Capece et al. (2020) revealed a significant surge in blockchain applications since 2017 and, as of 2020, BCT was primarily used in payment systems (94 projects), supply chain management (67), data and document administration (64), and the capital market (51).

Many studies investigated the application of BCT to supply chain management (AlShamsi et al., 2022) as a tool for companies to transparently store and share their products' traceability data making them immutable and visible to supply chain stakeholders (Mahyuni et al., 2020; Saberi et al., 2019). Researchers proposed that firms store their products' traceability data stating the provenance of raw materials, components, or ingredients on a blockchain (Westerkamp et al., 2020) to increase transparency and prove the products' originality (Islam & Kundu, 2019). Once the traceability data are uploaded to a blockchain, a tag (e.g., RFID, NFC, or QR code) is applied to the product or its batch so that it can be scanned by supply chain stakeholders to access the blockchain and audit the data (A. Tan & Ngan, 2020; Violino et al., 2020).

According to the academic literature on the topic, increasing transparency in supply chains is one of the most important applications of BCT for companies since it brings them many benefits (Alawi et al., 2022): increasing the accountability of all supply chain partners (Longo et al., 2019); enabling trust among supply chain stakeholders (S. Wang et al., 2019); helping identify counterfeit products (Hosseini Bamakan et al., 2021); building consumers' trust and brand loyalty (Dujak & Sajter, 2019) which may persuade them to pay a higher price compared to similar products that are not traced with BCT (Guido et al., 2020; Violino et al., 2019).

The adoption of BCT in supply chains for product traceability is a particularly relevant case study in Italy, due to the importance of Made in Italy products in the Italian economy (EU Blockchain Observatory & Forum, 2020). As stated by Bianchini & Kwon (2020) in an OECD report, firms of the Made in Italy need to valorise their products in the eyes of the consumers and protect them from counterfeiting. This problem affects especially small and medium-sized enterprises (SMEs) of the Made in Italy since they usually do not have the means to fight counterfeiting of their products with traditional methods (OECD, 2018). BCT has shown potential for firms of the Made in Italy against counterfeiting (Caldarelli et al., 2020) and "Italian sounding" – a term used to describe products that sound or look Italian but aren't authentic (Scuderi et al., 2019) – and for business-to-consumer (B2C) marketing (Galati et al., 2021; Violino et al., 2020).

A hint of the importance of BCT-enabled traceability in Italy is the fact that Italy has become a significant player in the use of blockchain for tracking food products, accounting for 9% of global projects in this area (Startup Italia, 2022). This prevalence is quite remarkable considering that all of Europe contributes to 28% of global projects, while the Americas and Asia each contribute 16% and 9% respectively. The heightened activity in Italy can potentially be attributed to the high demand for food traceability by Italian consumers, with a minimal 7% being indifferent to food provenance. A study published in 2023 by the Osservatorio Blockchain & Web3 of the Politecnico di Milano[3] stated that 16% of the over 2000 surveyed BCT projects in Italy utilize the immutability and transparency properties of BCT to record certain data on it so that these can be visible and verifiable by stakeholders. Many projects of this type have been developed in the agri-food sector, to offer greater guarantees to the end consumer on the traceability of products.

However, most studies that mentioned the benefits of BCT are conceptual, indeed, there is a lack of empirical evidence on the continued use of BCT (AlShamsi et al., 2022), especially in supply chains (Batwa & Norrman, 2020; Gonczol et al., 2020; Rogerson & Parry, 2020). Thus, the benefits declared by researchers are largely assumed. Instead, some real challenges of BCT adoption may overshadow these supposed benefits.

Recent news indicates that several prominent blockchain projects experienced failures, highlighting challenges in implementing this technology in various sectors. From 2015 to 2018, there was hype on blockchain as a technology that was expected to disrupt several economic sectors (Kietzmann & Archer-Brown, 2019; Michelman, 2017). But in 2019, a Forbes news article[4] argued that while BCT had attracted significant interest and experimentation from major companies in the previous years, many projects were failing to achieve their goals. The most notable case is the failure of the TradeLens platform in 2022, which was a collaborative effort between IBM and Maersk. Announced in 2018, it was created as a blockchain-based shipping solution aimed at enhancing efficiency and security in global trade, with the ambitious goal of revolutionizing the digitization of global supply chains as an open and neutral platform for the industry. Despite successfully creating a functional platform, the anticipated widespread collaboration across the global industry did not materialize, and TradeLens has fallen short of achieving the commercial success required to

3 Valeria Portale, “Blockchain for business, utilizzare la Blockchain in azienda”, Osservatorio Blockchain & Web3 del Politecnico di Milano, published November 6th 2023, accessed November 22nd, 2023, https://blog.osservatori.net/it_it/blockchain-business-applicazioni-aziende

4 Dante Alighieri Disparte, “Why Enterprise Blockchain Projects Fail”, Forbes, published May 20th, 2019, accessed on December 14th 2023, https://www.forbes.com/sites/dantedisparte/2019/05/20/why-enterprise-blockchain-projects-fail/

sustain operations and fulfil its financial goals as a standalone business[5]. A news article from the Wall Street Journal[6], published in 2022, discusses the challenges BCT has faced in achieving widespread adoption in enterprise applications, particularly in supply chain management. Even large companies like Walgreens Boots Alliance and Walmart have encountered challenges in implementation, with issues ranging from supplier onboarding to justifying the investment in BCT. The article references Walmart's slow-moving initiative to track groceries on the blockchain, illustrating the difficulties companies face in enlisting participants and integrating the technology. The article concludes with observations that interest in large-scale enterprise blockchain initiatives has waned, as the technology has been slower to bring change than initially predicted. Indeed, Tokkozhina et al. (2022) conducted interviews with adopters and consultants of BCT for supply chain traceability and found that global supply chain actors may not be convinced about the benefits of decentralisation and still focus on furthering their advantages by exploiting information asymmetry. Finally, BCT has faced setbacks in the financial sector too, which was the sector where the most disruption by BCT was predicted to happen, with several high-profile projects failing, as a news article published in 2022 in the Financial Times discusses[7], also mentioning the growing realization that blockchain's practical applications in finance are more limited than initially expected.

In sum, on the one hand, researchers stated that BCT can bring benefits in many sectors, including supply chains, but their studies are mostly conceptual rather than based on evidence from real and long-term applications of BCT, so these benefits are largely assumed. On the other hand, recent news articles report that BCT projects backed by multinationals such

5 A.P. Moller, “Maersk and IBM to discontinue TradeLens, a blockchain-enabled global trade platform”, Maersk press release, published November 29th, 2022, accessed December 14th, 2023, https://www.maersk.com/news/articles/2022/11/29/maersk-and-ibm-to-discontinue-tradelens

6 Isabelle Bousquette, “Blockchain Fails to Gain Traction in the Enterprise”, Wall Street Journal, updated on December 15th, 2022, accessed December 14th, 2023, https://www.wsj.com/articles/blockchain-fails-to-gain-traction-in-the-enterprise-11671057528

7 Martha Muir, “Case for blockchain in financial services dented by failures”, Financial Times, published December 30th, 2022, accessed December 14th 2023, https://www.ft.com/content/cb606604-a89c-4746-9524-e1833cd4973e

as Maersk, IBM, and Walmart have failed or are failing to achieve their goals. Thus, there is a need for more case studies of real implementations of BCT in supply chains (Antonucci et al., 2019).

As declared at the beginning of the Introduction, this Thesis has the objective of understanding how BCT can help firms, especially SMEs, in the Marche Region to be more competitive in domestic and international markets. Since the Marche Region's economy is mostly based on SMEs (Cutrini et al., 2013) specialised in the classic industries of the Made in Italy (Cappelli, 2020), and considering the supposed benefits of BCT to supply chain traceability for firms of the Made in Italy, this Thesis focuses on exploring BCT applied to supply chain traceability for firms of the Made in Italy in the Marche region. Due to the lack of empirical evidence in the academic literature, the research is conducted with a strong empirical approach, using qualitative methodologies of interviews and surveys to collect evidence from the real implementation of BCT in Italy, especially in SMEs of the Made in Italy. Also, the Thesis aims to cover the technical, economic, and legal aspects of BCT adoption through an interdisciplinary approach. This is done to provide practical evidence-based insights to managers and policymakers of the Marche region.

The Thesis is divided into six chapters.

The first focuses on the technical aspects of BCT, individuating the scope of its use and individuating its limitations.

The second, recognising the relevance of BCT for supply chain traceability, conducts a literature review and a thematic analysis on the topic, through which it was possible to individuate the different benefits brought by BCT-enabled supply chain traceability and the drivers and barriers to its adoption in firms.

After that, the third chapter explores how BCT is used for supply chain traceability in firms of Made in Italy, finding that the benefits that firms are looking for pertain to B2C marketing in the form of increased brand awareness and consumer trust. The chapter then continues with a second study, that surveys Italian adopters of BCT for supply chain traceability to collect their opinion on the usefulness of the blockchain service they use.

The fourth chapter sheds light on the dynamic capabilities as enablers, and legal challenges as barriers, for the adoption of blockchain technology for supply chain traceability in Italy.

After that, recognising that Italian firms rely mostly on providers and consultants in the decision to adopt BCT for supply chain traceability, the fifth chapter argues that a plethora of public and private institutions should help these firms understand the implications of using this technology and its limitations. Thus, the first study of the chapter expresses the need for a triple helix approach to help spread the knowledge on BCT in firms of the Marche region. The triple helix would see academia, government, and firms of the region collaborating among them, and innovation intermediaries facilitating the knowledge flow among these actors. The chapter then concludes with a call for the future integration of BCT-enabled supply chain traceability in the context of smart cities, recognising that digital-infused cities are a future development that presents the opportunity for the integration of digitalised supply chains in urban areas.

The conclusion of the Thesis is dedicated to making final remarks, declaring the limitations of the Thesis, and outlining the managerial and policy implications of the evidence found on the use of BCT for supply chain traceability of Made in Italy products.

CHAPTER I - STORING DATA IN BLOCKCHAINS: USEFULNESS, LIMITATIONS, AND CHALLENGES

This chapter introduces what is a blockchain database, how it functions, how it is possible to store data on it, and the implications of using this kind of database compared to centralised ones. It describes the features and limitations of BCT-enabled tools such as smart contracts, decentralised applications, and non-fungible tokens. After focusing on the "what" and the "how" of BCT, the chapter focuses on the "why" of using it, discussing the conditions that make blockchain databases preferable to centralised ones. BCT is usually adopted to remove the need for trust and intermediaries in the exchange of data between stakeholders. However, when BCT is applied to supply chains, the data is not created by the blockchain protocol and is provided by oracles instead. In this case, trust between stakeholders seems to be a pre-condition to BCT adoption and trusted intermediaries may be still necessary to check the validity of the data, creating a paradox between the scope of blockchain adoption, which is to remove the need for trust and intermediaries, and what is necessary to adopt it, which are pre-existing trust or trusted intermediaries. Finally, one of the biggest limitations of BCT, the lack of scalability, is discussed within the framework of the trilemma that affects all blockchains. The most studied and used solutions to blockchains' limited scalability are then discussed, evidencing how they reintroduce centralisation and intermediaries in blockchain networks, possibly hindering trust.

1.1 Data storage in blockchains

As Chowdhury et al. (2019) explained, BCT is a type of distributed ledger technology (DLT), which is a digital system for recording transactions on multiple nodes (computers, servers, or other devices) at the same time. The nodes are part of the distributed ledger's network and participate in its maintenance, verification, and updating. Each node in the network maintains a copy of the ledger and follows a certain protocol for reading, writing, or verifying transactions in the ledger. Transactions in DLTs have the following characteristics: conducted peer-to-peer (P2P) without intermediaries;

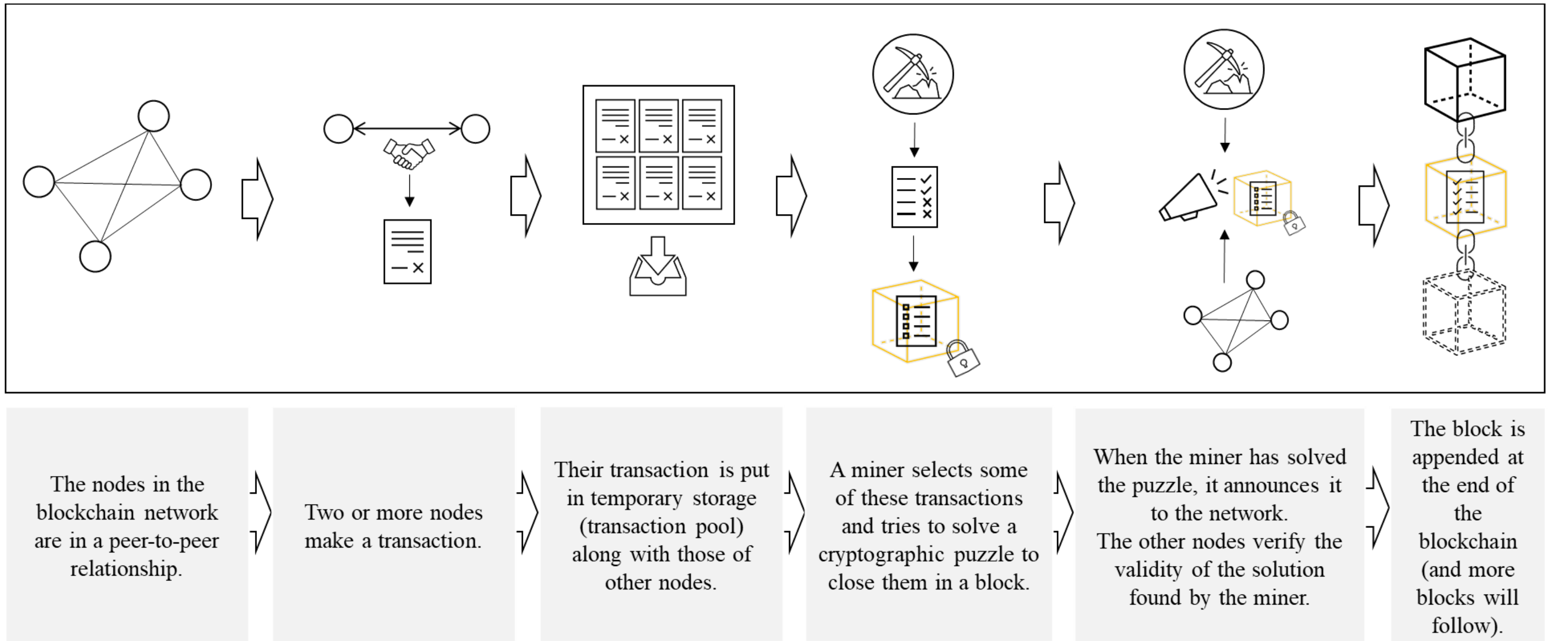
digitally signed by the issuer and the receiver; hashed, i.e., identified with a code that is unique to every transaction; timestamped, proving their existence at a certain point in time. Since blockchains are a type of distributed ledger, they share these characteristics with them. What differentiates blockchains and distributed ledgers is the data structure, wherein blockchains the ledger containing the transactions is structured in blocks that are concatenated one to the other, forming a chain of blocks (a block-chain) which is very difficult to modify because it would require breaking the chain in a certain block and reconstructing all the subsequent blocks. This makes the data stored on blockchains almost immutable. Although many different blockchains exist, they all share the aforementioned characteristics (Viriyasitavat & Hoonsopon, 2019).

Immutability and visibility of the transactions stored on a blockchain enable transparency, thus removing the need for intermediaries or trusted third parties such as banks to conduct and validate the transactions, indeed, Satoshi Nakamoto (2008) invented BCT to enable transactions for the Bitcoin cryptocurrency, which is based on the Bitcoin Blockchain. The primary purpose of this Blockchain is to maintain an immutable and transparent record of digital transactions of Bitcoins, accessible to all participants, without the need for a trusted central authority.

The process of adding new transactions to blockchains is based on the blockchains' consensus mechanisms, with each blockchain having its own (S. Zhang & Lee, 2020). For example, the Bitcoin Blockchain employs a Proof-of-Work (PoW) consensus algorithm (Nakamoto, 2008). Within this framework, when transactions between nodes are signed, they are put in a pool of pending transactions. Then, special nodes called "miners" take as many transactions as possible a block would fit and compete to solve a complex mathematical puzzle using their computational resources to create the block. The miner who solves the puzzle first is granted the right to append the new block to the blockchain and is rewarded for their efforts with newly minted Bitcoins. The new block contains a collection of new, validated transactions. Upon successful block creation, the miner broadcasts the new block to the network. Other nodes, upon receipt, validate the block and add it to their local copy of the blockchain, so that all nodes have the same updated copy of the ledger. This process, often referred to as achieving consensus, results in the replicated and synchronized distribution of the blockchain across the network, reinforcing the system's decentralization and resilience to data loss or manipulation (Nakamoto, 2008). While the consensus mechanism described is specific to PoW blockchains like Bitcoin, other consensus mechanisms exist and employ different methodologies for block creation and validation but ultimately share the same objective of achieving distributed consensus and maintaining the blockchain's integrity (Tschorsch & Scheuermann, 2016; S. Zhang & Lee, 2020). Figure 1 shows the general aspects of the transaction validation process in blockchains.

Every transaction contains the addresses of the wallets that did the transaction, a timestamp, and other metadata (Nakamoto, 2008). Inside this metadata, it is possible to input textual content. Since strings of text can be written inside the transactions (Bianchini & Kwon, 2020), blockchains can serve generic data management purposes and are a valid alternative to centralised databases to bring security and transparency to data management (Swan, 2015).

Figure 1 General aspects of the transaction validation process in blockchains



Source: own elaboration based on Nakamoto (2008)

1.2 Blockchain-enabled tools: smart contracts, decentralized applications, and non-fungible tokens

After the invention of BCT in 2008 with the Bitcoin Blockchain, digital tools have been developed that stay and operate in a blockchain, leveraging its immutability, security, and transparency. These tools are smart contracts, decentralized applications, and non-fungible tokens.

Smart contracts were introduced with the advent of the Ethereum Blockchain in 2015 (P. Mukherjee & Pradhan, 2021). A smart contract is a self-executing program that runs on a blockchain, making its code immutable and auditable; it digitally verifies and carries out traceable and irreversible agreements among peers when certain conditions specified in the contract are met, without the intervention of a trusted third party to execute the clauses of the contract (Zheng et al., 2020). This enables more complex, programmable transactions that automatically execute when predefined conditions are met, opening a wide array of possibilities for blockchain applications beyond cryptocurrencies, including supply chain management, digital identity verification, and decentralized finance, among others (Rouhani & Deters, 2019). According to the experts interviewed by Helliar et al. (2020), smart contracts stand out because they incorporate rules directly into each transaction, a departure from the norm where rules are generally applied to databases or applications. This approach enables the embedding of both legal and financial details within the transactions themselves. Notably, these contracts are recorded in computer language, encompassing all agreed contractual arrangements, making them universally applicable irrespective of jurisdiction or geography. Furthermore, all interactions are digitally signed, providing verifiability and reducing disputes, as long as all potential outcomes are considered in the contract (Christidis & Devetsikiotis, 2016). Finally, smart contracts also enhance blockchain interoperability, allowing one blockchain's results to be recorded on another (Besancon et al., 2019). In supply chains, smart contracts can be applied to track products and automatically execute conditions (e.g., payments from the producer to its suppliers) when materials or products reach certain steps in a supply chain (Prause, 2019). Nevertheless, Zheng et al. (2020) warned about some limitations of smart contracts. The parties who negotiate terms need software engineers as trusted third parties to write the terms in computer language which is not easily understandable by people who have no or little experience with coding. Also, once deployed, smart contracts can't be changed due to the blockchain’s immutability. Finally, smart contracts’ execution challenges involve identifying trustworthy oracles, i.e., people or machines that “feed” the data necessary to make the conditions written in the smart contract trigger.

Decentralised applications (DApps) are software applications that stay and run on blockchain systems, so they are resistant to modification, eliminate central points of failure (Cai et al., 2018), and are not controlled by a single entity (K. Wu et al., 2019), contrarily to what happens to the centralised Apps that are commonly used. However, as Besancon et al. (2022) note, to function effectively, most DApps require additional services, including a front-end engine for user interaction and storage systems, which may be centralised.

Finally, BCT allows the creation and use of non-fungible tokens (NFTs) to tokenize assets. An NFT is a cryptographically unique, indivisible, irreplaceable, and verifiable token that represents a given asset, be it digital, or physical, on a blockchain (Valeonti et al., 2021). As Westerkamp et al. (2020) explain, an NFT contains information registered on a blockchain constituting proof of authenticity and ownership; information about the changes of ownership of the asset and the money transactions involved is written in the blockchain when these occur. For example, NFTs can be used in blockchain-enabled supply chain traceability systems to tokenize and track products, their change of ownership, and related payments (Chiacchio et al., 2022). As with smart contracts, these changes require information coming from oracles that are placed in the real world, thus, these oracles must be trusted (Caldarelli et al., 2020).

1.3 When is blockchain useful? The relation between blockchain and trust

Trust is an essential psychological foundation for cooperation where uncertainty and risk characterize interpersonal relationships (Rousseau et al., 1998). When a trusting individual takes a risk, they make themselves vulnerable, believing that the other party will act beneficially. The trustor lacks control over the trustee's actions, creating a degree of uncertainty

(Schilke et al., 2021). This trust is a vital component for economic transactions to take place; without it, transactions become virtually impossible (Akerlof, 1970). As trust minimizes transaction costs and facilitates new forms of cooperation and business advancement (Morgan & Hunt, 1994), its absence can impede economic growth (Pollitt, 2002). With an increasing number of transactions happening digitally, trust becomes even more critical. However, the centralization of user data in databases controlled by a single entity raises issues. This model is technically and governance-wise centralized, leading to distrust towards these data-holding organizations, mainly due to their lack of transparency in information sharing (Dewar, 2017) which is crucial in inter-organizational digital collaborations (Barrane et al., 2021).

As a result, decentralized networks such as blockchains are seen as a natural progression, where trust shifts from centralised systems controlled by banks or states to algorithms and encryption software (Baldwin, 2018). Blockchains allow trust in the system's outcome without needing to trust individual participants (Davidson et al., 2016). This is achieved through the blockchains' consensus protocol, which is a set of rules and processes that allows all the nodes of the blockchain network to agree on the validity of transactions and the current state of the distributed ledger; this agreement is crucial in a decentralized system where there is no central authority to dictate or validate the state of the ledger (Ølnes et al., 2017). This ensures that participants have faith in their ledgers' accuracy and consistency (Werbach, 2018). Further, cryptographic techniques solve problems such as double-spending, which refers to the illicit act of spending the same digital currency twice, exploiting vulnerabilities in the ledger, and the challenge of achieving consensus in distributed systems with unreliable components (Nakamoto, 2008). Consequently, actors place trust in the technology rather than the involved parties (Finck, 2018; Hileman & Rauchs, 2017). With BCT, algorithmic trust replaces traditional interpersonal trust, representing a paradigm shift from trusting people to trusting mathematics (Atzori, 2015; Swan & de Filippi, 2017). Also, cryptographic consensus and transparency allow everyone to operate without needing trusted intermediaries (Christidis & Devetsikiotis, 2016) such as institutions (Wright & De Filippi, 2015).

As Chowdhury et al. (2018) state, a deficit of trust among parties is the most important requirement for choosing to use blockchains rather than centralized databases to store and exchange data. Blockchains are preferable to centralised databases when multiple parties wanting to share data between them do not trust each other and cannot, or do not want to, find trusted third parties for data management. Indeed, Sternberg et al. (2020) theorize that if trust between parties is already present, then the adoption of BCT is unnecessary.

The features of predictability, reliability, and transparency of the blockchain protocol establish the blockchain as a trust-free technology (Beck et al., 2016; Ishmaev, 2017); in other words, BCT removes the need for trust in the P2P exchange of value, because peers can rely on the predictable and reliable functioning of the blockchain protocol itself. The blockchain, often termed as a trust-less system or a trust machine, can be seen as the basis for a truly trust-free economy (Glaser, 2017) for its capacity to create a secure, publicly accessible record of past transactions agreed upon by all, removing trust issues in P2P exchange of value (Hawlitschek et al., 2018).

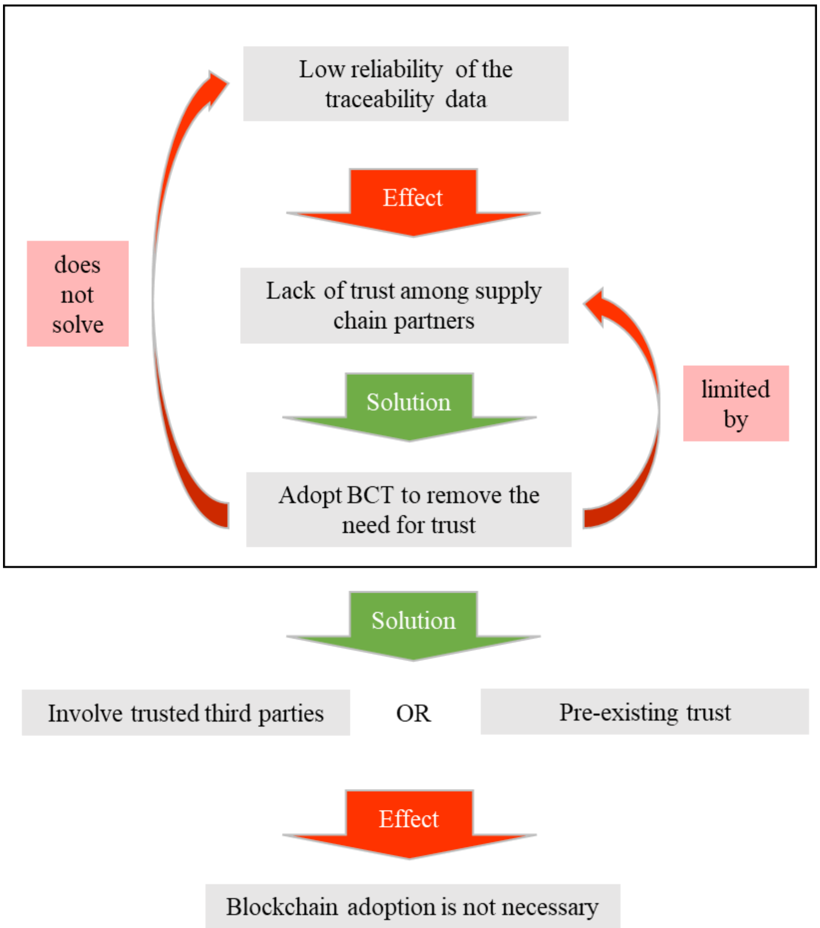
The term “value”, in the context of BCT, is not limited to the monetary value represented by the cryptocurrency, but rather the possibility of exchanging cryptocurrency safely and transparently without intermediaries. In this sense, the value lies in the possibility for stakeholders to access the metadata about the transactions (e.g., the addresses of the peers between which the transactions were made, how much cryptocurrency was exchanged, the timestamps stating when the transactions were made, the information about the blocks containing them) and that such metadata are immutable. Since all metadata are generated by the blockchain protocol and stored immutably on the blockchain, they can be trusted as true.

In other cases, BCT is not used to exchange cryptocurrency as metadata but to store data collected from the outside world and not generated by the blockchain protocol. This data is relevant to someone, for whom the value is also the metadata associated with the transactions that contain the data. For example, transactions can contain supply chain traceability data that are valuable for authorities and consumers, who want to check the metadata to know who put the data on the blockchain, when, in which block, etc. In this case, while the stakeholders can trust the metadata created by the blockchain protocol, they cannot be sure about the truthfulness of the data stored inside the transactions (Hilal et al., 2023). Indeed, the data are provided by oracles which are people or machines placed in the real world that could lie or make errors and provide incorrect data (Caldarelli et al., 2020).

Continuing with the example of storing products' supply chain traceability data in blockchain transactions, the stakeholders cannot know if the data collected by oracles correctly represents what occurred in the supply chain (Violino et al., 2020). On the one hand, theoretically, blockchains' transparency and immutability should discourage oracles from any misconduct (e.g., in the example of supply chain traceability, providing false or inaccurate data) (Longo et al., 2019), on the other hand, blockchains cannot eliminate the risk of fraudulent behaviour (Violino et al., 2020), so trust must be placed in the oracles providing the data who are usually the supply chain partners (Caldarelli et al., 2020).

This creates a situation, individuated by Sternberg et al. (2020) in their study of BCT applied to supply chains, where supply chain partners want to adopt BCT to remove the need for trust in the exchange of data among them, but since they cannot be sure of the correctness of the data they provide to each other through the blockchain, they need to know and trust each other before adopting BCT (Sternberg et al., 2020). This means that trust among supply chain partners may be a prerequisite for BCT adoption, which leads to a paradox: if trust among supply chain partners was already present, then the adoption of BCT to remove the need for trust would not be necessary (Sternberg et al., 2020). Figure 2 shows the trust paradox in the adoption of BCT in supply chains.

Figure 2. The trust paradox in the adoption of BCT in supply chains



Source: own elaboration based on Sternberg et al. (2020) and A. Zhang et al. (2020).

Likewise, it can be argued that if a deficit of trust among supply chain partners was the reason for their will to adopt BCT, then BCT would not help solve it. The interviews conducted by Tokkozhina et al. (2022) with supply chain partners that adopted BCT revealed that these actors wanted to leverage third-party elimination and the decentralization of data to feel more secure and build trust among them, however, adopting BCT did not eliminate the need for trust and they still had to build relationships based on human communication. Further, pre-existing trust may be necessary to reduce friction among supply chain partners in the adoption of BCT: initiation of a blockchain network by a supply chain partner might cause resistance (Behnke & Janssen, 2020) and companies that hold a dominant position in a supply chain could put pressure on smaller supply chain partners to adopt BCT, which can create frictions that pre-existing trust may ease (A. Zhang et al., 2020). Finally, as A. Zhang et al. (2020) noted, if supply chain partners do not trust each other, then they would need to involve trusted third parties to ensure that the data are correct, nevertheless, this would reintroduce intermediaries in a blockchain network that was adopted to remove the need for them. It is not surprising, then, that there is scepticism that BCT will be able to remove the need for trust and intermediaries in non-cryptocurrency-based applications such as supply chain traceability (Caldarelli et al., 2020).

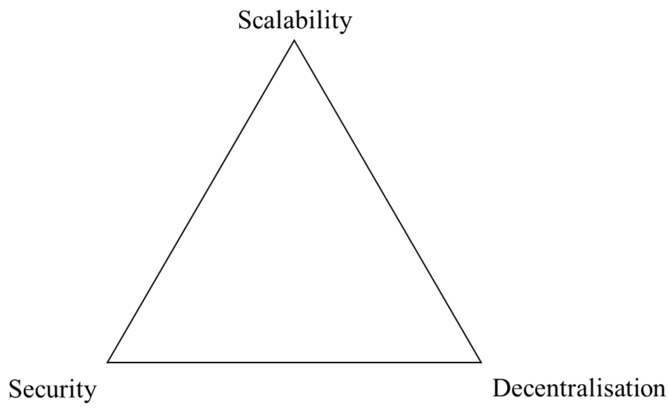
1.4 The lack of scalability of blockchain technology within the blockchain trilemma

Centralised databases are usually siloed, i.e., not visible to stakeholders interested in accessing the data they contain, and the data stored in them can easily be changed or eliminated by the database owner(s) or hackers (Chowdhury et al., 2018). Contrarily, blockchains are usually accessible and almost immutable databases (Attaran and Gunasekaran, 2019; Bodkhe et al., 2020). Also, blockchains are more secure than centralised databases because the ledger containing the transactions is copied in all the nodes of the blockchain network, thus eliminating the problem of the single point of failure caused by the single node's malfunctioning or hacking (Chowdhury et al., 2018; Viriyasitavat & Hoonsopon, 2019).

However, this technical feature also requires that new information is distributed to all the nodes of the network before any other additional information can be written in the database, making blockchains not as scalable as centralised databases (Gobel & Krzesinski, 2017). The limited scalability issue happens when the number of transactions to be validated at a certain moment goes beyond a critical threshold: the bandwidth needed to process the increasing volume of transactions will get higher (Al-Jaroodi & Mohamed, 2019), leading to an increase in the time required to validate transactions (Casino, Kanakaris, et al., 2019). The validation time can be related to various factors: network delay, consensus delay among multiple orders, execution time, endorsement delay, and block validation delay (Al-Jaroodi & Mohamed, 2019). It can also be related to the amount of data included in transactions. Transactions that embed heavy files (e.g., digital textual documents, images, and videos) require a higher amount of bandwidth to maintain a sustainable transaction throughput speed, even with a good Internet connection (Casino, Kanakaris, et al., 2019). This means that it is impossible to store huge amounts of data in a short time in blockchains (The European Union Blockchain Observatory & Forum, 2019b), making it not feasible to use BCT to store heavy files (Hepp et al., 2018) unless the number of nodes is greatly decreased, in which case the blockchain's decentralisation and security is hindered (Del Monte et al., 2020).

The challenge of simultaneously achieving security, scalability, and decentralization in a blockchain is the "blockchain trilemma". As explained by Reno & Haque (2023) and shown in Figure 3, balancing these factors is complex because enhancing one of them often negatively impacts the others. For instance, increasing decentralisation and security compromises scalability. Adding nodes that store the ledger to the network increases decentralisation. Additional nodes perform redundant computation and data storage across the network and, consequently, make the blockchain more resilient against attacks, increasing its security (X. Xu et al., 2019), but reduce scalability (Singhal et al., 2018). On the contrary, having more scalability means either having fewer nodes or using more centralised consensus algorithms, thus diminishing decentralisation and security (Reno & Haque, 2023). How the blockchain system can scale and operate with an increasing number of stakeholders and a large amount of generated transactional data while maintaining decentralisation and security is the prime challenge (H. Wu et al., 2019), since the blockchain trilemma limits BCT adoption across industries (Reno & Haque, 2023).

Figure 3 The blockchain trilemma



The blockchain trilemma refers to the challenge of simultaneously achieving security, scalability, and decentralization in a blockchain. Balancing these factors is complex because enhancing one of them often negatively impacts the others. Source: own elaboration based on Reno & Haque (2023).

1.5 Solving blockchain's limited scalability at the expense of trust

The lack of scalability in blockchains is a problem when there is the need to store huge amounts of data in them in a short time, as firms would like to do (S. Wang et al., 2019; Westerkamp et al., 2020). To accommodate the need for higher scalability, some solutions have been proposed, such as fragmenting a ledger into sub-ledgers, removing old transactions, and using multiple blockchains on different levels (Dib et al., 2018); however, the solutions studied, proposed, and applied the most are off-chain storage, the use of specific consensus algorithms, and the creation of permissioned blockchain networks.

As will be explained in the following paragraphs, all these solutions enable more scalability at the expense of decentralization and security. Since decentralization and security are positively linked to stakeholders' trust (Chowdhury et al., 2018; Viriyasitavat & Hoonsopon, 2019), these solutions may have the effect of decreasing trust among blockchain stakeholders.

1.5.1 Off-chain storage

Off-chain storage has been proposed as a solution to the low scalability of blockchains (Hepp et al., 2018; Reno & Haque, 2023). Using off-chain storage means that the data are not uploaded on-chain to the blockchain, but off-chain to a centralised database while only the hashes derived from the data are stored on-chain for reference (X. Zhang et al., 2020). Hashing is a process where an algorithm, known as a hash function, converts any content it is given as input into an output that is a fixed-size string of bytes, typically a sequence of numbers and letters, called hash, which univocally identifies that content (Chi & Zhu, 2018). Since all hashes have the same size and weigh all the same limited amount of bytes independently of the data they are derived from, uploading only the hashes to a blockchain mitigates the on-chain storage scalability problem because it decreases the size of the data exchanged on-chain between the nodes and, consequently, lowers the time that it takes for the data to be broadcasted to the whole network before another block can be added to the blockchain, which makes the blockchain more scalable (Hepp et al., 2018). In sum, with off-chain storage, data are stored in a centralised database, while the data's hashes are stored in the blockchain for reference. A stakeholder having access to both a file on the centralised database and its immutable hash on the blockchain can check if the hash calculated from the file at that moment is the same as the one previously uploaded to the blockchain. If the two hashes coincide, the stakeholder has the proof that the file's content has not been modified after its hash was uploaded to the blockchain (Shahid et al., 2020).

But, as noted by Hepp et al. (2018), a fundamental flaw of off-chain storage is the risk of loss of data or the impossibility of accessing the data. This could happen because of a malfunction of the centralised database, which is a single point of failure, or because the data manager(s) eliminated them or restricted access to them. To mitigate this risk, some researchers have proposed to store the data off-chain in decentralised networks that allow replication of data on multiple nodes (Salah et al., 2019; Shahid et al., 2020). Nevertheless, the data are still under the control of the data manager(s) who could arbitrarily decide to eliminate the data or make them unreachable to stakeholders. Indeed, Hepp et al. (2018) say that off-chain storage might not always align with the principle of decentralization and data transparency, leading to potential trust issues among stakeholders. Chowdhury et al. (2018) state that if data durability required by stakeholders, then on-chain storage must be used.

1.5.2 Consensus algorithms

A consensus algorithm is a set of rules and processes that allows all the participants (nodes) of a blockchain network to agree on the validity of transactions and the current state of the distributed ledger. This agreement is crucial in a decentralized system where there is no central authority to dictate or validate the state of the ledger (Ølnes et al., 2017). Many consensus algorithms exist, each one with its characteristics (Chowdhury et al., 2019; Rebello et al., 2022), but for the scope of explaining the impact of consensus algorithms on trust, only the three most studied and used ones will be considered: Proof-of-Work (PoW), Proof-of-Stake (PoS), and Proof-of-Authority (POA).

PoW is the original consensus algorithm, used by the Bitcoin Blockchain which represents the first generation of blockchains (P. Mukherjee & Pradhan, 2021). Miners, who are anonymous and do not need permission to have this role, compete to solve complex cryptographic puzzles to create a new block; the first to solve the puzzle gets to add the new block to the blockchain. The process is costly because it requires significant computational power, meaning that miners need to have powerful hardware, use lots of electricity, and spend much time trying to solve the puzzle. But precisely for this reason, it is complicated and anti-economic to conduct a 51% attack to change the data in a block, which would require obtaining at least 51% of the total computational power of the blockchain miners to be able to break the chain where the block to be changed is and reform it by mining all subsequent blocks so that the new fraudulent blockchain is longer than the original one and, thus, considered as the valid one. Also, since all miners are competing to create the same block and it takes a long time to create it, PoW does not allow for a high throughput of transactions, which makes the blockchains using it not scalable (Chowdhury et al., 2019).

The PoS consensus algorithm, used in the Ethereum Blockchain which represents the second generation of blockchains (P. Mukherjee & Pradhan, 2021), was invented to solve the problem of the high electricity consumption of PoW (Chowdhury et al., 2019). In PoS, participants express their willingness to be part of the block creation process by locking a specified amount of their cryptocurrency in an escrow account. If they lock enough cryptocurrency, they gain the right to become "validators", which have the same role as the miners in the PoW and are similarly anonymous. The higher the stake, the greater the chance of being chosen to create the next block; furthermore, miners can lose their stake if they are found to be acting against the protocol's rules. This stake acts as a form of security, ensuring that participants adhere to the protocol rules. PoS can lead to faster transaction processing and less electricity usage compared to PoW because miners are chosen beforehand to mine their assigned block, allowing multiple miners to mine their block simultaneously with other miners' blocks, and no time is spent to solve a puzzle. Despite allowing for more scalability, PoS makes the blockchain network less decentralised and lower its security by enabling a few richer nodes to have consistently more probability to be chosen as miners (Nair & Dorai, 2021), making the blockchain more vulnerable to 51% attacks (Nicolas, 2014; Rebello et al., 2022).

Finally, the consensus on the validity of transactions and the current state of the distributed ledger in PoA is not based on computational power as in PoW or cryptocurrency stakes as in PoS but on identity and reputation (Rebello et al., 2022). Nodes' identities are known and are added to the network after permission is granted by the network operator(s), which is(are) generally known and trusted by the network participants. Nodes become validators thanks to their good reputation and earn mining rewards, incentivizing them to maintain their reputable position by not committing fraud. Despite PoA reducing the need for mining and expensive computational operations, leading to higher scalability and little energy usage than most other consensus protocols (Dinh et al., 2017), Ekparinya et al. (2019) found that PoA exposes blockchain networks to security issues because the validators are low in number and must be pre-approved by the trusted controller(s) of the blockchain, usually without a transparent on-chain election system.

The consensus algorithm plays a vital role in BCT in maintaining the system's security and efficiency. Each consensus algorithm has its own set of trade-offs, including factors like energy efficiency, security, and the potential for centralization or decentralization. The consensus algorithms requiring more work to mine blocks and allowing a larger number of actors to become miners or validators, enable more decentralisation and distribution of power among the nodes in the blockchain network and thus are more secure because are less vulnerable to 51% attacks, but are more costly to operate and less scalable. So, PoW brings more security and decentralisation but less scalability than PoS, and likewise PoS compared to PoA. The choice of which consensus algorithm to implement in a blockchain depends on the governance and efficiency requirements that the blockchain must have for its stakeholders, who are the ones that benefit from writing and reading the data on the blockchain. As E. Tan et al. (2022) state, PoW may be more suitable to create systems where power among nodes is distributed and decentralisation of governance is considered more important than scalability by the stakeholders. In this regard, PoS achieves less decentralisation but increases scalability. Finally, PoA provides a high level of efficiency at the cost of being more centralised and may be more suitable to semi-decentralized systems where it is important for stakeholders to know and trust the validator nodes and when it is necessary to store data in the blockchain in larger amounts and with less cost. PoS and PoA are used in the latest third-generation blockchains, where the trade-off between higher scalability and lower decentralisation and security is accepted by stakeholders (P. Mukherjee & Pradhan, 2021).

1.5.3 Blockchain architectures: public, private, consortium

Different blockchain architectures have been invented to accommodate the needs not only for more scalability but also for more control over the block creation process and data privacy. Ownership and governance differentiate the architectures. The distinction is between “permissionless” and “permissioned” blockchains: permissionless blockchains have a “public” kind of architecture, while permissioned blockchains can have a “consortium” or “private” architecture.

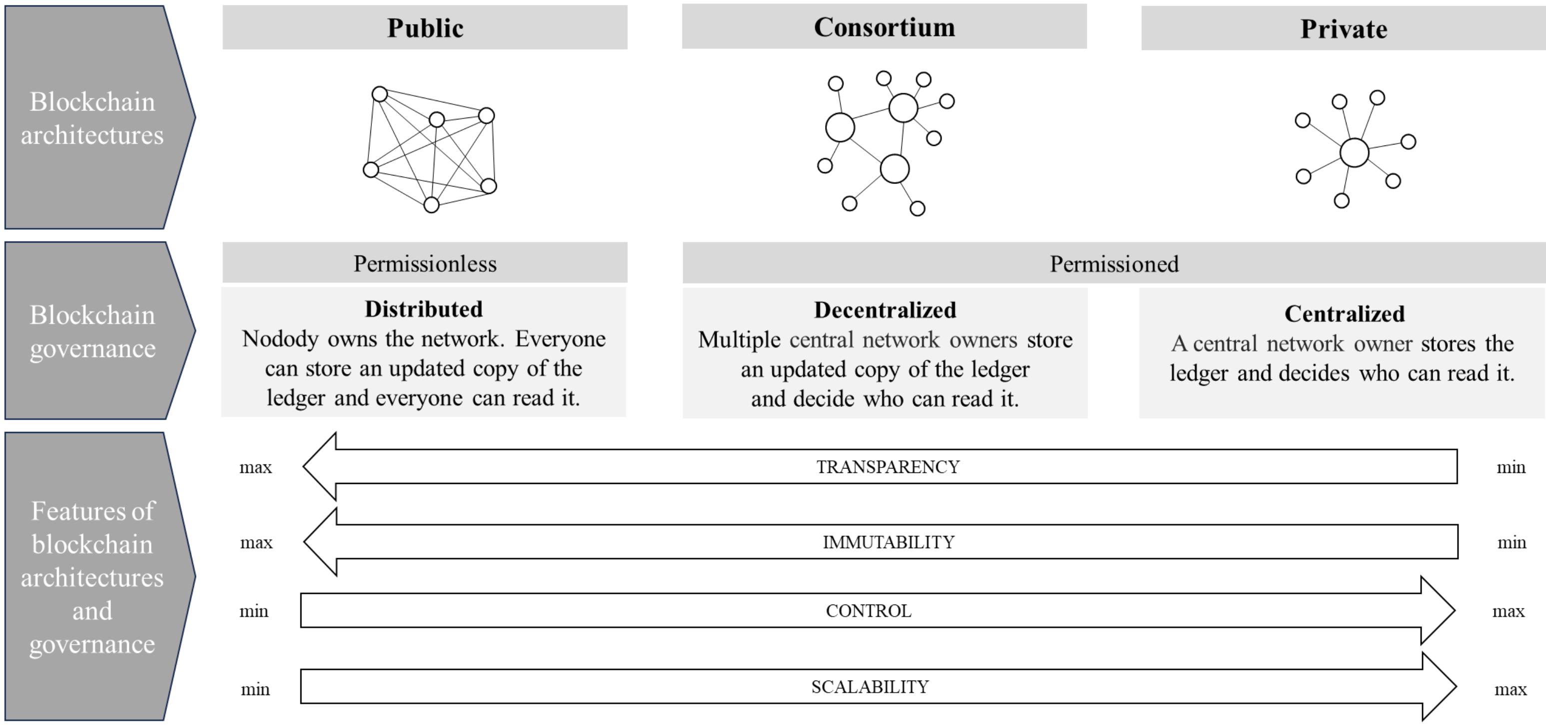
Permissionless blockchains such as Bitcoin are fully decentralized, are owned by nobody, and allow any node in the blockchain network to write, validate, and read the information stored in them. Thus, governance in permissionless blockchains is completely decentralised, with powers being equally distributed among the nodes. All nodes are anonymous, ensuring their privacy. Since anonymity could increase moral hazard and, consequently, perceived risk, the transactions are recorded, made immutable, and visible to everyone, creating a trust-less environment where trust between nodes is not necessary to start transactions of value (Dib et al., 2018). On the contrary, permissioned blockchains can be owned either by one or more owners who have full control of the blockchain's functioning and can set different levels of accessibility and writing and reading rights to nodes. Validators that add blocks are known to the owners and pre-approved by them to have this role (Helliar et al., 2020). Thus, their governance is semi-decentralised.

Permissioned blockchains have some advantages and disadvantages compared to permissionless blockchains. First, they perform more efficiently in terms of transaction validation speed (i.e., they are more scalable) due to a faster validation process and a smaller number of validating nodes (Cui et al., 2019). The average time of a transaction being validated can be of milliseconds and this could even enable real-time readability of data as soon as they are uploaded to the permissioned blockchain (Casino, Kanakaris, et al., 2019). Second, permissioned blockchains enable owners to restrict access to the data uploaded to the blockchain (Mao et al., 2018), protecting sensitive data that nodes want to share just with other selected nodes (Chan et al., 2019), making it ideal for companies wanting to share data with selected stakeholders only (J. M. Song et al., 2019). Data visibility to the public in permissionless blockchains may not always be desirable for companies that value data confidentiality, indeed, control of access to the blockchain to ensure confidentiality is an important condition for the adoption of BCT by companies (Behnke & Janssen, 2020). Third, as noted by Mirabelli & Solina (2020), should some actors begin to act maliciously, they can be quickly removed from the network by the owners; additionally, in permissioned blockchains, all nodes are known and accountable for their actions, so they might be incentivized to act ethically, contrarily to what happens in permissionless blockchains where every node is protected by anonymity.

However, even full accountability does not eliminate the risk of fraudulent behaviour (Violino et al., 2020). Lastly, permissioned blockchains can allow their validators to change or eliminate the data in the blockchain, which is not possible in permissionless blockchains. Indeed, data immutability, while being considered a good feature of blockchains might not always be desirable. For example, it could be necessary to change the information uploaded to a blockchain if it contains errors or to eliminate some data that is not necessary to keep on the blockchain anymore. If a track of these operations and who did them is stored on the blockchain, the process is transparent (Cui et al., 2019; Sund et al., 2020). For these reasons, permissioned blockchains are generally considered more suited for adoption by companies, compared to the permissionless ones, although they are not very adopted due to limited awareness in firms (Helliar et al., 2020) and cannot be used if public verifiability is a requirement (Chowdhury et al., 2018).

Further on the discourse about blockchain architectures, permissionless blockchains have a public architecture with completely decentralised governance since nobody owns the blockchain and everyone can validate blocks and write and read transactions. Contrarily, permissioned blockchains can have private and consortium architectures. A private blockchain is owned by a single entity that has total top-down control over the write and read rights and the validation process. The structure of a private blockchain might look decentralized if the data contained in it are distributed among multiple nodes, however, these are controlled by the owner of the blockchain or by other parties under its control – so, private blockchains are the same as centralized databases (Cui et al., 2019). The owner of a private blockchain can unilaterally choose to restrict access to some information, not to write certain transactions, or to modify or remove them altogether, although performing these actions would lead to reputational damage for the owner itself if caught (Sidorov et al., 2019). The other kind of permissioned blockchain is the consortium one. Consortium blockchains mitigate some of the risks of private blockchains by removing centralized control on the blockchain (Cui et al., 2019) since control is shared among multiple equally powered owners, instead of being centralized in the hands of a single entity. The owners decide who can become a node of the network and who must be kicked out, grant writing, validating, and reading rights to nodes (Saberi et al., 2019). Validators are often pre-determined at the genesis of the blockchain and are usually its original owners (Sidorov et al., 2019). While being different in terms of the level of decentralization, both private and consortium blockchains share the advantages of a faster transaction throughput speed, compared to permissionless blockchains, and the possibility for the owners to amend the data already stored in the blockchain (Cui et al., 2019). Figure 4 shows the characteristics of the different blockchain network architectures.

Figure 4 Different blockchain network architectures and their governance



Source: own elaboration based on Cui et al., (2019), Dib et al. (2018), Saberi et al. (2019), Sidorov et al. (2019).

The scalability issue is relevant in permissionless blockchains, which can be accessed by an unlimited number of users, while it can be less relevant in permissioned blockchains where access is restricted to a limited number of users (Behnke & Janssen, 2020). Nonetheless, higher scalability in blockchains is usually achieved at the cost of lower decentralisation and security (Del Monte et al., 2020). Permissionless public blockchains are the most distributed and secure, but the least scalable; private and consortium blockchains are more scalable but sacrifice decentralisation and security (Chowdhury et al., 2019; Dib et al., 2018). Consortium blockchains, which compromise between decentralisation, security, and scalability, can be less transparent than permissionless ones and fail to build the stakeholders' trust. The owners of a consortium blockchain could collude among themselves to limit access to important traceability information that, if disclosed, could damage them. Also, since only they grant the right to mine and validate the blocks, they could keep the power of writing transactions for themselves. This would allow them to refuse to validate some transactions or cancel or change pre-validated transactions by mining the block that contains them and the following blocks. If the governance rules of the consortium blockchain do not require unanimity to take these kinds of decisions, only a part of the owners must collude for fraudulent behaviours to occur. Surely, they put their reputation at stake in front of all the other stakeholders, and this should refrain them from misbehaving. Moreover, the actual risk of consortium blockchains' owners colluding is not proved by any empirical evidence in the academic literature – meaning that it has not happened yet, or maybe it happened but nobody noticed. However, the mere hypothetical possibility of this happening could be enough to invalidate the stakeholders' trust in the owners. Consequently, a consortium BC would fail to build trust among stakeholders.

A possible way to ensure scalability, decentralisation, and security, while also ensuring data confidentiality, could be using hybrid blockchain architectures, where data are written on one blockchain and then passed to one or multiple other blockchains. For example, Wu et al. (2017) proposed a system where permissioned blockchains are used for sharing private business information among partners of a supply chain; then, data of public interest are uploaded from these blockchains to a permissionless blockchain. Similarly, Ding et al. (2020) tested a double-layer system for supply chain traceability, composed of several sub-layer private blockchains and one main layer consortium blockchain, and Gonczol et al. (2020) proposed a multi-chain system consisting of multiple side-blockchains, both permissionless and permissioned, which run parallel and allow the transfer of data between them. However, while the use of multiple interconnected blockchains may be desirable for simplicity, adaptability, and extensibility, the interoperability between them must be ensured (Sparer et al., 2020), which remains a challenge (Laforet & Bilek, 2021).

Finally, E. Tan et al. (2022) warn about the possibility that the power relations of actors may alter an initially decentralised governance structure into a centralised one: if on-chain governance is controlled by a few major operators with significant control over mining resources or token holdings, a system initially designed to be decentralized could operate more like a semi-centralized or polycentric governance structure. This is what happened, for instance, to the Bitcoin Blockchain network, where a limited set of entities currently control the mining and, consequently, the decision-making (Gervais et al., 2013). Despite the notion of a decentralized network being democratic and egalitarian, it can obscure the power imbalance and differences among the nodes (Baldwin, 2018).

CHAPTER II - BLOCKCHAIN FOR SUPPLY CHAIN TRACEABILITY: THE STATE OF THE ART

Transparency in supply chains brings benefits both to consumers and firms, but centralised traceability systems do not enable it. Considering the recognition of BCT as a promising technology to bring transparency in increasingly global and complex supply chains, a literature review is performed to individuate themes throughout the academic literature on the use of BCT for supply chain traceability, with a focus on the business and management implications. Two themes in the academic literature were identified through a thematic analysis. The first theme addresses the benefits of using BCT for supply chain traceability, which can be articulated in three sub-themes: one benefit regards transparency enabled by BCT and its positive impact on trust between supply chain stakeholders; the second addresses the benefits stemming from an increase in consumers' trust about the product's originality and safety given by BCT-enabled traceability; the third focuses on how this technology fosters supply chains' effectiveness in their resilience, performance, and sustainability. The second theme addresses the drivers and barriers to the firms' intention to use BCT for supply chain traceability. The review of the literature presented in this chapter shows that BCT for supply chain traceability promises to ease some of the problems of centralised supply chain traceability systems, especially the issue of lack of trust among supply chain stakeholders. However, despite the increasing academia's interest in this topic, there is still not enough empirical evidence of the benefits and challenges for companies adopting BCT for supply chain traceability.

2.1 The problem of low transparency in supply chains

Supply chains have become increasingly complex, stretching globally across countries and involving many actors (Pettit et al., 2013; Zhang et al., 2020a). This makes it more difficult to monitor them effectively and exacerbates problems in product safety or security such as contamination or counterfeiting (Marucheck et al., 2011), which have become increasingly important issues in recent years with calls for greater scrutiny and transparency (Kros et al., 2019). At the same time, consumers have become more demanding of the provenance of the products they purchase, increasing the pressure on retailers and distributors to provide products with transparent traceability information (Kittipanya-ngam & Tan, 2020).

Supply chain traceability refers to access to information about a product (Olsen & Borit, 2013), like weight and temperature, energy and resource consumption, batch quantity and size, production, transformation, and distribution (Casino et al., 2020). Companies use traceability to ensure the safety and quality of their products (Sun and Wang, 2019), comply with regulations, prove product provenance and identity against frauds and counterfeiting (Dabbene et al., 2014), manage recalls of defective products with low economic and logistic efforts (Dai et al., 2015). Access to information on products by supply chain stakeholders (i.e., suppliers, producers, distributors, retailers, authorities, certifiers, and customers) is recognised as a mechanism to ensure product quality and safety (Manzini & Accorsi, 2013) and increase customers' trust (Gharehgozli et al., 2017). Hence, traceability systems that enable transparency in complex supply chains are needed.

Transparency in a supply chain is the extent to which the supply chain's stakeholders have access to information about a product (Hofstede et al., 2004). Companies can make the traceability information about their products visible to supply chain stakeholders for several purposes: to assure them of the safety and quality of the products (S. Sun & Wang, 2019); attest to product provenance and identity against frauds and counterfeiting (Dabbene et al., 2014); foster trust among supply chain partners (Casino et al., 2020; Kittipanya-ngam & Tan, 2020); increase customers' brand loyalty and trust by giving them the possibility to check the quality and safety of the products they buy (H. Yu et al., 2018).

Contrarily, when companies do not share their supply chain traceability information, they create low transparency, information asymmetry (Mao et al., 2018), and a lack of trust in their relationship with all supply chain stakeholders (Chan et al., 2019). This can damage both products' buyers and sellers. As Akerlof (1970) explained, the lack of transparency about products causes information asymmetry, meaning that buyers cannot assess the actual quality of products which is known by the sellers. This creates mistrust and leads buyers to prefer buying products of certain low quality rather than uncertain high quality. The consequence is that consumers end up buying lower-quality products overall, while sellers of high-quality products do not sell as much as they would if the information asymmetry had been reduced thanks to product transparency, which is defined as the disclosure of traceability information concerning a product (Ospital et al., 2022). Also, when consumers perceive a high risk due to information asymmetry, they can choose not to buy a product altogether (Zhou et al., 2018). Finally, regarding food, consumers associate benefits with traceability such as health, quality, safety, and control (van Rijswijk et al., 2008) and value supply chain monitoring and accountability on what firms declare about their products (Gellynck et al., 2001). Companies failing to implement traceability of food products can harm consumers' health and see their reputations damaged (Ringsberg, 2014) and decrease consumers' confidence in product safety (Aung and Chang, 2014). Consequently, ensuring transparency in supply chains is beneficial both to consumers and companies.

Companies can use I4.0 technologies such as the IoT and big data analytics software for traceability (Chiacchio et al., 2019; Corallo et al., 2020) to obtain information in real-time, identify problems before they become severe (Granillo-Macías et al., 2020), and satisfy regulations on product tracing (Latino et al., 2022). For example, Radio Frequency Identification (RFID) enabling mass serialized identification of every single product in a supply chain (Kelepouris et al., 2007) has been used to track products along supply chains with great precision and apply recall strategies rapidly to improve product safety (Regattieri et al., 2007), while QR codes and NFC tags applied to the product's label allow consumers to access to the product's information by scanning them (Violino et al., 2019).

However, traceability does not refer only to the recording of information about a product at every step of its supply chain, but also to the ability of supply chain stakeholders (e.g., supply chain partners, certifiers, authorities, and customers) to access the traceability information (Olsen and Borit, 2013). Companies usually store traceability information about their products in their centralized databases, making such information inaccessible to supply chain stakeholders (Agrawal et al., 2021) and modifiable or removable by malicious actors (Haq & Muselemu, 2018). Centralized data management causes low transparency, information asymmetry (Mao et al., 2018), lack of trust among supply chain stakeholders (Chan et al., 2019), and makes it difficult to detect counterfeit products (K. Abbas et al., 2020), increasing the chances of frauds on product quality and identity (Dabbene et al., 2014). Thus, the greatest challenge for traceability is the transparent exchange of information between all the stakeholders involved in a supply chain (Aung and Chang, 2014).

BCT is considered a valid candidate to bring transparency in increasingly global and complex supply chains (Bannor & Kyire, 2021). Thus, the following study reviews the academic literature on the use of BCT for supply chain traceability and its business and management implications to individuate themes throughout the academic literature.

2.2 A review on the business and management implications of blockchain for supply chain traceability[8]

2.2.1 Methodology

The method for this literature review is based on the guidelines by Snyder (2019) on reporting the search and selection of papers and their completeness and inclusivity. A search was conducted in January 2022 on Scopus, ScienceDirect, and Web of Science to increase the completeness of results. Given the objective of the research, the following keywords were searched in the title, abstract, and keywords fields: "blockchain" and "supply chain", alongside "traceability" or "tracking" or "tracing". The last two keywords were chosen to include forward traceability ("tracking") and backward traceability ("tracing"). All years of publication were included to increase the inclusivity of results. The research categories chosen were those addressing "business" and "management" issues. Non-peer-reviewed sources such as conference papers, book chapters, and conference reviews were excluded to ensure a higher quality of the results. Articles written in English were selected to avoid comprehension issues and increase the replicability of results by the international research community. Following these criteria, 169

8 This paragraph is based on Niccolò Testi, Leonardo Borsacchi, & Francesca Spigarelli. (2023). Blockchain Technology for Supply Chain Traceability: A Literature Review. L'industria, 1, 77–100. https://doi.org/10.1430/107737

records were selected (102 from Scopus, 23 from ScienceDirect, 44 from Web of Science). After eliminating duplicates, 133 remained. To include only relevant internationally peer-reviewed articles, this study considered articles published in Association of Business Schools (ABS) ranked journals as done by Razak et al. (2021), refining the number of results from 133 to 86. The papers' abstracts and, when necessary, their full texts were manually analysed to exclude those not focused on the business and management implications of using BCT for supply chain traceability. All 86 articles were found eligible to be included in the literature review.

The academic literature reviewed is recent. Only one article was published in 2017, two in 2018, and eight in 2019. The number of publications greatly increased in 2020 with 21 articles and more than doubled the following year with 44 articles. In January 2022, when the search for this literature review was conducted, already 10 articles had been published since the beginning of the year. This demonstrates a growing research interest in the topic of BCT for supply chain traceability in the field of business and management among relevant internationally peer-reviewed articles. As for the type of articles, 58% of the 86 articles were conceptual papers (33 frameworks and 17 reviews) while 42% were empirical (19 case studies and 17 interviews), confirming that most of the literature on BCT for supply chain traceability is conceptual. As for the research topics, 33 out of 86 articles (38%) address BCT for agri-food supply chains, showing a relevant research interest in this field. Other supply chains analysed in the articles found eligible are pharmaceutical (5 articles), humanitarian (4), maritime (2), construction (2), textile (1), fashion (1), luxury goods (1), oil industry (1), aviation (1), while the remaining 35 articles addressed generic supply chains.

By using a qualitative perspective, as suggested by Kraus et al. (2022), a thematic analysis was conducted on the articles found eligible by subjectively organizing their content into themes. This methodological approach was useful to identify themes that addressed the research objective. The results are presented in the next paragraph.

Based on the qualitative thematic analysis of the articles found eligible for the review, two main themes were individuated. The first theme addresses the benefits of using BCT for supply chain traceability, which can be articulated in three sub-themes: one regards transparency enabled by blockchain technology and its positive impact on trust between supply chain stakeholders; the second addresses the benefits stemming from an increase in consumers' trust about the product's originality and safety given by BCT; the third focuses on how BCT fosters supply chains' effectiveness in their resilience, performance, and sustainability. The second theme addresses the drivers and barriers to the firms' intention to use BCT for supply chain traceability.

The method followed has some limitations. It could have omitted some relevant articles because of the selection of databases, keywords, and filters, and for the choice of considering only articles published in ABS-recognised journals. To reduce this bias, the author did not restrict the search of articles to specific years of publication and examined thoroughly the articles' abstracts to assess their eligibility. Also, the content of the articles was organised into themes by the author following a qualitative approach which exposes the study to the author's subjective bias.

2.2.2 Improving transparency and trust in supply chains

Verifying the provenance of products and their characteristics has become more difficult in today's global and complex supply chains. BCT can provide a transparent supply chain traceability system; indeed, an increase in transparency is one of the most important advantages reported when adopting BCT in supply chains (Kim and Laskowski, 2018; Shoaib et al., 2020). The prominent sector of application of BCT for supply chain traceability is the agri-food (Masudin et al., 2021), including fresh products supply chains (Collart and Canales, 2021; Wu et al., 2021) where BCT can be used to trace product origin and sourcing, distribution, safety and quality (Mangla et al., 2021; Menon and Jain, 2021). Some key features make BCT an eligible solution to provide a transparent traceability system. Blockchains make the traceability information stored in them visible, auditable (W. Liu et al., 2021; Y. Wang et al., 2019), and immutable (Hald & Kinra, 2019; Kamble et al., 2020), which in turn enables transparency in a supply chain and accountability on what supply chain partners stated regarding their products (X. Li et al., 2022; Rodríguez-Espíndola et al., 2020) and the money transactions involved (Cho et al., 2021).

For their characteristics of transparency, immutability, decentralisation, and disintermediation, blockchains can effectively lead to an increase in trust among supply chain stakeholders (e.g., supply chain partners, certifiers, authorities, customers) (Casino et al., 2020; W. Liu et al., 2021). Since the supply chain traceability data uploaded to a blockchain becomes immutable, information from the past can be easily retrieved (Agrawal et al., 2021; Yacoub and Castillo, 2021), so supply chain partners are more protected from corruption (Razak et al., 2021) and opportunistic behaviours when collaborating between them (Qian and Papadonikolaki, 2021). Transparency of all data makes it easier to detect fraudulent transactions (Gupta et al., 2021), especially when machine learning technologies are applied to blockchains to check for unusual data (Yong et al., 2020). Moreover, a blockchain is a decentralised database where an always updated copy of the ledger is distributed to all nodes of a network, which makes it more secure against cybercriminals, data manipulators, and others who mishandle data (Kshetri, 2017; Y. Wang et al., 2019); if fraudulent nodes exist, secure authentication protocols can be developed to detect them (Long et al., 2021). Also, blockchains enable reliable data sharing between peers because data can be verified without the intervention of third parties that could be corrupted (Y. Wang et al., 2019).

These benefits could be especially tackled in blockchain consortia, which are new forms of organisation where supply chain stakeholders use a permissioned blockchain to share data between them. As explained by Saberi et al. (2019), in a permissioned blockchain some nodes of the network administer the blockchain and have special rights and functions: controlling accesses, deciding who can become a node of the network and who must be kicked out for violating the rules, granting writing and reading rights, and validating transactions. Blockchain consortia are usually based on permissioned blockchains to enable control of access to the data stored in the blockchain, which ensures the confidentiality of sensitive business information (Behnke and Janssen, 2020). Because they ensure both transparency and confidentiality, blockchain consortia are the widely accepted and appropriate model for use in business (Kayikci et al., 2020).

2.2.3 Increasing consumers' trust

Consumers are increasingly demanding when it comes to transparency about product provenance and safety (Casino et al., 2020; Rainero and Modarelli, 2021). With traceability enabled by BCT, consumers can access a product's traceability information stored in a blockchain by scanning the tag attached to the product. By doing so, they can get the information they need to make informed decisions about the products they buy (Bumblauskas et al., 2020). Transparency and immutability of the products' originality and provenance help detect fraud in logistics (Jain et al., 2020) and individuate counterfeited products (Hosseini Bamakan et al., 2021), thus effectively protecting consumers from being victims of fraud (Guido et al., 2020).

For these reasons, BCT traceability in supply chains delivers added value to consumers (George et al., 2019) and always benefits them (Niu et al., 2021).

Companies could enjoy advantages too. Producers could gain a competitive advantage if they use BCT to allow consumers to check their products' originality and environmental and social sustainability (Kittipanya-ngam and Tan, 2020; Niu et al., 2022). Additionally, producers can demonstrate the higher quality of their products and enjoy higher wholesale prices and market shares than the low-quality ones (Liu, 2022). Consumers can be persuaded to pay a higher price compared to similar products that are not traced with BCT (Guido et al., 2020). Since consumer awareness of product traceability increases the intention to purchase blockchain-traced products (Dionysis et al., 2022), companies who use BCT should publicize its advantages for traceability to improve the consumers' knowledge on the topic and increase the market demand for their products (Fan et al., 2020). However, Xu and Duan (2022) state that the demand in BCT-supported supply chains is not always higher than that in supply chains using centralised traceability tools.

2.3.4 Enhancing supply chains' resilience, performance, and sustainability

BCT can help increase the resilience of supply chains against disruptions (Montecchi et al., 2021), thanks to its capabilities of immutability and transparency, disintermediation, and decentralisation (Kayikci et al., 2021; A. A. Mukherjee et al., 2021). In a supply chain, BCT can improve risk awareness (Razak et al., 2021) and help anticipate disruptions, trace the roots of disruptions and observe their propagation (Ivanov et al., 2019), and reduce bottlenecks (Asante et al., 2021). BCT can be beneficial in supply chains that are characterised by cross-border trade, long service cycles, complex structures, and heterogeneous information coming from multiple sources, such as the maritime supply chain (J. Liu et al., 2021). In times of the COVID-19 pandemic situation, BCT can be used to enhance the shorter supply chain network structure needed to mitigate risks and disruptions (M. Sharma et al., 2021). Moreover, BCT improves trust between supply chain stakeholders, which in turn improves supply chain resilience (Dubey et al., 2020; Razak et al., 2021).

BCT can also increase the performance of supply chains by enabling a more efficient organization of their processes. Integration among all supply chain functions using BCT leads to an increase in operational performance (Aslam et al., 2021), for example in customer order management (Martinez et al., 2019). It also improves the cost-efficiency of supply chain operations (Mahyuni et al., 2020). supply chain partners could use cryptocurrency instead of bank transfers to lower commissions for payments between them (Pournader et al., 2020).

Further benefits to supply chain resilience and performance are related to transparency enabled by BCT. First, supply chain partners can access a blockchain to have real-time information about the activities of the other partners and better organize theirs (Guido et al., 2020). Second, real-time monitoring helps to identify defective batches easily and timely and decrease recall costs (Guido et al., 2020). Third, transparency of all business activities can allow companies to monitor the performance history and previous commitments of logistics professionals and help them select responsible logistics solution providers, thus improving supply chain performance (Jain et al., 2020). Finally, access to critical data by authorized members of a supply chain could reduce disputes between them (Jain et al., 2020). Other benefits to supply chain performance stem from the disintermediation of transactions between supply chain partners (A. Srivastava & Dashora, 2022; Y. Wang et al., 2019).

Applying BCT to supply chains can also provide indirect benefits. Wang et al. (2019) stated that BCT can help digitize non-digital processes in supply chains, which in turn would make data management more efficient (Köhler and Pizzol, 2020). Further indirect improvements in supply chain performance would come from combining BCT and the Internet of Things (IoT) in supply chains. IoT tracking solutions can be used for automated and reliable product tracking which removes human error or malicious data tampering, but usually, the traceability data collected are stored in centralized databases where data can be tampered with and that are inaccessible to stakeholders. BCT can be integrated with the IoT for full transparency and accessibility of data collected by sensors (Feng et al., 2020; H. Liu, 2022). Finally, BCT enables the use of smart contracts that can further enhance the performance of supply chains. A smart contract is a program that runs on a blockchain and self-executes certain conditions when these are met, based on the agreements among peers stated in the smart contract and without the intervention of a third party. The results of the conditions executed are then recorded in the blockchain, making them immutable and auditable (Agrawal et al., 2021). In supply chain traceability, smart contracts can be used to link together information regarding a product at every step of the supply chain (Agrawal et al., 2021). Smart contracts can be used successfully to benefit all kinds of supply chains (Y. Wang et al., 2019), including agri-food (A. A. Mukherjee et al., 2021; A. Tan et al., 2020) and pharmaceuticals (Hosseini Bamakan et al., 2021; X. Liu et al., 2021). The benefits of using smart contracts are particularly related to the automation of business flows (Chang et al., 2019), which leads to a reduction of the time necessary for the management of operations and payments between supply chain partners (Varriale et al., 2021). For example, smart contracts can be used to automatically distribute proportions of revenue among supply chain partners when certain predefined conditions are met (R. Liu et al., 2021).

BCT can also be used for sustainability in supply chains. BCT can ensure fairer supply chains by making the firms' social and environmental sustainability activities transparent (Diniz et al., 2021; Friedman & Ormiston, 2022), thus enforcing sustainability standards, especially in developing countries where violations of sustainability principles are more frequent than in developed countries (Kshetri, 2021). Additionally, when combined with tracking technologies such as RFID, BCT allows sustainable production management (Rana et al., 2021; Varriale et al., 2021) and helps firms to achieve Sustainable Development Goals by identifying issues and implementing interventions in real time (Tsolakis et al., 2021). Finally, BCT can provide transparency in circular supply chains (R. Sharma et al., 2021), foster their resilience (Nandi et al., 2021), and help manage the complexities in their management (Centobelli et al., 2021; Paul et al., 2022).

2.3.5 Drivers and barriers in the intention to use blockchain technology for supply chain traceability

Blockchain is just one of the technologies that companies can use for tracking and tracing in their supply chains. This paragraph identifies the drivers that lead companies to choose BCT for supply chain traceability and the barriers that make them desist.

Traceability systems enabled by BCT can be desirable for companies for their characteristics of decentralisation, immutability of data, and transparency (A. A. Mukherjee et al., 2021). Several researchers found that traceability is the most significant driver for BCT implementation in supply chains (Kamble et al., 2020; Laforet & Bilek, 2021), which is also related to the need to increase trust among supply chain stakeholders (Saurabh & Dey, 2021; Y. Wang et al., 2019) and to provide accountability in supply chains by tracing what each supply chain partner declared about its products and processes (Baharmand et al., 2021). Companies also want to adopt BCT in their supply chains to comply with institutional regulations (Hew et al., 2020; Sumarliah et al., 2022), regulatory governance, and industry standards (X. Li et al., 2021). Other reasons relate to obtaining efficiencies in customs clearance and management, digitalization and easing paperwork, standardization and platform development (Yang, 2019), and reduction of administrative work (Baharmand et al., 2021). Lastly, companies might want to adopt BCT for supply chain traceability in the hope of profiting from the positive perception that consumers have about traceability enabled by BCT (Sander et al., 2018). Some researchers found that consumers are willing to pay a premium for BCT-traced products (Saurabh & Dey, 2021; Shew et al., 2021). However, given that the consumers' willingness to pay a premium is proportional to their concerns about product quality and safety, companies could find that in some cases the revenues of adopting BCT outweigh the costs only if consumers' valuation uncertainty is high (Xu and Duan, 2022). Thus, companies should adopt BCT in their supply chains only if the customers' concerns are high (Fan et al., 2020).

As for the barriers that reduce the propensity of companies to adopt traceability solutions enabled by BCT in their supply chains, Yi et al. (2021) note that these can be related to a perceived lack of the need for BCT tracking of products that have low value and risk, even though the authors underline that companies might not always be aware of the importance of traceability and effective products recalls. Other barriers include a lack of digital knowledge, insufficient resources, unclear regulations, governance challenges, privacy concerns, and technical issues of BCT (Alkhudary et al., 2020; Baharmand et al., 2021). Companies often lack the necessary digital knowledge to implement BCT and integrate it into their business processes (David et al., 2022), given also the insufficient resources at their disposal for training their workforce and access to the necessary digital tools (Kshetri, 2021). Moreover, firms may be reluctant to invest resources in BCT because of the lack of regulations on this innovative technology (Srivastava and Dashora, 2022). Further, governance challenges can make it impossible for supply chain partners to adopt a blockchain to share traceability data between them and with other supply chain stakeholders. For a BCT traceability system to be effective, all supply chain partners must participate and upload their traceability data to a blockchain (Westerlund et al., 2021), but too many partners could make it very difficult to accomplish (Alkhudary et al., 2020; de Boissieu et al., 2021). Initiation of a blockchain network by a supply chain partner might cause resistance (Behnke and Janssen, 2020), especially in the case of unequal power distribution among supply chain partners (Kshetri, 2021) and excessive interference from the dominant supply chain partner (Masudin et al., 2021). In these cases, pre-existing trust among supply chain partners could help alleviate frictions and favour the adoption of BCT in supply chains, although it would lead to a paradox in which the pre-existing trust would make unnecessary the adoption of BCT to enable trust (Sternberg et al., 2020).

Privacy concerns about the visibility of the data uploaded to a blockchain can be an important barrier too. Blockchains make the information they store visible to interested parties; this may not be a desirable feature for companies that want to keep certain business-sensitive information private or share it with selected parties only. The confidentiality of data is a typical design requirement for blockchain solutions applied to supply chains (Büyüközkan et al., 2021). Lack of data privacy (Srivastava and Dashora, 2022) and issues regarding who is permitted to access them (Hosseini Bamakan et al., 2021) are important challenges to the diffusion of BCT in companies. However, a solution could be adopting blockchains of the permissioned kind that sacrifice a certain degree of decentralisation and transparency to make sure that only selected parties with different access rights can access the data (Guido et al., 2020) and that some data remain private (Behnke and Janssen, 2020), although the low level of decentralisation opens the possibility for nodes to collude to change or eliminate the data in the blockchain (Saberi et al., 2019). Finally, on the technical side of BCT, some issues need to be solved. The main technical challenge is the limited scalability of blockchain databases compared to the centralised databases usually used for supply chain traceability (Hosseini Bamakan et al., 2021; A. Srivastava & Dashora, 2022). However, Behnke and Janssen (2020) found that the scalability issue is relevant only in permissionless blockchains, which can be accessed and written on by an unlimited number of users, while it can be less relevant in permissioned blockchains where access and writing rights are restricted to a limited group. Another technical issue is the lack of interoperability between blockchains and software already existing in companies (Hosseini Bamakan et al., 2021; Laforet & Bilek, 2021) and between the blockchain databases and the companies' centralised databases (Kayikci et al., 2020). Given these technical limitations, Saurabh and Dey (2021) declare the need for a modular, scalable, interoperable, and cost-effective blockchain architecture for supply chains, while Behnke and Janssen (2020) call for an effort to achieve standardization towards a single type of blockchain supporting different processes.

2.3.6 Discussion

This analysis reviewed the academic literature on the use of BCT for supply chain traceability, which has gained traction in the three years before January 2022 when the literature review was conducted, with a continuously increasing number of articles being published. Many of the articles reviewed were focused on the use of BCT in agri-food supply chains, accounting for more than one-third of all the articles reviewed, probably because of the growing attention in societies to the dangers of food contamination (Menon and Jain, 2021). Other kinds of supply chains make up for another third of the total, with a prevalence of pharmaceutical supply chains, probably due to the hazard that counterfeited medicines pose to human health (S. Srivastava et al., 2019). The remaining third addresses generic supply chains of no specific economic sector.

This review individuates some themes that are recurrent in the articles analysed. The consensus among the different authors is that BCT brings more transparency to data sharing among supply chain stakeholders. Based on the benefit of data transparency, different authors suggested that firms might want to adopt BCT to improve trust and accountability in their supply chains, comply with regulations, detect fraud and counterfeiting, and increase supply chain resilience, performance, and sustainability. Some of the articles selected for this review addressed the barriers to the intention of companies to use BCT, such as the lack of digital knowledge, insufficient resources, unclear regulations, governance challenges, privacy concerns, and technical issues of blockchains.

It must be noted that more than half of the articles selected for this review are conceptual and describe the potential advantages and disadvantages of BCT from a theoretical point of view, while the articles based on empirical research are often qualitative or, if they measure quantitatively the benefits and costs for companies using BCT, do not benchmark BCT to other centralised supply chain traceability solutions. Thus, there is still little evidence of the actual convenience of using BCT, i.e., how much value-added margin it brings compared to the cost of implementing it and to existing and already thoroughly tested centralised supply chain traceability solutions.

Some authors mentioned that sharing data on a blockchain leads to cutting costs of supply chain operations (Mahyuni et al., 2020) and enables real-time monitoring which decreases recall costs (Guido et al., 2020), but it is not clear if the same results could have been achieved with already existing centralised supply chain traceability solutions that allow data sharing among supply chain stakeholders. Other authors stated that BCT brings indirect benefits because it incentives firms to digitalise their supply chains (Y. Wang et al., 2019), nevertheless, firms can achieve digitalisation even without resorting to BCT. The same argument applies to the use of BCT's smart contracts to automate supply chain processes (Chang et al., 2019) since automation can be achieved even without implementing BCT. Finally, some authors found a potential source of income from BCT in the preference of consumers to buy products traced using BCT and their willingness to pay a premium for such products (Liu, 2022). However, the scarce and sometimes conflicting evidence on this topic (Xu and Duan, 2022) seems to suggest that applying BCT to supply chain traceability may be convenient only if companies first invest in marketing to educate consumers about the importance of BCT-enabled traceability (Fan et al., 2020).

Aside from how profitable BCT may be, the main advantage of using a blockchain to handle data compared to centralised solutions could be to enable trust among supply chain stakeholders, which is one of the most important drivers in the intention of using BCT (Saurabh & Dey, 2021; Y. Wang et al., 2019). Enabling trust could be a sufficiently desirable reason for companies to adopt BCT in situations where there is a lack of trust among stakeholders, even if it is not profitable to do so.

The review of the literature shows that there is also little evidence of the potentially negative effects of transparency on data confidentiality, which has been individuated as a major barrier to the intention of companies to use BCT (Hosseini Bamakan et al., 2021; A. Srivastava & Dashora, 2022). Companies are aware that the traceability information uploaded to a blockchain for transparency would be visible to their competitors. The use of permissioned blockchains has been suggested as a means to give differentiated access rights to the data on a blockchain to different supply chain stakeholders so that sensitive business information is kept concealed from competitors (Behnke and Janssen, 2020). A novel kind of stakeholders' organisation and blockchain network, a blockchain consortium, can be created if multiple companies use a permissioned blockchain to share data between them and then make the data accessible to selected supply chain stakeholders except competitors (Kayikci et al., 2020). However, blockchain consortia are a recent innovation and their supposed benefits compared to the potential governance challenges are yet to be demonstrated. Additionally, blockchains of the permissioned kind may fail to enable trust among stakeholders. The lower decentralisation of a permissioned blockchain makes it possible for malicious actors to change or eliminate the data stored in it (Saberi et al., 2019). This eventuality could be enough to invalidate the supply chain stakeholders' trust and make a permissioned blockchain not more desirable than a centralised database shared by multiple owners. Therefore, if companies want to use BCT to enable trust in their supply chains, it may be better for them to use a permissionless blockchain, even if this means exposing some sensitive business information that competitors could use to their advantage.

Another issue that needs to be addressed is that of the reliability of data uploaded in a blockchain. The fact that data about a product are stored in a blockchain does not mean that the data state the truth about the product. The data can be false due to a human error in data measurement or reporting or be falsified by malicious actors before they are uploaded to a blockchain. Using the IoT was suggested as a way to automatically collect data and upload them on a blockchain without human intervention to increase data reliability (Feng et al., 2020), however, more research is needed on how to prevent malicious actors from manipulating IoT devices that are trusted as reliable sources of traceability data.

CHAPTER III - BLOCKCHAIN AND TRACEABILITY: THE CASE OF THE MADE IN ITALY

Recognising the potential of BCT applied to supply chain traceability for valorising and protecting the Made in Italy, this chapter presents two studies that focus on gathering empirical evidence on the topic. The first study conducts expert interviews with managerial and technical staff from Italian SMEs that utilize BCT for tracing Made in Italy products, as well as technology companies that provide these services, to uncover the use and implications of BCT for supply chain traceability in SMEs of the Made in Italy sector. First, BCT enhances transparency and trust in supply chains, however, its awareness and understanding among firms and consumers are limited and there is an absence of clear regulations. Second, the findings show that among all the benefits of BCT-enabled supply chain traceability that were individuated through the literature review in Chapter II, Italian SMEs apply BCT in their supply chains only for B2C marketing purposes. Third, many of the blockchain services adopted involve notarizing the hashes of off-chain documents on public third-generation blockchains, with traceability information accessible through the provider's App. This approach, however, poses risks to data retrievability and reliability. The second study conducts a survey to Italian adopters of BCT for supply chain traceability of Made in Italy products, with a questionnaire based on the evidence found in the previous study of this chapter, to gather their opinion on the BCT service they use. The findings show that adopters perceive a positive impact of BCT on areas of B2C marketing. Interestingly, only a limited number of firms have access to and actively use the data about the performance of the BCT service for business decision-making.

3.1 The use of blockchain for traceability as a B2C marketing tool in Italy[9]

Given the lack of empirical data on the use of BCT services for supply chain traceability, the study analyses primary data from SMEs using it

9 This paragraph is based on Testi, N. (2023). Blockchain technology for supply chain traceability: The case of SMEs of the Made in Italy. Piccola Impresa / Small Business, 2. https://doi.org/10.14596/pisb.3501

(adopters) and technology companies providing it (providers). The objective is to understand what issues of supply chain traceability of Made in Italy products BCT addresses (RQ1) and which BCT services for supply chain traceability SMEs of the Made in Italy can use according to their objectives (RQ2).

This study is based on the exemplary case of supply chain traceability of Made in Italy products. The Made in Italy refers to high-quality Italian products and has evolved into a brand with a global reputational capital (Schmitz & Knorringa, 2000) that gives the companies exploiting it a competitive advantage in the global market (Festa et al., 2020). Companies of the Made in Italy could use BCT applied to supply chain traceability for B2C marketing (Violino et al., 2020) and against counterfeiting (Caldarelli et al., 2020).

3.1.1 Methodology

The expert interview is used as a qualitative empirical method conducted to explore a specific field (Döringer, 2021) by gathering the interviewees' perspectives on a topic (Edwards & Holland, 2013) as experts, i.e., persons who hold a certain status or exercise a function in decision-making processes in a particular field of action and, therefore, own specific knowledge of the field of interest (Bogner & Menz, 2009).

This study aims to collect first-hand empirical data by interviewing managerial and technical staff of Italian SMEs adopting BCT for supply chain traceability of Made in Italy products and tech companies providing it. The choice to interview both adopters and providers was taken because their insights complete and compensate for each other. While the adopters tell their experience as users of blockchain services for supply chain traceability, the providers can give insights on the technical aspects of the blockchain service they offer and information on multiple use cases from their clients. Even though the providers alone may have given a sufficiently detailed picture of how BCT is used by SMEs of the Made in Italy, interviewing only them may have biased the answers towards exalting the advantages of BCT and belittling its disadvantages, thus it was deemed necessary to interview the adopters too.

A web search was conducted to identify adopters and providers of BCT for supply chain traceability of Made in Italy products, using keywords both in English and Italian, specifically “Made in Italy”, “blockchain”, “traceability”, “supply chain”, and “Made in Italy”, “tracciabilità”, “catena di fornitura”, “filiera”. The keywords were not enclosed in quotations to allow for the inclusion of similar terms. Information about providers and adopters was retrieved mainly from online blogs and news articles, which led to the identification of 19 providers and 14 adopters.

These were contacted for an interview via email, using the contact information provided on their websites. If no response was received, a message was sent to the firm and/or its management on the social media LinkedIn. Six providers and three adopters agreed to be interviewed via calls online or by telephone. The providers interviewed offer blockchain services mainly, but not only, to SMEs of the agri-food sector. Of the three adopters, two produce food and one furniture.

The interviewees were assured of anonymity and confidentiality to reduce bias from them and increase the reliability of the results. The six providers are named P1, P2, …, and P6. The three adopters are A1, A2, and A3. The two tables below show some key characteristics of the providers (Table 1) and the adopters (Table 2) interviewed. All the providers and adopters that accepted being interviewed were micro and small-sized firms. No additional details about the firms interviewed can be mentioned here without putting their anonymity at risk.

Table 1 Key characteristics of the providers interviewed

Provider	Type of firm	Size of the firm	Interviewee’s role
P1	Startup	Small	Project Manager
P2	Joint-stock company	Micro	Project Manager
P3	Startup	Micro	CEO
P4	Ltd	Micro	CEO
P5	Ltd	Small	Project Manager
P6	Ltd	Small	CEO

Table 2 Key characteristics of the adopters interviewed

Adopter	Type of firm	Size of the firm	Interviewee's role
A1	Joint-stock company	Small	Marketing Manager
A2	Ltd	Micro	Sales Manager
A3	Ltd	Small	CEO

The interviews took place between November and December 2021 and were 40 minutes long on average. The interviews were semi-structured, with open-ended questions allowing greater flexibility for the respondents to enrich the description of the underlying context, thereby providing a wider picture of the phenomenon under investigation (Seidman, 2006). Expert interviews were based on a topical guide regarding the specific knowledge of the expert in the field of interest (Döringer, 2021). The interviews addressed the following topics: issues in supply chain traceability that BCT was expected to solve; technical features of the BCT services provided/adopted; challenges faced in providing/adopting BCT services; collaborations with academic institutions to develop/adopt BCT services. The interviews were integrated with follow-up emails to the experts interviewed to gain additional information and to cross-check the findings. The interviewees' answers were grouped by topic and are presented in the following paragraphs.

This study faces three main limitations. First, it is a qualitative study based on a small group of six providers and three adopters from Italy, so the results cannot be generalised. Second, interviewing the providers of the BCT solutions for supply chain traceability in Italy may have biased the answers towards exalting the advantages of using BCT and belittling its disadvantages; however, this bias was mitigated by interviewing the adopters too. Third, although the objective of this study was to gather evidence from SMEs, the adopters and providers that accepted being interviewed were all micro and small-sized firms, whereas no larger firms were interviewed. Thus, all evidence collected on the use of BCT for supply chain traceability by Italian medium and large-sized enterprises comes from the declarations made by the providers and cannot be checked against those from medium and large-sized adopters.

The findings from the interviews describe why and how BCT can be applied for supply chain traceability of Made in Italy products. The following paragraphs illustrate the benefits, challenges, technical features, and potential risks for data reliability of the blockchain solutions provided and adopted.

3.1.2 The benefits of BCT-enabled transparency in product traceability

All providers and adopters interviewed underlined that BCT increases data transparency and, consequently, accountability since it is easy to verify who declared what and when, even after a long time, without the risk of such data being tampered with. Accountability safeguards supply chain partners in case of scandals about their supply chain: "The attribution of responsibility guarantees the producer because, in case of a scandal regarding its product, the producer can blame the single supplier responsible for providing the false or incorrect information. It also protects the other suppliers from being wrongfully accused" (P5). Accountability can indirectly improve data correctness: "With a blockchain, you cannot edit the information you stored, so you have to be more careful and take responsibility for what you write […]. The advantage for a company using blockchain technology in its supply chain is having a higher guarantee that the traceability data is correct" (P5); since data are visible to supply chain stakeholders and auditable, "companies storing incorrect information on a blockchain would suffer from reputational damage, so they are incentivized to upload the data correctly" (P1).

Transparency and accountability enabled by BCT can help building trust between supply chain stakeholders. Nevertheless, pre-existing trust can make BCT useless: while all providers and two of the three adopters confirmed the role of BCT in creating trust in supply chains, A2 stated that "our customers are prevalently local entrepreneurs who know us directly and trust the provenance and quality of our products, so the blockchain for us is not necessary [to build trust in our relationship with them] and gives no advantages from that point of view".

Another advantage of using BCT for supply chain traceability is anti-counterfeiting. Transparency and immutability of the traceability data stored on a blockchain can help individuate counterfeit products. In the centralised traceability systems usually used by companies, the traceability information often does not reach the consumer and, even if it does, it can be modified at any time (P5). Instead, with BCT, consumers can be involved in anti-counterfeiting activities by giving them the possibility to verify the products' originality (P3). However, this is possible only if the distribution phase is tracked: "If in the blockchain we put the information about the shop or wholesaler to which it is delivered, together with the status of the product such as sold or in circulation, we can guarantee to the final customer that the products are authentic. If by scanning a tag on a product the customer sees that the product is supposed to be in another shop or that it has been sold already, then she will have the certainty that the product is counterfeit" (P2). Counterfeiting is an important issue for SMEs of the Made in Italy, indeed, all the providers except for P6 stated that their solution is used against counterfeiting. P3's solution also enables consumers to report the existence of a counterfeit product, which is then blacklisted. As for the adopters, A1 decided to use BCT to give its B2C and B2B customers a guarantee that the company's products are Made in Italy. This is essential for them since they get much of their revenue from selling abroad to customers who otherwise could not distinguish a Made in Italy product from a fake one.

Using BCT to give supply chain stakeholders the possibility to verify the products' originality may increase the adopter's revenues. A3 state that their customers prefer to buy BCT-traced products and pay a higher price compared to products not traced with BCT. All the providers and adopters interviewed use BCT for high-quality Made in Italy products of which consumers value the provenance, indeed, they all agree that BCT benefits are especially relevant for high-quality products. Moreover, A3 uses BCT also because distributors are asking companies like theirs to register more traceability information about the entire production process transparently. Companies using BCT to trace their products "can demonstrate the originality and genuineness of their products transparently and benefit from a competitive advantage because large-scale distributors and retailers will prefer to buy from them" (P2).

3.1.3 The use of BCT-enabled traceability for B2C marketing

All the providers and adopters remarked that BCT can be used for B2C marketing to promote products to consumers who value product transparency and as a tool to do storytelling about products. A3 said that "during the Covid-

19 pandemic, our company had difficulties connecting to the customers because we couldn't meet them in person, while thanks to the blockchain we were able to reconnect with them by allowing them to learn about our products". Additionally, when consumers scan a tag on a product, they land on a webpage where web analytics software can collect data about their characteristics and preferences that firms can use to make informed decisions (P6). The advantages of BCT for B2C marketing are so relevant, that in the providers' opinion, most adopters in Italy use BCT only for marketing purposes to increase the willingness of consumers to buy their products rather than to enable transparency in supply chain traceability: "our clients use our blockchain solution mainly for marketing" (P6); "for companies in Italy, blockchain is a matter of marketing to ride the blockchain trend" (P1); "many companies want to use blockchain only for marketing reasons and not for traceability […] [So,] many providers build solutions that provide a good user experience and a suggestive storytelling for a consumer who is not aware of what traceability with blockchain is" (P2).

3.1.4 Challenges to the adoption of BCT for traceability

Firms of the Made in Italy are getting interested in BCT but are still confused about how to use it in supply chains (P5) and do not know much about its benefits (P4), especially SMEs (P1). For proper traceability, it is necessary that all supply chain partners put their data on a blockchain (P5), but sometimes firms do not want to put their traceability data on a blockchain because they fail to understand the benefits of doing so (P6). "It is very complicated to ensure that a product is traced along the entire supply chain. Already for a small artisanal company, nearly fifteen supply chain partners may have to agree to be part of the network and put their data on the blockchain" (P1). Effective communication of what BCT is and the benefits it brings to supply chains is crucial to incentivize firms to adopt it. "The problem of technology companies that offer blockchain services is that they focus on creating solutions that are good on a technical level, but then they fail in communicating the benefits to companies" (P3). A2, as an adopter, had problems explaining BCT to its suppliers and was unable to communicate the benefits of increased trust, bargaining power towards distributors, turnover, and earnings for all the players involved in the supply chain.

Providers diffuse the knowledge on BCT during exhibition fairs and other events. Instead, knowledge diffusion by universities remains marginal. While all providers collaborated on blockchain-related projects with universities, none of the adopters found out about BCT from universities. A1 discovered BCT thanks to a consulting company. A2 casually learned about BCT while having an informal conversation with a PhD student who was using their company as a case study for an unrelated project. A3 became aware of BCT and developed some prototypes thanks to contacts with people they knew for professional reasons.

Apart from the lack of knowledge of BCT and the difficulty to understand its benefits, SMEs of the Made in Italy could be reluctant to adopt BCT for supply chain traceability because of the lack of regulations in Italy, which might create a situation of uncertainty. "Regulators should clarify what data must be put on blockchains, in what way, and in what format it must be recorded" (P6). As P5 argued: "if some data are not present on a blockchain, then you cannot say it is traceability" and "the intervention of regulators should ultimately lead to the standardization of the traceability data". Nevertheless, P6 stated: "While there are no laws for traceability with blockchain technology, the blockchain makes up for the lack of regulations because it is built to give a mathematical proof that something was written at a certain time [i.e., it enables data notarization], so in a certain way is replaces laws on traceability".

Another factor that could limit the adoption of BCT is the lack of digitalisation. Using BCT requires that firms collect traceability data in digital form, but P5 stated that most do not. Likewise, A1 declared: "For many of our supply chain partners, traceability is a handwritten paper document that they send to us [as producers] together with the goods", but continued saying that: "The second generation of younger entrepreneurs is starting to use Industry 4.0 tools such as the IoT that allow the automatic collection of data from multiple sources and storage of data in a database shared with us".

Moreover, few companies use management software like ERP that would enable efficient storage of digital traceability data, and that is why some providers offer a BCT solution that can be used as management software (P2, P5). If companies already have internal management software, all the providers offer customised integration with their BCT service. However, P5 notes that "if the company is already using a management software, the software's provider can sometimes ask for up to ten thousand euros to the company to provide the data [necessary for proper integration with blockchain technology]; this is an investment that many SMEs are not willing to make".

Finally, BCT enables the use of NFTs, which can be used to create unique digital representations of assets, trace them, and transfer their ownership between supply chain partners (P2). However, no providers or adopters use them to tokenize products. P1 uses NFTs only to tokenize the documents containing traceability data. P5 states that the complexity of using NFTs to tokenize every single product does not come from BCT, but from the tag printing phase: "You would need a printer that manages to create many labels in a fast way, each having a different QR code identifying a single product". Instead, A3 does not plan to use NFTs to tokenize its products anytime soon, because "the recent hype on NFTs has created a bad reputation around these tools, so using them could damage the image of our firms. We will likely use them when consumers can understand their potential".

3.1.5 Scalability and confidentiality at the expense of data retrievability

Off-chain storage is used by all the providers and adopters interviewed to enable scalability, reduce storage costs, and ensure the confidentiality of sensitive business information. Since off-chain storage exposes to a risk of data loss, the actors holding the data in their private databases are responsible for data retrievability: "The data are uploaded to the cloud database we own, so we are responsible for correctly storing the data" (P4). To enhance data integrity and retrievability, P2, P3, P4, and P5 store the traceability data in the decentralised storage InterPlanetary File System (IPFS), although, these data are still controlled either by the providers or the producers or the supply chain partners, who could eliminate the data. The files' hashes are then uploaded to a blockchain where they are visible to all interested parties. The files themselves can be accessed only by authorised parties that have access to the off-chain database, thus preserving data confidentiality, P1 declared.

Differences in the technical features of the blockchain solutions provided emerged in the architecture used. P4's solution involves a consortium blockchain type, which brings two advantages compared to a public one: the predictability of operational costs, which instead fluctuate in public blockchains, and the fact that known supply chain partners own the nodes of the network, which are usually not known in public blockchains. However, all providers agreed that firms looking for data immutability should upload their data only on public blockchains. Even in P4's solution, once the data is uploaded on the consortium blockchain it gets aggregated, hashed, and notarized on a public blockchain to ensure transparency against tampering with the data on the consortium blockchain. This hybrid architecture is adopted by A3.

Apart from P4 and A3, all the other providers and adopters use public blockchains to notarize the hashes derived from the traceability data. When asked about the problem of low scalability and lack of data confidentiality of public blockchains, the providers using them replied that these are not critical issues anymore, as long as only hashes are uploaded to the blockchain and not the traceability data themselves, that need to be stored off-chain. Also, if a firm does not need to make the hashes visible in real time, then low scalability is not a problem (P6). If many hashes have to be uploaded to the blockchain in a short time, then transaction scalability is required, which is obtainable by using third-generation public blockchains. These are capable of faster transaction validation at a lower cost, compared to public blockchains of the first generation (e.g., Bitcoin) and second generation (e.g., Ethereum). However, it must be noted that these new generations of blockchain use kinds of consensus algorithms such as PoS and PoA that enable more scalability at the expense of decentralisation and security.

3.1.6 Risks of traceability data unreliability

Blockchains make the data almost impossible to tamper with. Nevertheless, the data can be incorrect due to human error or fraudulent manipulation. Additionally, the data itself could be correct but a falsified version of them could be displayed to stakeholders in the interface. Potential sources of unreliable data have been individuated in the interviews.

Supply chain partners may have an interest in declaring false traceability information even if they know it will become immutable and visible on a blockchain. Alternatively, the data could be incorrect because mistakes have been made during the collection or registration of data. All the providers confirmed that nobody can be sure that the data uploaded to a blockchain are true, so they cannot be relied on completely. All providers recommended applying the IoT so that data about materials, temperature, manufacturing processes, chemical analysis, transportation, and others are automatically collected and uploaded without human intervention.

Further risks of poor data reliability may come from the producers. A product is made of components or ingredients that pass through different stages of a supply chain, including its distribution. In many of the BCT-enabled solutions provided and adopted, each supplier collects the traceability data about its supply chain stage and sends them to the producer to be stored in the producer's private database. Then, the producer creates a digital document declaring all the traceability data received by the suppliers, which is then notarized in a blockchain. This BCT-enabled solution could be called "notarization of the producer's declaration". In P2's opinion, this solution does not ensure that the traceability data was not changed by the producer before being notarized on a blockchain.

A further potential source of data unreliability comes from the providers if they are the ones receiving the traceability data from the adopters and uploading them to a blockchain. In this case, the providers act as gateways for the passage of data from the supply chain partners to the blockchain and have access to them. P1, P4, and P6 collect data from the supply chain partners and put them on the blockchain.

Instead, P2, P3, and P5 enable each supply chain partner to autonomously upload its traceability data to the blockchain. They do so by employing smart contracts to track products and keep together the otherwise scattered information that is uploaded to the blockchain by each partner of a supply chain. This solution enables more accountability in supply chains and avoids the problem of the data being tampered with by the producer or provider but does still not ensure the reliability of the data uploaded by each supply chain partner. In this solution, supply chain partners must have and use a blockchain wallet. Also, since the data referring to a product is uploaded to the blockchain by different supply chain partners at different times, it must be kept together with smart contracts.

Even if the solution allowing each supply chain partner to upload its traceability data to the blockchain using blockchain wallets and smart contracts could enable more accountability and data reliability, all providers stated that the notarization of the producer's declaration is the most adopted BCT-enabled solution by SMEs of the Made in Italy. Indeed, all the adopters interviewed used it. This solution is adopted when it is neither considered necessary, feasible, or desirable that supply chain partners upload their traceability data autonomously. On this matter, P5 declared: "Even though our solution enables each actor in the supply chain to put the data on the blockchain, it is not always considered necessary because the producer can upload the data provided by the suppliers". Additionally, using wallets and smart contracts may not be feasible because many companies lack the necessary knowledge to operate and maintain their blockchain wallets (P6). P1 had to replace some digital wallets because their customers lost the digital keys to access them. Finally, there are cases in which this solution is not desirable, as underlined by P1: "Sometimes the suppliers are not willing to upload their sensitive data and make them public. In this case, the notarization of the producer's declaration, even with incomplete traceability data, is the only blockchain-enabled solution that a producer can hope to adopt in its supply chain". Moreover, the lack of desirability could be caused by unawareness of what blockchain and traceability are, both from firms and customers. "We, as producers, give the data to be put on the blockchain. The data are not entered by suppliers even if the platform gives this possibility because there is a cultural obstacle to overcome in our suppliers that do not understand blockchain" (A1); "the average entrepreneur has no idea what blockchain and traceability with blockchain are, so they opt for other kinds of solutions" (P2); "the small-sized companies we turn to for some phases of the production process do not understand blockchain technology and asking them to upload data to the blockchain would be useless" (A2). Other than the aforementioned factors, the higher desirability of the notarization of the producer's declaration over the wallets and smart contracts solution may depend on why the firm wants to adopt BCT. As P6 said, "If the adopter wants the blockchain only for marketing reasons, then a simple notarization of documents containing the traceability data by the producer may be sufficient". In fact, according to all providers, most companies in Italy use BCT for B2C marketing rather than to enable transparency in supply chain traceability, and that may be why the notarization of the producer's declaration is the most adopted blockchain solution even though it does not ensure data reliability.

A final risk to data reliability comes from using the provider's centralised App to display the traceability information to supply chain stakeholders. Most of the BCT-enabled traceability solutions analysed involve a Mobile or Web App as a trusted channel between the user scanning the tag and the traceability data stored in the blockchain. This is deemed necessary because a counterfeiter could apply a tag to its fake product, directing the stakeholder scanning the tag to a webpage containing false traceability information which would induce the stakeholder to believe that the product is original. In this case, BCT could be used by the counterfeiter to store false traceability data and make it visible and immutable to deceitfully increase the stakeholders' trust that the data are true just because they are on a blockchain. Since the provider's App works only when scanning legitimate tags pointing to the original traceability data, users are safeguarded because scanning the counterfeiter's tag with the provider's App would not be possible. However, P2 argues that the Mobile or Web App channel cannot be completely trusted as it runs on a centralised interface owned by the provider. The provider or hackers could manipulate the App's interface to display false information.

P2 and P3 use a Decentralised Application (DApp) that runs on a public blockchain as a more trustworthy channel. The DApp is a smart contract combined with a front-end user interface. The code that makes the DApp work is stored on the blockchain and is open source, so it is immutable and visible to whoever wants to audit it. This means that users can know exactly what the DApp does – if they have the necessary programming skills to be able to read the DApp code. When a user scans a tag to access a product's traceability data, the smart contract of the DApp retrieves the pieces of notarized information that were uploaded to the blockchain and displays them to the user in an organic way. The DApp is more trustable than an App because it "leads the user directly from the tag to the blockchain containing the information on the product, and not to a static webpage where the info can be edited [by the provider or hackers] […] moreover, it would be necessary to attack the entire blockchain to change the way the DApp works" (P2).

3.1.7 Discussion

The interviews conducted showed why and how BCT is used in SMEs for supply chain traceability of Made in Italy products, confirming the literature on the topic and adding novel findings.

The interviewees confirmed that BCT can increase transparency in supply chains (Mahyuni et al., 2020) and accountability of supply chain partners, incentivising them to upload correct data (Longo et al., 2019). Transparency and accountability enable trust between supply chain stakeholders (S. Wang et al., 2019). If trust is already present, then adopting BCT does not bring any additional benefits in terms of trust, as noted by Sternberg et al. (2020) in their case study. As Ge et al. (2017) say, BCT may not offer added value to short food supply chains where supply chain partners, authorities, and customers can more easily check the firms' and certifiers' claims.

Transparency also helps with anti-counterfeiting, as outlined by Hosseini Bamakan et al. (2021). On this matter, BCT is especially useful to protect the Made in Italy brand (Caldarelli et al., 2020). Also, enabling supply chain stakeholders to verify a product's originality involves them in the process of anti-counterfeiting (Ma et al., 2020), but this only works if the product distribution phase is tracked with BCT too. Finally, using BCT for supply chain traceability can increase the competitiveness of SMEs because it assures distributors about the products' originality.

The interviewees confirmed the benefit of increased revenues from an increase in sales by customers who value product transparency (Kittipanya-ngam & Tan, 2020) and from persuading them to pay a higher price compared to similar products not traced with BCT (Guido et al., 2020). Traceability with BCT is especially beneficial in the case of products of which consumers value provenance more, as Rogerson & Parry (2020) theorized, such as those Made in Italy.

Another key benefit is that of B2C marketing (Violino et al., 2020). While adopting blockchain BCT in supply chains to trace products can benefit firms in various ways, from increasing transparency and reducing information asymmetries in supply chains, improving consumers' trust, and enhancing supply chains' resilience, performance, and sustainability Testi et al. (2023), this study found that BCT is used by SMEs of the Made in Italy mainly for consumer marketing and to do storytelling about their products. This is consistent with the studies by Galati et al. (2021) and Compagnucci et al. (2022), who found that Italian SMEs use BCT for agrifood supply chain traceability as a B2C marketing tool to present themselves as reliable and trustworthy to consumers and showcase their products as high-quality and safe.

However, the use of BCT-enabled traceability as a B2C marketing tool is based on the assumption that consumers would trust more the traceability data if they were stored on a blockchain, and this would increase their purchasing intention and willingness to pay a premium for blockchain-traced products. On the one hand, this assumption is based on some evidence of the positive perception of consumers regarding BCT-enabled traceability, mainly for food products, but on the other hand, the participants' perception could be caused by biases caused by the studies' authors who may have described BCT to the participants emphasising its potential benefits and capabilities without adequately addressing its limitations. If blockchain was presented to the participants emphasizing its benefits as a technology that improves transparency in traceability, without mentioning the impossibility of storing the traceability data on-chain in public blockchains and the necessity to use off-chain data storage which exposes to the risk of data loss, and without warning them that the data uploaded to a blockchain may still be false, then this may have increased the desirability of BCT-enabled traceability. For example, Cozzio et al. (2023) found that BCT boosts consumer trust for local foods with an experiment comparing two hospitality situations: one implementing a BCT-based traceability system and the other employing a company-owned (centralised) traceability system. However, the authors may have biased the participants' answers due to how they described BCT-enabled traceability. They told participants in the treatment group (i.e., the group exposed to information about BCT) that the company was using a “blockchain-based traceability system for food products which tracks the supply chain. This system is based on a certified information flow that can be directly verified by the recipients through a QR code”, while participants in the control group (i.e., the group not exposed to information about BCT) were told that “all food products are tracked by the company-owned information system. This system is based on the host self-declaration”. As found by the study presented in Chapter III of this Thesis (Testi, 2023), what the authors told the participants does not reflect the reality. Indeed, also in the blockchain-based traceability systems the products are tracked by company-owned systems and stored off-chain and the system is based on the host self-declaration which can be the producer or a supplier. Since the participants in the treatment group were exposed to a message that provided a wrong representation of what BCT can do for traceability, it is quite likely that their perception of BCT was biased. An experiment by Acciarini et al. (2023) showed that visible information on product labels about the use of BCT for traceability positively affects customer purchase intentions. In this experiment, the participants had to indicate their preference between two web pages showing traceability information about a product: in one, just the traceability information was displayed; in the other, next to the information there was a sentence saying: “100% secure information provided by: blockchain network platform”. Since BCT was presented so enthusiastically, it is not surprising that the participants preferred the label with secured information – whatever “secured” meant for them – rather than the one where the information was implicitly presented as non- secured. This does not demonstrate that consumers desire BCT-enabled traceability, but rather it may indicate that they perceive a risk associated with information implicitly presented as non-secured. Mazzù et al. (2021) conducted a study which showed that BCT-validated information can significantly enhance perceptions of flavour and healthiness, acting as an effective extrinsic cue alongside others like brand, country of origin, and nutritional information. In this survey, participants had to choose between a product with a label containing no detailed traceability information, and a label stating: "The company employs an advanced blockchain technology to certify the origin and health of the animals and the entire production process, to ensure traceability and transparency of the dietary characteristics of the milk". It is not surprising that participants preferred the second label reassuring them about the use an "advanced technology for traceability", which incidentally was BCT, rather than the label with no detailed information. Treiblmaier & Garaus (2023) used signalling theory and data from two experimental studies, finding that blockchain labels serve as effective signals to boost perceived food product quality, leading to an increased intention to purchase. The participants were asked to express their preference between three products: the first with no label, the second with a label stating that the product had been tracked with QR code tracking, and the third with a label stating that the product had been tracked with BCT. To find participants, the authors of the study asked university students of a marketing research class to "acquire a convenience sample by forwarding the link to the online experiment to their family members, friends, and colleagues in return for course credits". Given that the participants were people intimate with the students, it is plausible that the students revealed to them the real objective of the study (i.e., assess the desirability of BCT labels compared to the other tow kinds presented), biasing their answers. It is also likely that they explained what BCT was to the participants and may have exalted its benefits, again biasing their answers. It is even possible that some – or several – students just pretended to submit the survey and answered the questions impersonating fictitious participants as an easier way to get the course credits. Thus, the results of this survey must be considered with due caution. Violino et al. (2019) conducted an anonymous questionnaire to Italian consumers, showing that almost 94% were interested in knowing the traceability of extra virgin olive oil and were willing to pay, for the integration of traceability technologies including (but not limited to) blockchain, an additional price equal to almost 18% more than the amount they commonly spent. In this study, the participants could choose between three traceability solutions: NFC; a tamper-proof device protected by RFID sticker; a QR code protected by a "scratch and win" system and associated with blockchains. The authors stated: "The QR code blockchain system appeared to be the most attractive technology from the consumer's point of view", but the contribution of BCT in the desirability of this system is not clear because the researchers linked it with other two potentially desirable factors: a "prize-winning mechanism and gamification approach and […] easy access to the information through QR code". Thus, the results do not show a clear indication of the desirability of blockchain as a standalone technology. Finally, other studies like Y. Li et al. (2023), Rao et al. (2023), and H. Liu et al. (2023) found evidence of the potential of BCT-enabled traceability for marketing purposes, but it was not possible to assess how they portrayed BCT-enabled traceability to the studies' participants and if they caused them to develop biases. In sum, caution is required about the consumers' positive perception of BCT-enabled traceability based on the results of these studies because researchers may have described BCT-enabled traceability in a way that created biases in the participants of their surveys and experiments.

As for the challenges to the diffusion of BCT for supply chain traceability in Italian SMEs, there is a lack of clear legal frameworks on BCT (Iftekhar et al., 2020) and its application to supply chain traceability, specifically on the standardisation of traceability data (Aung & Chang, 2014). The second problem is the lack of knowledge of BCT, as found by Bianchini & Kwon (2020). Effective communication of what BCT is and what benefits it brings is considered crucial to making companies interested in the potential of this technology. This may be crucial to the success of BCT for supply chain traceability, since the benefits of using BCT in supply chains depend on the adoption of BCT by a critical mass of supply chain partners (Sternberg et al., 2020) and cannot be achieved if some of them do not share their traceability data since this would create gaps in traceability (Laforet & Bilek, 2021). As for the role of public and private academic institutions as knowledge promoters (Hausman, 2012), they do not seem to be very active in spreading the knowledge of BCT among companies in Italy. The further challenge deriving from the lack of digital knowledge inside SMEs which limits their capacity to adopt BCT for supply chain traceability, as theorized by Garrard & Fielke (2020) and Sternberg et al. (2020), was confirmed by the providers. BCT can benefit supply chains only if traceability is well-practised by each supply chain partner, which depends also on the degree of digitalisation of the tracking process (Bumblauskas et al., 2020). However, many companies still use paper documents for tracking, as underlined by Garrard and Fielke (2020). As for the challenge of integrating BCT with the companies' internal business application software such as ERP, mentioned by Tan & Ngan (2020) and deemed problematic by Al-Jaroodi & Mohamed (2019), this did not emerge as an issue since all the providers interviewed offer such integration. However, for successful integration, the adopter must first have control of the data stored in its internal management software, which is not always the case and could be very expensive for adopters to obtain from the management software provider. Finally, NFTs can be used to uniquely identify products and track their change of ownership and related payments, as presented by Chiacchio et al. (2022). However, no providers and adopters use NFTs for these purposes: the bad reputation surrounding NFTs and limits in the speed of label printing on each unit of product were mentioned as barriers to the intention to use them.

Regarding the technical aspects of the blockchain services analysed, all providers and adopters implement off-chain storage to provide scalability and data confidentiality, as advised by Shahid et al. (2020) and Behnke and Janssen (2020). However, this exposes them to loss of data. To increase data integrity, some providers store data off-chain in decentralized databases (Shahid et al., 2020) such as IPFS (Salah et al., 2019); however, the data in these databases are still controlled by either the provider or the producer or by each supply chain partner, who could eliminate the data stored in them. Instead, one provider and one adopter use a hybrid blockchain combining a consortium blockchain for scalability (Dib et al., 2018) and data confidentiality (Bumblauskas et al., 2020; Chan et al., 2019) with a public blockchain for data immutability, similar to that proposed by Wu et al. (2017). Nevertheless, most providers use off-chain storage coupled with public blockchains: the traceability data is stored off-chain, and their hashes are uploaded to the blockchain for reference. Scalability of transactions containing the hashes is not an issue for them because third-generation public blockchains are used, while data confidentiality is ensured with off-chain storage. Hence, the benefits of permissioned blockchains may be obtained by combining third-generation public blockchains for enhanced transaction scalability with off-chain storage to ensure traceability data scalability and confidentiality. However, third-generation public blockchains improve scalability by using consensus algorithms such as PoS and PoA (P. Mukherjee & Pradhan, 2021) that hinder the decentralisation and security of the blockchain network.

In addition to the risks of data loss, this study found risks of traceability unreliability in certain BCT services provided. The primary source of data incorrectness may be any supply chain partner. Nobody can be sure that the data provided by supply chain partners is correct, as noted by Violino et al. (2020). The providers recommended using the IoT to automate the collection and upload of traceability data to a blockchain to remove any human intervention in these processes, as advised by Iftekhar et al. (2020), K. Abbas et al. (2021), and Violino et al. (2019). Other sources of data incorrectness may be the producers or the providers if they are the ones responsible for collecting the traceability data from the supply chain partners and uploading it to the blockchain, since they could manipulate or omit data before storing them. This solution can be defined as a "notarization of the producer's declaration". Alternatively, smart contracts can be used to store the hashes of single traceability events and relate them to a specific product (Chang et al., 2019; Prause, 2019), which is a solution that allows each supply chain partner to upload their traceability data anonymously. Even if the latter solution eases the risk of traceability data unreliability, the former is the most adopted in Italy because it is considered not necessary, desirable, or feasible that each supply chain partner uploads its traceability data on the blockchain, for reasons that include a lack of awareness of BCT and traceability and lack of knowledge on how to use and maintain a blockchain wallet. Moreover, many companies in Italy use BCT for B2C marketing reasons rather than to enable transparency in traceability, thus the notarization of the producer's declaration might be sufficient for their scope. A final risk of data unreliability could come from the providers' Mobile or Web App interface displaying different information than that stored on the blockchain it links the product to. To solve this problem, some providers use a DApp running on a public blockchain to create a direct connection between the user and the data on the blockchain. Thus, DApps may guarantee more transparency, accountability, and trust among supply chain stakeholders, compared to Mobile or Web Apps.

3.2 Italian adopters' opinions on the usefulness of BCT-enabled traceability

Recognising that in Italy BCT is adopted in supply chain traceability mostly for B2C marketing purposes, as shown in the previous study of this chapter, a survey is conducted to adopters to gather their opinions on the usefulness of BCT-enabled traceability in this area, while also addressing other dimensions of the use of BCT services.

3.2.1 Methodology

A total of 52 Italian firms using BCT for supply chain traceability were individuated mainly by web searches in May 2023, using the keywords "blockchain" coupled with "tracciabilità" (Italian translation of "traceability") or "catena di fornitura" or "filiera" (both meaning "supply chain"). The names of the adopters were mostly retrieved from media news and by accessing the use cases displayed on the providers' websites and LinkedIn pages. For one adopter it was impossible to retrieve any contact information. The CEOs of the remaining 51 adopters were contacted either through their e-mail contact (5 cases) or their personal LinkedIn profile (29); otherwise, if this was not possible, an e-mail was sent to the firm's e-mail address (14) or a message was sent to the firm's LinkedIn page (3). The electronic message to the CEOs contained a brief presentation of the scope of the survey and the link to an online questionnaire which was created using Google Forms. The questionnaire addressed the main characteristics of the respondents' firms, the firms' BCT adoption process, and the respondents' opinions regarding the advantages and disadvantages of using BCT for supply chain traceability. The questions were constructed based on the academic literature on the adoption of BCT for supply chain traceability, specifically on the findings of the paper by Testi (2023) on which the first study of this chapter is based. The questions have been reviewed by a University Professor, who is an expert in surveying methods for Marketing studies. Of the 51 adopters contacted, 9 responded to the questionnaire (18% participation rate). One of the persons contacted replied stating that the online media news about her firm using BCT for supply chain traceability referred to a pilot project which was then discontinued. Given the limited number of respondents, it was not necessary to use statistical analysis tools to analyse the results. Counting the number of responses was done in Excel.

This study has some limitations. First, the adopters to be surveyed were individuated with searches on the web and LinkedIn social network, so the study may have excluded those that have no online presence. Second, this survey does not count how many firms were using BCT and stopped, so it is limited to the ones that continued using it or just started. Third, only 9 adopters out of 52 participated in the survey, thus, the results of the survey cannot be generalised to all the adopters in Italy. The limited number of respondents does not make it possible to find statistically meaningful correlations between the answers. Finally, the survey is not based on business data such as revenues, profit, number of products sold, costs of the blockchain solution per amount of traceability data stored; thus, the answers given to the question assessing the influence of blockchain services on the firm may only reflect the perception of the respondents rather than the reality.

3.2.2 Discussion of the survey results

Table 3 shows that most of the respondents (5) are from micro-sized companies, followed by small (2) and medium-sized (2) companies. Only one large company participated in the survey. This distribution may be reflective of the broader business landscape in Italy, where micro and small enterprises form a significant portion of the economy (in 2021, micro-sized enterprises accounted for 95% of the total number of enterprises in Italy, while small were 4,3%, medium 0,5%, and large 0,1%)[10].

Table 3 Adopter firms' size

Adopters' size	**N. of responses**
Micro	5
Small	2
Medium	2
Large	1

Seven firms out of ten are in the agri-food sector, two are in the furniture sector, and one is in fashion (including textile. clothing, and footwear) (Table 4). These represent three of the four typical sectors of the

10 Author's elaboration on data by ISTAT, "Imprese e addetti", http://dati.istat.it/Index.aspx?DataSetCode=DICA_ASIAUE1P

Made in Italy, which are food, fashion, furniture, and instrumental machinery (Maghssudipour et al., 2023).

Table 4 Adopter firms' sector

Adopters' sector	N. of responses
Agri-food	7
Furniture	2
Fashion (textiles, clothing, footwear)	1

Half of the adopters sell B2C, the other half B2C and B2B, and none B2B only. Also, as shown in Table 5, half of the adopters sell their products predominantly abroad and marginally in Italy, while less than half focus on the domestic Italian market with marginal international sales; only one adopter sells exclusively in the Italian market.

Table 5 Adopter firms' product destination markets

Adopters' products destination markets	N. of responses
Mainly abroad, marginally Italy	5
Mainly Italy, marginally abroad	3
Only Italy	2

The trend in the adoption of blockchain services for SC traceability is recent, as shown in Table 6, with most companies having started using it in and after 2020, and just one in 2018.

Table 6 Year in which the respondents adopted BCT for supply chain traceability

Year of blockchain adoption	N. of responses
2023	1
2022	3
2021	3
2020	2
2019	0
2018	1

The respondents were then asked to state the influence of the blockchain services they use on their business on a scale from “very negatively” to “very positively”, with the possibility of answering “I don’t know” (Table 7). The influence areas are based on the findings the paper by Testi (2023) on which the first study of the present chapter is based. The total positive perception for each influence area was calculated by summing the number of answers “positively” and “very positively” of an area and dividing them by 10, which is the number of respondents. The table shows that 90% of the adopters perceive that the blockchain services they use for supply chain traceability have a positive influence on the trust that customers have in the adopters’ products. Next, 80% declared that BCT had a positive influence on brand awareness and the trust that firms downstream the supply chain (distributors, retailers, etc.) have in the adopters, while 70% believe that there was a positive effect on the price that customers are willing to pay for their BCT-traced products. Further, 60% of the respondents considered as positive the impact of the blockchain service on the time spent in traceability processes and trust towards suppliers and companies downstream of the supply chain. Only 50% saw a positive impact on the trust that suppliers have in the adopters, and 40% on the simplification of product checks by certifiers and authorities and the number of products sold. Interestingly, on the B2C marketing side of the use of BCT services for traceability, it seems that the positive impact is concentrated around increased customer trust (90%) and the price that customers are willing to pay (70%), possibly indicating a benefit in terms of brand loyalty. However, it seems that the positive effect on brand awareness (80%) does not have an equally positive impact on the number of products sold after the implementation of BCT (40%). These findings show that the BCT services used by the adopters impact positively B2C marketing areas, more than areas concerning trust among supply chain partners or efficiency. The findings are consistent with the use, by Italian adopters, of BCT for supply chain traceability for B2C marketing tool more than to enable trust in supply chains, as previously found by Testi (2023).

Additional advantages of the blockchain service for supply chain traceability mentioned by the respondents are to promote the true products from the Italian supply chain (i.e., the Made in Italy), increase transparency, and simplify data collection for future Digital Product Passport legislation.

No disadvantages or damages to the firms' business were reported by the respondents. For most of the aforementioned areas, no respondents indicated a negative influence of blockchain services, meaning that when the impact was not positive, it was not negative either. Only one respondent mentioned a negative effect of using the blockchain service on the time spent in the traceability processes. However, some respondents did not know how to respond to the question, which may indicate that they could not assess the impact of BCT in the business processes analysed.

Table 7 The adopters' perception of the influence of blockchain services on their business

Influence area	Don't know	Very negatively	Negatively	Neither positively nor negatively	Positively	Very positively	Total positive perception*
Customer trust in products	0	0	0	1	6	3	90%
Brand awareness	1	0	0	1	5	3	80%
Trust from downstream companies	1	0	0	1	7	1	80%
Price customers are willing to pay	0	0	0	3	5	2	70%
Time spent in traceability processes	0	0	1	3	4	2	60%
Trust towards suppliers	2	0	0	2	4	2	60%
Trust towards downstream companies	2	0	0	2	5	1	60%
Trust from suppliers	2	0	0	3	2	3	50%
Simplification of product checks by certifiers and authorities	2	0	0	4	1	3	40%
Number of products sold	0	0	0	6	2	2	40%

** The total positive perception for each influence area was calculated by summing the number of answers "positively" and "very positively" of an area and dividing them by 10, which is the number of respondents.*

Aside from their positive perception, do the adopters have the means to assess if the blockchain service they are using is convenient for them? The firms were asked if they have access to the data on the performance of the blockchain service they are using (e.g., how many consumers scanned the QR code on the products' labels) (Table 8). Three adopters out of ten can access such data at any time, without intermediaries, allowing them to monitor constantly the performance of the blockchain service and make decisions accordingly. Four adopters must first ask the providers to access the data. The difference between having direct access or having to ask the providers may seem unimportant; however, it exposes adopters to the risk of being frauded by the providers who may send them false data overestimating the performance of the blockchain service (e.g., reporting a higher number of scans of the QR code on the products' labels). Furthermore, two adopters stated they cannot access the data, meaning that they need to trust completely what their providers tell them about the performance of the blockchain service.

Table 8 Adopters' access to data on the performance of the blockchain service they use.

Adopters' access to data on the performance of the blockchain service	**N. of responses**
Yes, the firm has direct access to data at any time	3
The data are kept by the service provider and are accessible to the firm on request	4
No, the firm cannot access that data	2
Still to be defined	1

Remarkably, only two adopters use the data about the performance of the blockchain service to make business decisions (Table 9). This may hint to a lack of awareness of the importance of data about actual or potential customers, or maybe to the lack of easy access to such data, or that the data provide no relevant information.

Table 9 Adopters' use of the data about the performance of the blockchain service to make business decisions.

Company use of data on the performance of the blockchain service to take business decisions?	N. of responses
Yes	2
No	6
I don't know	2

The final question asked if the adopters intended to continue to use the blockchain services for traceability in the next 3 years (Table 10). Eight responded affirmatively, one of which remarked that the customers demand it and one other that the service will be necessary for future Digital Product Passport legislation. One respondent will continue to use blockchain services depending on the management costs, while one respondent who is using a free blockchain service will use it as long as it remains free, anticipating the intention to stop using it once the free trial is finished.

Table 10 Adopters' intention to continue using the blockchain services in the next 3 years.

Intention to continue to use blockchain in the next three years	N. of responses
Yes	8
Depends on management costs	1
Will use it as long as the service is free	1

In sum, the findings show that adopters perceive a positive impact of BCT on areas of B2C marketing such as customer trust, brand awareness, and brand loyalty, that may impact on the price that consumers are willing to pay for the BCT-traced products. Instead, it does not seem that BCT impacts much on an increase of the number of products sold. Additionally, perception of the usefulness of BCT to enable trust among supply chain partners is less perceived as a benefit. Finally, only a limited number of firms have access to and actively use the data about the performance of the BCT service for business decision-making.

CHAPTER IV - THE ADOPTION OF BLOCKCHAIN FOR TRACEABILITY IN ITALY: DYNAMIC CAPABILITIES AND LEGAL CHALLENGES

This chapter explores the dynamic capabilities as enablers, and legal challenges as barriers, to the adoption of BCT for traceability in Italy. The first study in this chapter focuses on individuating the enablers in the form of the adopters' dynamic capabilities, finding that enabling capabilities include a high education level, openness to innovation, and exposure to external expertise in the form of consultants and BCT providers. The findings show that most firms relied on consultants to know about BCT and choose the right provider. The chosen provider then managed the implementation of BCT in the firm. This reliance on external sources may indicate a weakness of the firms' sensing and seizing capabilities. As for the transforming phase, the adoption of BCT did not necessitate a transformation of competencies or supply chain processes, and thus, did not have a noticeable impact on the firms' dynamic capabilities. The second part of the chapter examines the legal challenges of BCT and BCT-enabled smart contracts and NFTs in the European Union, Italy, and the Marche Region. It highlights the difficulty of integrating BCT within existing legal frameworks, especially considering the GDPR. Then, it analyses the legal recognition of smart contracts and NFTs, noting the Italian legal system's struggle to adapt traditional legal principles to these new technologies.

4.1 Adopters' dynamic capabilities and the role of consultants

A relevant field of study is that of BCT for managing supply chains; research has focused on the benefits and challenges of adopting BCT to trace products (Akhtar et al., 2021; Chen et al., 2021), as well as the drivers and barriers to the firms' intention to use it (Kouhizadeh et al., 2021; Moretto & Macchion, 2022).

The use of BCT for supply chain traceability has been identified as pivotal for Italian SMEs to valorise their products and protect them from counterfeiting (Bianchini & Kwon, 2020). However, very little is known about how Italian SMEs identify BCT as a potentially useful technology for supply chain traceability, seize its opportunities, and align it with the firms' existing systems, processes, and strategies. The only research addressing the topic is that by Galati et al. (2021), who conducted a multiple case study on three Italian wineries that implemented BCT to notarize their products' traceability data on blockchains. Thus, the present study aims to add more evidence on the topic by applying the dynamic capabilities (DCs) theory (Teece, 2007) to the adoption of BCT for supply chain traceability in Italian SMEs.

DCs involve three activities: sensing, seizing, and managing opportunities. In the context of technology adoption, these capabilities become critical as firms need to identify the potential of the technology (sensing), take actions to utilize it (seizing) and adapt their organizational structures and processes to incorporate the new technology (transforming). Sensing is the first stage, where the firm recognizes the potential of BCT for supply chain traceability. The firm learns about the existence of BCT, understands its benefits, and acknowledges its relevance to its business. In the following phase, the seizing, the firm has sensed the opportunity that BCT provides for supply chain traceability and decides to adopt the technology, choosing a suitable BCT provider and planning how the technology will be used within the firm. The final stage is transforming, which includes the actual implementation of the BCT within the firm. The transformation phase may involve integrating the new technology with existing systems, changing business processes, training employees, and managing change. In this phase, the firm might also have to reconfigure or reallocate resources and capabilities to support the new technology. After this final stage, the firm may have developed new DCs thanks to the adoption of BCT.

This study aims at answering three research questions, relative to the sensing, seizing, and transforming phases of BCT adoption for supply chain traceability in Italian SMEs:

RQ1: How do Italian SMEs sense, understand, and identify opportunities related to BCT for supply chain traceability?

RQ2: Once the opportunities related to BCT for supply chain traceability are identified, how do Italian SMEs seize them?

RQ3: After implementing BCT for supply chain traceability in the firm and seizing its opportunities, how do Italian SMEs transform and reconfigure their operations and processes to use this new technology effectively?

By conducting interviews with six Italian SMEs using BCT for supply chain traceability, this study uncovers the sensing, seizing, and transforming activities related to BCT adoption, contributing to understanding the intersection between DCs and the adoption of BCT for supply chain traceability. The findings of this study have implications for firms, policymakers, and researchers.

This paper is structured as follows. The theoretical framework section presents an overview of firms' DCs, specifically concerning technology adoption, providing context for the subsequent analysis. The last part of this section links these two concepts, framing the investigation into how firms' DCs influence their adoption of BCT. The method section outlines the research design and methodology used in the study, providing details about the data collection and analysis processes. The results section presents the findings of the study, which are then discussed in the following paragraph.

4.1.1 Theoretical framework: firms' dynamic capabilities in relation to blockchain technology adoption

DCs explain the differences across firms' ability to exploit opportunities (Teece, 2007) such as those brought by innovations (Ahmadi & Arndt, 2022). DCs are underpinned by organizational routines and managerial skills which help a firm sense future opportunities, seize them, and transform the firm to exploit these opportunities (Teece, 2018). Sensing capabilities are about scanning, identifying, and assessing strategically relevant information from outside the organization, like market trends, new technologies, best practices, and competitors' activities (Teece, 2007). Seizing means deciding whether the sensed information has a potential value, transforming it into concrete business opportunities that fit the organization's strengths and weaknesses, and making decisions accordingly, addressing the identified technological or marketing opportunities through developing, maintaining, and improving the firm's technological competencies as well as complementary assets (Teece, 1986). Transforming capabilities enable renewing company processes by assigning responsibilities, allocating resources, and ensuring that the workforce possesses the newly required knowledge so that the firm can benefit from opportunities already sensed and seized (Khurana et al., 2022; Teece, 2007). Researchers have explored the relationship between DCs and the adoption of digital technologies, which seems to be mutual: the adoption of digital technologies is enabled by their DCs (Shen & Wu, 2021), and, in turn, their implementation may lead to the development of new DCs in firms (McLaughlin, 2017). On the one hand, DCs help firms to embrace digital technologies (Khurana et al., 2022), guaranteeing their effective implementation (Galati et al., 2021) and enabling the firms' digital transformation (Warner & Wäger, 2019). On the other hand, the adoption of digital technologies may force firms to innovate their processes, contributing to the elevation of their DCs (Redwood et al., 2017) and consequently to the firms' performance and competitive advantage (Jiang & McCabe, 2021; Parida et al., 2016). The DCs of a firm, specifically sensing, seizing, and transforming, guide firms' adoption of digital technology. The first two processes, sensing and seizing, clearly involve a trajectory from the firms towards the technology. Sensing involves the firms actively monitoring and understanding shifts in the external technological environment, while seizing entails strategic decisions made by the firms to exploit the opportunities identified through sensing, including the adoption of specific technologies. The transforming phase, on the other hand, involves a more complex, bidirectional interaction between the firms and the technology. On one side, the firms direct change towards the technology, integrating it into existing systems, reconfiguring teams, or modifying roles to accommodate the technological change. Conversely, the adopted technology exerts influence on the firms' DCs, possibly necessitating the development of new competencies, reallocation of resources, or even adaptation of the firms' business model. Thus, the transforming phase signifies a reciprocal relationship where the firms shape how the technology is assimilated and utilized, while concurrently, the technology impacts the firms' DCs.

While the relationship between firms' DCs and digital technologies has been thoroughly addressed in the literature, evidence on the relation between DCs and BCT specifically is scarce. A search on Scopus conducted in January 2023 for peer-reviewed academic articles on DCs and BCT in the business and management research area gave only 12 results[11]. A screening of the articles' content revealed that many just mentioned BCT without investigating how its adoption in firms relates to their DCs. Among those that did investigate the adoption of BCT related to DCs, some addressed how firms' DCs influence BCT adoption, while others how BCT influences firms' DCs. Wamba & Queiroz (2022) found that the adoption of BCT in firms in India and the United States is favoured by top management's support and ability to identify (sense) and exploit (seize) new opportunities or ideas and, sometimes, its technical competence. Conversely, regarding how BCT transforms firms' DCs, Sharma et al. (2023) stated that BCT adoption strengthens firms' DCs to undertake proactive and innovative initiatives in an uncertain business environment, and Lambourdiere & Corbin (2020) found that BCT increases performance in maritime supply chains. Galati et al. (2021) conducted the only study, among those retrieved in the search on Scopus, that analyses both how firms' DCs help them sense and seize BCT and how BCT transforms the firms' DCs. Given the lack of academic literature on the topic, Galati et al. (2021) conducted a qualitative study to gather empirical evidence via a multiple case study. They surveyed three wineries in Italy that were using BCT for supply chain traceability to valorise their products and preserve their authenticity against counterfeiting. The results show that the three wineries possessed DCs that allowed them to rely on internal skills and external sources of knowledge when introducing innovations like BCT. In the sensing phase, the managers' in-depth knowledge of the competitive environment and high propensity for risk and innovation facilitated the selection of information relevant to the company and the introduction of BCT. New knowledge about BCT and its application to supply chain traceability has been acquired by relying on external expertise such as consultants and BCT providers. For seizing the opportunities given by BCT, the wineries, on the one hand, exploited the IT knowledge they already had on digital systems for traceability that made the adoption of BCT easier, on the other hand, relied on the external expertise of the providers of

11 The following search string was used: TITLE-ABS-KEY ("dynamic capabilit*" AND blockchain) AND (LIMIT-TO (SUBJAREA , "BUSI")) AND (LIMIT-TO (DOCTYPE , "ar"))

the BCT-based supply chain traceability systems. The transforming phase saw little changes in the firms' organizational structure. The three wineries foresaw no new hires for implementing and using BCT, just limited training sessions with the providers of the BCT-based supply chain traceability systems. Instead of incorporating the engineering function internally, they preferred to outsource the application phase of BCT to external providers with proven expertise. The three wineries invested more in knowledge acquisition (sensing) and internal assimilation (seizing), and less in transformation and exploitation of acquired knowledge preferring to outsource the application phase of BCT (transforming). The sensing, seizing, and transforming occurred in close collaboration with the providers of BCT, showing that the firms heavily relied on external expertise.

4.1.2 Method

Given the lack of evidence on the relationship between firms' DCs and the implementation of BCT, particularly when BCT is applied to supply chain traceability, this study aims to gather empirical evidence by conducting a multiple case study comparing Italian firms that implemented BCT for supply chain traceability. The multiple case study approach is an empirical inquiry that investigates a contemporary phenomenon within its real-life context (Palmberg, 2010) and is suited for addressing novel phenomena (Chetty, 1996) such as the use of BCT in firms.

A purposeful sampling approach based on similarity was adopted to identify all cases that met a predetermined criterion of importance (Palinkas et al., 2015), i.e., cases of firms that implemented BCT for supply chain traceability. The cases were individuated through a web search using the keywords "blockchain" and "traceability" both in English and Italian language. Nineteen firms were identified. Potential interviewees were selected among the owners, CEOs, or the firms' employees in managing positions, since "the highest-order capabilities are those on which top management is (or should be) most focused" (Teece, 2018). All the nineteen firms identified were contacted and six of them accepted to be interviewed.

To collect data on cases, this study adopted a qualitative inductive approach with semi-structured interviews, which are particularly useful for understanding novel phenomena since they give the interviewer the possibility to ask open-ended questions and follow-up queries (Adams, 2015). An interview topical guide with a blend of closed and open-ended questions was created, without limitations in the number and order of questions, and with the possibility for the interviewer to ask additional why or how questions during the interviews, as recommended by Adams (2015).

The first set of questions regarded the firms' characteristics and the interviewees' positions. The information about the education level of the firms' owners and/or CEOs was collected (even though the interviewees may or may not be the owners or CEOs) because the education level of owners and managers gives them the ability to handle complex information, engage in boundary-spanning activities, and be more receptive to the adoption of innovations, which may be related to the sensing, seizing, and transforming capabilities of a firm (Døving & Gooderham, 2008). In particular, a bachelor's degree is an indicator that the individual possesses wider and more general knowledge and skills needed to develop and produce nonstandard services. The second set of questions was aimed at gathering insights into the firms' DCs. The questions addressed the sensing, seizing, and transforming phases separately and in this order to reflect the actual phases of implementation of BCT in firms. Indeed, as outlined by Teece (1986), the three phases are ordered chronologically: initially, a company senses opportunities, then seizes them and finally transforms itself to continue exploiting these opportunities.

Interviews were conducted conversationally with one respondent at a time. To present the results, case descriptions were developed based on transcripts of the interviews and notes from observations (Yin, 2018), and are presented in the results section of this study. The interviewees were assured that their identities would remain confidential, and as such, all gender-identifying information has been removed from the interview transcripts and each interviewee is referred to using the feminine third person ("she", "her") to ensure anonymity.

4.1.3 Results

This paragraph first presents the size, sector, and scope of BCT adoption of the firms interviewed, the interviewee's position, and the owners' and/or CEOs' education level, with Table 1 summarizing them. After the table is presented, the results of the interviews are reported.

As for the characteristics of the firms interviewed, four firms out of six are micro-sized, one is small, and one is medium. The small size of the firms is consistent with the fact that 95% of Italian firms are micro-sized (Osservatorio Innovazione Digitale nelle PMI, 2020). Coherently with the focus of this study, all the firms interviewed use BCT for supply chain traceability. In the cases of firms A, D, and E, the owner and/or CEO were interviewed. Instead, for firms B, C, and F, employees in managing positions who followed the adoption process of BCT in the firm were interviewed. The results show that the owners' and/or CEOs' educational level is relatively high (one interviewee has a high school diploma, two have a Bachelor's Degree, three have a Master's Degree), considering that in Italy, in 2021, 62.7% of people aged 25-64 had a high school diploma versus 79.3% in the EU27 countries, and 20% of them had a university degree versus 33.4% in the EU27 (ISTAT, 2022). Table 1 summarizes the size, sector, and scope of BCT adoption of the firms interviewed, the interviewee's position, and the owners' and/or CEOs' education level.

Table 11 Details of the firms' size, sector, and use of BCT, interviewees' position in the firm, and education level of the firms' owners and/or CEOs

Firm	**Size**	**Sector**	**Scope of BCT adoption**	**Interviewee's position in the firm**	**Education level of owner and/or CEO**
A	Micro	Agrifood	Supply chain traceability	Owner and CEO	Master's Degree
B	Micro	Agrifood	Supply chain traceability	Production Manager	Bachelor's Degree
C	Micro	Agrifood	Supply chain traceability	General Manager	Bachelor's Degree
D	Micro	Agrifood	Supply chain traceability	Owner and CEO	High school diploma

E	Small	Furniture	Supply chain traceability	Owner and CEO	Master's Degree
F	Medium	Agrifood	Supply chain traceability	Marketing Manager	Master's Degree

The sensing, seizing, and transforming DCs of these firms in the adoption of BCT for supply chain traceability are described below.

Firm A is a micro-sized, innovative start-up in the agri-food sector. The interviewee is the owner and CEO. She holds a master's degree in civil engineering and has experience as a project manager and technical director in various companies. Her technical expertise enabled her to comprehend the workings of BCT and its benefits for supply chain traceability and select the most suitable BCT solution provider in Italy. She first learned about BCT through media news and discovered its potential for supply chain traceability during her MBA, when she attended a presentation by the CEO of a company providing BCT-enabled traceability solutions. Subsequently, she reached out to the provider, expressing her intent to create an innovative start-up utilizing BCT for supply chain traceability, after which the provider implemented BCT in Firm A. It is necessary to have just basic IT knowledge to upload the data on the blockchain through the provider's platform, thus, the interviewee did not have to develop additional skills.

Firm B is a micro-enterprise in the agrifood sector that utilizes BCT for supply chain traceability. The Production Manager was interviewed for this study. She stated that the owner of the firm became aware of the potential to use BCT for supply chain traceability through an external private consultant, with whom she was in contact. The interviewee mentioned that the owner's degree in economics has consistently helped the owner to be receptive to exploiting innovations. Nevertheless, it was the consultant who contacted the provider, and the BCT implementation in the firm's processes was carried out entirely by the provider. No changes were necessary in the traceability process, except for manually inserting the traceability data on the provider's platform.

Firm C is a micro-sized enterprise in the agri-food sector aiming to become an innovative SME, and as part of that goal, it has adopted BCT for supply chain traceability. The General Manager was interviewed. Firm C's owner has a bachelor's degree. The company discovered this technology by chance during a conversation with a PhD student who interviewed them for a research project. Afterwards, they independently searched online for providers and contacted one. The chosen provider's solution is user-friendly and did not demand the development of any further competencies to use.

Firm D is a micro-sized enterprise in the agri-food sector, producing high-quality DOP oil and primarily selling through Amazon e-commerce. The owner and CEO, who was interviewed, has a high school diploma. She learned about BCT for supply chain traceability by attending a webinar on export and digitization. At the end of the webinar, participants had the opportunity to express interest in connecting with the consultants who had led the sessions, and the interviewee did. The consultant then introduced the owner and CEO to a BCT provider who supplied the platform for supply chain traceability. The owner and CEO personally uploads the traceability data on the provider's platform so that they can be notarized in the blockchain. She did not have to learn additional skills to use BCT.

Firm E is a small enterprise in the furniture industry that uses BCT to notarize supply chain traceability information on non-fungible tokens (NFTs) for Life Cycle Assessment (LCA) and counterfeiting protection. The firm has been family-owned for three generations, with the current owner and CEO being the third generation. When she was interviewed, she shared that her grandfather and father both embraced innovation and passed on this open-minded approach to her, thus, she is always on the lookout for new technologies, and she discovered BCT through a consultant with whom she was already collaborating. She has a master's degree which may have helped her understand the marketing implications of using BCT to trace the firm's products. The consultant contacted a BCT provider that implemented the technology in the firm. No transformations were deemed necessary in the firm's processes.

Firm F is a small enterprise in the agrifood sector with a strong focus on export. They use BCT to notarize their products' traceability information as a countermeasure against counterfeiting. A large consultancy firm they were collaborating with introduced them to BCT for marketing purposes, persuaded them to adopt it and oversaw the implementation of the blockchain solution by a provider within the company. The interviewee is the Marketing

Manager of Firm F. She and her team, including the owner and CEOs, all consisting of highly educated individuals with master's degrees, evaluated the use of BCT and monitored its implementation process. The product traceability data is automatically uploaded from their ERP system to the blockchain through the provider's platform, thus, it was not necessary to learn new competencies to be able to use the blockchain.

Table 12 summarizes the various ways in which firms have discovered, adopted, and integrated BCT for supply chain traceability.

Table 12 The sensing, seizing, and transforming phases of the DCs for each firm.

Firm	Sensing	Seizing	Transforming
A	Learned about BCT through media.	The owner and CEO contacted a BCT provider.	The BCT solution was implemented by the provider. No new capabilities were developed in the firm.
B	Introduced to BCT by an external private consultant	The external consultant contacted the BCT provider, which handled the implementation of BCT in the firm.	No additional competencies were developed to accommodate the use of BCT.
C	Discovered BCT during a conversation with a PhD student.	Conducted a web search to find and contact a suitable BCT provider, which implemented BCT in the firm.	The blockchain solution is user-friendly and does not require high IT skills, so no new skills were developed.
D	Attended an export and digitization webinar where BCT was presented.	Expressed interest in BCT and was introduced to a consultant who then contacted a provider which implemented BCT.	No additional skills are required to upload the traceability data on the blockchain.
E	Learned about BCT through a consultant.	The consultant introduced BCT in the firm with the help of a BCT provider.	No transformations were deemed necessary in the firm's supply chain processes.
F	Collaborated with a consultancy company which introduced them to BCT and convinced them to implement it.	The consultancy firm contacted a BCT provider which implemented the technology.	The firm did not have to transform its processes since the traceability data are automatically uploaded from its ERP system to the blockchain.

4.1.4 Discussion

Some insights can be drawn from the results about the sensing, seizing, and transforming phases of Italian SMEs adopting BCT for supply chain traceability.

Regarding RQ1 (how do firms sense, understand, and identify opportunities related to BCT?), the firms got to know BCT during seminars or webinars, or from external consultants and consulting firms. This may indicate that the firms are open to learning from various external sources, which can be seen as a strength as it widens their scope of learning and discovery. However, the firms may also be heavily reliant on external expertise for sensing technological changes, and particularly on consultants who may have a conflict of interest in proposing BCT, which might also point to potential weaknesses in the firm's sensing capabilities.

Likewise, regarding RQ2 (once opportunities related to BCT are identified, how do firms seize these opportunities?), in most cases, providers chosen by the consultants managed the technical implementation of BCT.

Finally, to answer RQ3 (after seizing BCT opportunities, how do firms transform and reconfigure their operations and processes to integrate this new technology effectively?), it seems that no transformation of the firms' internal capabilities or processes was necessary to use BCT. This is primarily due to the involvement of BCT providers in implementing and integrating the technology into the firms' supply chain processes. Thus, the effect of BCT implementation on the development of additional DCs was none.

Similarly to the multiple case study conducted by Galati et al. (2021) on three Italian wineries using BCT for supply chain traceability, the results show that firms are more invested in knowledge acquisition (sensing) and assimilation (seizing) and less in transformation and exploitation of acquired knowledge (transforming). Also, they prefer to outsource the implementation phase of BCT and rely on external expertise through all the phases of sensing, seizing, and transforming.

However, this study also uncovers a potential positive effect of the advanced educational qualifications of the firms' owners and/or CEOs on the successful adoption of BCT. The high education levels of owners or leaders, coupled with an openness to innovation and exposure to external knowledge sources, may be factors influencing positively the adoption of BCT. Firm A's adoption of BCT was facilitated by the owner and CEO's technical background in civil engineering, experience as a project manager, and MBA education. Her exposure to BCT during his MBA program enabled him to understand its potential for supply chain traceability and choose the right BCT solution provider. Similarly, Firm B's adoption of BCT can be attributed to the owner's degree in economics and the external private consultant who informed them about the potential of BCT in traceability. Firms C, D, and E also benefited from their exposure to BCT through external sources. Firm C's adoption of BCT was initiated by a conversation with a PhD student, while Firm D learned about BCT through an export and digitization webinar. Firm E's adoption of BCT was influenced by the multi-generational approach to innovation and the guidance of a consultant with whom the firm was already collaborating. Firm F's adoption of BCT was driven by their collaboration with a large consultancy company that introduced them to BCT for marketing purposes. The highly educated team at Firm F, consisting of individuals with master's degrees, facilitated the implementation of the blockchain solution by the provider.

The results of this study suggest that DCs play a significant role in driving the adoption of BCT for supply chain traceability. These capabilities include a high education level, openness to innovation, and the exposure to external resources and expertise. Consultants play a crucial role in the adoption of BCT for supply chain traceability in these firms. They act as knowledge brokers, introducing firms to the technology and its potential applications, helping firms understand the benefits of using BCT for supply chain traceability, and guiding them in selecting the right BCT provider. Additionally, consultants can assist in the implementation process by working with the chosen provider and ensuring a smooth integration of the technology into the firm's processes. Consultants and BCT providers facilitate BCT adoption which is particularly valuable for firms lacking in-house knowledge of this technology. However, firms should beware of relying too much on consultants and providers who may have a conflict of interest in proposing to implement BCT.

Nevertheless, the results of this study cannot be generalised. First, because only six firms accepted to be interviewed. Second, these firms are all very similar to each other and do not represent the diversity of the Italian entrepreneurial landscape: they all use BCT for supply chain traceability, excluding other applications (e.g., accounting, value exchange, governance); they are similar in size, since four out of six are micro-sized and there are no large enterprises; most of them operate in the same economic sector since five out of six are in the agri-food sector.

4.2 Legal challenges of blockchain in Europe, Italy, and the Marche region

In recent years, researchers have warned about the lack of clear legal frameworks on BCT (Iftekhar et al., 2020) which bring regulatory uncertainty (Hackius and Petersen, 2017) that can negatively affect BCT adoption (Allen et al., 2019). As of today, at the European Union (EU) level, there is no clear legal framework regarding BCT but only a general strategy by the European Commission (EC) to promote, among other things, legal certainty with a pro-innovation legal framework[12]. For example, the EC's study on smart contracts and the digital single market suggests a "law + technology" approach to develop solutions that encourage the evolution of smart contracts, rather than hindering it, in a direction that preserves and reinforces the DSM[13]. The EC launched the European Blockchain Regulatory Sandbox[14], a pan-European framework aimed at fostering regulatory dialogues and increasing legal certainty for innovative blockchain solutions. Given the importance of basing the legal frameworks on the concrete use of BCT, the sandbox supports projects including public sector use cases on the European Blockchain Services Infrastructure (EBSI)[15]. This lack of legal clarity at the EU level is reflected at the national level in Italy and the regional level in the Marche Region.

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12 European Commission, "Blockchain Strategy", https://digital-strategy.ec.europa.eu/en/policies/blockchain-strategy

13 European Commission, "Smart contracts and the digital single market through the lens of a "law plus technology" approach", https://digital-strategy.ec.europa.eu/en/library/smart-contracts-and-digital-single-market-through-lens-law-plus-technology-approach

14 European Commission, "European Blockchain Regulatory Sandbox", https://digital-strategy.ec.europa.eu/en/news/launch-european-blockchain-regulatory-sandbox

15 European Commission, "European Blockchain Services Infrastructure (EBSI)", https://ec.europa.eu/digital-building-blocks/wikis/display/EBSI/Home

4.2.1 The problematic relationship between blockchain and the GDPR

Although Italy has not yet introduced blockchain-specific regulations, companies should ensure that they comply with existing laws when using BCT. As reported by The European Union Blockchain Observatory & Forum (2019), in the European Union BCT is subject to the General Data Protection Regulation (GDPR) which poses a challenge for BCT due to its decentralized and immutable nature.

The European Commission, recognizing the profound impact of digital technology on personal data collection, usage, and access, introduced the General Data Protection Regulation (GDPR) (EU) 2016/679 on May 25, 2018[16]. As explained by Voigt & Von Dem Bussche (2017), this regulation, aimed at addressing the limitations of Directive 95/46/EC, seeks to standardize data protection laws across the EU and enhance the privacy and data protection for individuals, defining the requirements that organisations must follow for personal data processing. GDPR identifies three primary roles: the data subject who owns its data, the data controller who decides the purpose and method of processing personal data and is the primary accountable entity under GDPR, and the data processor who processes personal data on behalf of the controller. The GDPR acknowledges user consent as a valid basis for data processing and grants several rights to data subjects, including the right to rectification, access, erasure, and rights related to automated processing.

GDPR applies to all organizations processing the personal data of EU citizens, regardless of their location; however, the lack of transparency makes it difficult for data subjects to ascertain whether their data is being handled in full compliance with GDPR (Tikkinen-Piri et al., 2018). The challenge of informed consent, explained by Javed Ahmed et al. (2020), highlights the complexities of consent for personal data processing, a critical requirement under the GDPR, which aims to ensure that data subjects have full control over their data. Any GDPR-compliant mechanism should inherently possess transparency and auditability, enabling data subjects to monitor the collection

16 EUR-Lex, "General data protection regulation (GDPR)", https://eur-lex.europa.eu/EN/legal-content/summary/general-data-protection-regulation-gdpr.html, last update 07/01/2022, accessed 12/12/2023

and processing of their data by controllers or processors. Transparency in data collection, processing, and sharing is crucial to achieve GDPR compliance. BCT is suggested as a potential aid in providing the necessary transparency for personal data processing and sharing.

However, BCT characteristics, such as data immutability, public accessibility to data, and decentralized control, pose challenges to compliance with GDPR requirements such as the right to be forgotten and data minimization. As noted by Javed Ahmed et al. (2020) blockchain's immutability, a key feature ensuring data integrity, conflicts with the GDPR's right to erasure. The GDPR's right to erasure only includes personal data, including pseudonymized data like encrypted data, while completely anonymized data falls outside this scope. Techniques mentioned by Javed Ahmed et al. (2020) to enable data personal data erasure involve data obfuscation, encryption, and aggregation to transform personal data into digital signatures, linked cryptographically to the original data without revealing it. Notable proposals include a "forgetting blockchain" design for permissioned blockchains, facilitating data erasure while retaining key blockchain features, and a modular architecture ensuring GDPR compliance by enabling the right to be forgotten. Another solution mentioned by Javed Ahmed et al. (2020) would be that of using off-chain storage, where the personal data are stored in a centralised database while only their hashes are uploaded to the blockchain to identify the data and check its immutability in time. Such data can be modified or eliminated to preserve people's rights given by the GDPR. Javed Ahmed et al. (2020) also warn that the GDPR considers public keys as personal data, raising issues about their treatment as anonymous or pseudonymous data. To qualify as anonymous, a public key must irreversibly prevent the identification of a specific data subject. Since blockchain history shows that identification is possible through additional information, public keys are considered pseudonymous under GDPR. Designing GDPR-compliant solutions for public keys is complex, as they are integral to blockchain transactions and cannot be put off-chain like transactional data. Techniques for anonymizing public keys include mixing services, ring signatures, and zero-knowledge proofs (Chiarini & Compagnucci, 2022).

Another challenge for the compliance of BCT with the GDPR is individuating data controllers and processors in blockchains (Javed Ahmed et al., 2020). The data controller, accountable in the GDPR's legal framework, is responsible for determining the purposes and means of processing personal data. The data processor processes personal data on behalf of the data controller, adhering to their instructions. The processor must implement measures to safeguard data against unauthorized access and accidental loss or damage. However, identifying data controllers and processors is not straightforward with BCT due to its decentralized nature. As noted by Javed Ahmed et al. (2020), if the community collectively decides on the validation rules of the blockchain, all nodes may be considered joint data controllers, sharing compliance responsibility. Alternatively, if validators contribute to the blockchain without participating in defining validation rules, they are regarded as data processors. Anyway, the GDPR requires that companies ensure that the personal data they collect is processed lawfully, fairly, and transparently, therefore, companies as data controllers should ensure that they have a legal basis for the processing of personal data on the blockchain. One way for companies to comply with the GDPR is to use permissioned blockchains. As Lo Sapio (2023) noted, permissionless blockchains are inherently decentralized and open, lacking a central authority and allowing anyone to participate in the network and validate transactions, raising concerns about trust and security, where centralized control is necessary to ensure network security and reliability. In permissionless blockchains, it's challenging to pinpoint a specific data controller because every node in the network can potentially read, write, and participate in the consensus process. In contrast, permissioned blockchains are more centralized and controlled, permitting only a select number of authorized participants to validate transactions. This structure aligns better with demands for higher control and accountability (Chiarini & Compagnucci, 2022).

4.2.2 The legal framework on blockchain technology in Italy and the Marche Region

On its part, the Italian legislator has tried to give a first definition of DLT and smart contracts to regulate their use with Article 8-ter of DL

135/2018[17] titled "Technologies based on distributed ledgers and smart contracts".

Comma 1 defines "distributed ledger technologies" as the technologies and computer protocols that use a shared, distributed, replicable, simultaneously accessible, and architecturally decentralized register based on cryptographic principles. These technologies enable the recording, validation, updating, and storage of data, which can be either in plain text or further protected by verifiable cryptography, unalterable, and non-modifiable. Vulpiani (2021) noted that the article does not mention blockchain technology specifically. Moreover, as Carrière et al. (2023) explained, this definition makes the regulation inapplicable in cases where data modification is possible under predetermined conditions, for example in the case of permissioned DLTs.

Comma 2 defines a smart contract as a computer program that operates on technologies based on distributed ledgers and automatically binds two or more parties upon execution, based on predefined effects agreed upon by the parties. The regulation also clarifies that a smart contract satisfies the written form requirement in cases where the involved parties are previously identified electronically, through a process whose requirements are set by AgID (Agenzia per l'Italia Digitale, or Agency for Digital Italy).

Comma 3 states that the storage of an electronic document using DLTs produces the legal effects of electronic time validation, as outlined in eIDAS, Article 41 of Regulation (EU) No. 910/2014 of the European Parliament and Council, dated July 23, 2014. However, there may still be questions about the admissibility of such documents as evidence in court proceedings. Courts may need to consider factors like the integrity of the document, the authenticity of the time validation, and the reliability of the DLT used. Indeed, Comma 1 applies to permissionless ledgers, excluding permissioned ledgers which could allow the modification of data by qualified nodes or through the collusive agreement of a certain number of them. Consequently, the authors

17 Legislative Decree No. 135 of 14 December 2018, converted into law with Law 11 February 2019, n. 12, published on the Gazzetta Ufficiale della Repubblica Italiana, https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2019-02-12&atto.codiceRedazionale=19A00934&elenco30giorni=true

argue, a legal distinction would be created regarding data saved on different ledgers, since some would be granted full evidentiary value, while others would not (Carrière et al., 2023). This definition makes the regulation inapplicable in cases where data modification is possible under predetermined conditions.

Finally, Comma 4 states that the AgID is required to identify the technical standards that distributed ledger technologies must possess to produce the effects mentioned in Comma 3. In practice, the AgID's rules establish the technical standards that blockchains must comply with to produce the legal effects of electronic time validation, under European and national regulations, as well as the identification procedures for the parties involved in a smart contract. However, no guidance has been provided yet by the AgID, the absence of which continues to cause inconvenience for interpreters and economic operators (Rigazio, 2021). This did not stop the AgID from launching a project in 2021 for the creation of the Italian infrastructure IBSI (Italian Blockchain Service Infrastructure)[18] which sees the participation of public entities, universities and economic operators to promote the development of public utility services through the use of BCT (La Selva, 2022).

Cascinelli et al. (2019) emphasize the challenges related to introducing DLTs and smart contracts into the Italian legal system. They note the difficulty in providing a clear and comprehensive definition for these evolving technologies due to the lack of universal consensus. Additionally, they stress the need for further guidelines regarding the practical application of new definitions introduced by the Simplification Decree.

Inside Italy, specifically in the Marche Region, Regional Law No. 36, dated July 30, 2020[19], focuses on the use of DLT, including blockchain, for certifying public registers, ensuring traceability of local products, and incentivizing virtuous behaviours. The legislation aims to promote a multifunctional information platform that guarantees the security and control of data through an open, shared, transparent, secure, and immutable public

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18 IBSI Italian Blockchain Service Infrastructure, https://progettoibsi.org/

19 Consiglio regionale delle Marche, Legge regionale n. 36 del 30/07/2020, https://www.consiglio.marche.it/banche_dati_e_documentazione/leggi/dettaglio.php?idl=2174

register, utilizing non-erasable cryptographic language. The law particularly supports the application of this service to areas such as national and European funds, financing through calls for proposals, public tenders, waste management, tourism, public and private transportation, and the health system. The platform is also intended to be used for regional products, particularly certified agri-food products, to provide access to information on origin, nature, composition, and quality, as well as to promote local production throughout the entire supply chain. Finally, it encourages virtuous behaviours by citizens, which, once certified, may be rewarded by the region. Specifically, the law incentivizes virtuous behaviours related to public transportation usage, urban and special waste management, circular economy principles, and eco-friendly practices. However, it is not clear if and how this law has impacted the activities of firms and public administration and, more broadly, the lives of citizens in the Marche Region.

4.2.3 Legal aspects of smart contracts in Italy

Article 8-ter of DL 135/2018[20] of the Italian legislation defined smart contracts as "a computer program that operates on technologies based on distributed ledgers and whose execution automatically binds two or more parties based on effects predefined by them." Fortuna (2021) notes that while Italian lawmakers have attempted to define smart contracts, their definition may be too broad and generic to be effectively applied in a legal context. Specifically, the author notes that the definition is based on a description of how smart contracts work in practice, rather than on legal principles governing contractual relationships. This could make it difficult to apply the definition consistently and effectively in legal disputes involving smart contracts. As Vulpiani (2021) explained, there are different doctrinal opinions regarding the classification of smart contracts within the classical concept of contracts. Some argue that smart contracts are not agreements themselves, but rather channels for concluding and managing agreements, while others

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20 Legislative Decree No. 135 of 14 December 2018, converted into law with Law 11 February 2019, n. 12, published on the Gazzetta Ufficiale della Repubblica Italiana, https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2019-02-12&atto.codiceRedazionale=19A00934&elenco30giorni=true

recognize smart contracts as having a contractual nature, thus subjecting them to the general rules of the Civil Code. Finocchiaro & Bomprezzi (2020) conducted a legal analysis of using blockchain technology for creating smart legal contracts, highlighting that smart contracts are not necessarily contracts themselves. Existing contract law rules can be interpreted to accommodate blockchain-based smart contracts, taking into consideration contract requirements such as agreement, intention, form, information requirements, and acknowledgement of receipt. General principles and rules of contract law can be adapted to this new context, as the issues raised by smart contracts are similar to those faced in electronic commerce. These issues include transitioning from paper to electronic documents, using non-standard ways to make contract proposals, addressing the lack of trust between parties, and difficulties in linking contractual will to precise identities. Consequently, there is no need for new ad-hoc rules for contract formation in the context of smart legal contracts, as analogous legal questions can be addressed with analogous legal solutions.

4.2.4 Legal Aspects of Non-Fungible Tokens

The European Commission's proposed regulation on crypto-assets markets (MiCA)[21] defines crypto assets as "digital representations of value or rights capable of bringing significant benefits to both market participants and consumers." It remains unclear whether this broad definition includes non-fungible tokens (NFTs) (Vulpiani, 2021). Moreover, as Vulpiani (2021) explained, NFTs can be traded worldwide, raising legal issues such as intellectual property protection, contractual rights, protection of weaker parties, and privacy concerns. It is essential to examine the legal nature of NFTs, questioning whether they fit within the classical concept of goods, qualifies as a complex contractual situation representing real or credit rights, serve as a credit title, or function as a financial instrument.

21 European Commission, Proposal for a Regulation of the European Parliament and of the Council on Markets in Crypto-Assets - Q3 2020, https://www.europarl.europa.eu/legislative-train/carriage/crypto-assets-1/report?sid=6901

4.2.5 Legal implications of using blockchain for traceability

Legislators have been unable to provide regulatory certainty on BCT for supply chains (Hackius and Petersen, 2017) and policy challenges including regulatory recognition and interoperability across jurisdictions can negatively affect BCT adoption, especially in global supply chains (Allen et al., 2019).

Decision No 768/2008/EC[22] sets a common framework for marketing and circulating consumer products in the EU, including traceability requirements. Manufacturers or importers must provide their company name, postal address, and product identification information on the product, packaging, or accompanying documents. They must also track all economic operators in the supply chain and maintain this information for at least 10 years, including suppliers, manufacturers, importers, distributors, and retailers. The European Commission's Blue Guide recommends keeping invoices and other relevant documents for achieving these goals.

Specifically on food traceability, Charlebois et al. (2014) gave an overview of food traceability regulations and requirements in the EU. Regulation (EC) No. 178/2002 serves as a reference point for food operators in Europe, laying down the general principles of food law and establishing the European Food Safety Authority (EFSA). The regulation aims to protect the health of European consumers and ensure the free movement of food products within the EU. Food business operators are obliged to store information on their direct suppliers and customers, such as goods purchased or sold, their relative quantities, and actors involved in transactions. Regulation (EU) No. 1169/2011, Article 9, defines the information required on food product labels, which is only possible with an effective traceability system throughout the agri-food chain. The lot definition is a crucial aspect of this, with Directive 2011/91/UE defining a lot as a batch of sales units of foodstuff produced, manufactured, or packaged under practically identical conditions.

Lattanzi & Mariani (2020) analysed the potential legal implications of BCT for supply chain traceability. Article 18 of the General Food Law (GFL)

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22 EUR-Lex, Decision No 768/2008/EC of the European Parliament and of the Council, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32008D0768

Regulation (EC) No. 178/2002 mandates traceability requirements, adopting a "one step back-one step forward" approach for food and ingredients in the EU market. Food business operators (FBOs) must identify their suppliers and recipients, while the burden of reconstructing the entire food chain during an incident is on authorities. The design of the traceability system is up to FBOs, and the level of detail they choose for internal traceability. A recent Fitness Check on the General Food Law Regulation highlighted the EU traceability system's effectiveness but identified areas for improvement, such as occasional interruptions in the traceability chain due to errors or incomplete documentation. BCT could help overcome traceability limitations and enhance its benefits. However, challenges such as data standardization, protecting intellectual property, establishing privacy mechanisms, and setting international common standards must be addressed through updated legal frameworks and digitalization strategies for agrifood businesses. This would create a better regulatory environment for incorporating blockchain in food law.

4.2.6 Discussion

The exploration of BCT, smart contracts, and NFTs in the EU, Italy, and the Marche Region, reveals a legal landscape that is still uncertain. The primary challenge lies in the integration of BCT within existing legal frameworks, particularly regarding data privacy as defined by the GDPR presents significant hurdles due to the decentralized and immutable nature of blockchains. Permissioned blockchains and off-chain storage emerge as potential solutions in this context. Permissioned blockchains, as opposed to permissionless ones, offer a more centralized and controlled environment. This structure is more conducive to legal compliance, particularly concerning the GDPR, as it facilitates higher control and accountability. Off-chain storage, where personal data are stored in a centralized database and only their hashes are uploaded to the blockchain, provides a practical workaround to the challenges of data immutability and the right to be forgotten by enabling data modification or deletion. The legal challenges extend to the implementation of smart contracts and the recognition of NFTs. The Italian legal system's broad and somewhat generic definitions of these concepts reflect the difficulty in applying traditional legal principles to these innovative technologies. The adaptation of existing laws, as seen with the Italian legislation on DLTs and smart contracts, indicates a willingness to evolve, but also underscores the need for more precise and comprehensive legal guidelines. In conclusion, the legal framework surrounding blockchain technology, smart contracts, and non-fungible tokens in the EU, Italy, and the Marche Region is still in its early stages, leaving several uncertainties and challenges for firms, policymakers, legislators, and researchers. Indeed, these actors are called to collaborate to address the legal challenges posed by BCT, with the help of other institutions that have technical knowledge. The need for this kind of collaboration is explored in the next paragraph.

CHAPTER V - THE ROLE OF TRIPLE HELIX ACTORS OF THE MARCHE REGION FOR BLOCKCHAIN KNOWLEDGE AND ADOPTION IN FIRMS AND INTEGRATION IN SMART CITIES

Since knowledge on the use of BCT for supply chain traceability in Italian firms is scarce and heavily influenced by providers and consultants, this chapter argues that triple helix actors and innovation intermediaries should be involved in the diffusion of knowledge on BCT in firms of the Marche region to foster its adoption. Since BCT is one of the innovative Industry 4.0 technologies, the first study aims to suggest measures to foster the knowledge and diffusion of BCT among Industry 4.0 technologies in the regional context through triangulation of data by combining second-hand qualitative data from a literature review, with data retrieved from the Web on the Marche region's policies, and first-hand data from an explorative qualitative survey to innovative firms that are part of a technological cluster in the Marche region. The findings of the survey indicate that collaborations, particularly with technology providers, universities, and government institutions, are vital for the successful implementation and use of I4.0 technologies, including BCT. Moreover, the findings indicate that collaborations with Digital Innovation Hubs are underdeveloped. In the second part, the chapter argues that institutions need to plan for the long-term use of BCT in tracking and tracing supply chains by integrating it in smart cities so that information from supply chains can be shared transparently with citizens, the government, and businesses.

5.1 A triple helix approach for increasing knowledge and adoption of blockchain in firms of the Marche region[23]

In recent years, several firms have embarked on a trend towards automation and data exchange in their business processes, known as Industry

23 This paragraph is based on a) Testi, N. (2023). A triple helix model for the diffusion of Industry 4.0 technologies in firms in the Marche Region. Open Res Europe; b) Testi, N.

4.0 (I4.0) (Colombo et al., 2014), which is "a revolutionary industrial concept of the production process in manufacturing, focused on new technologies that interconnect machines and equipment with digital data into automatic and intelligent systems" (Pech & Vrchota, 2020a). The technologies that constitute the pillars of I4.0 are the IoT, cloud computing, big data analytics, autonomous robots, simulation, additive manufacturing, horizontal and vertical integration, digital twins, cyber–physical systems, and cybersecurity (Erboz, 2017), augmented and virtual reality (Yagol et al., 2018), artificial intelligence (Javaid et al., 2022). Among the I4.0 technologies, BCT has recently emerged (Subic et al., 2018).

From a general standpoint, I4.0 technologies enable firms to adopt new business models (Moeuf et al., 2020) and gain competitive advantages (Bravi & Murmura, 2021; Masood & Sonntag, 2020). However, many firms, especially SMEs, have difficulties understanding and adopting innovative I4.0 technologies (Ghobakhloo et al., 2022; Pech & Vrchota, 2020b). Research demonstrated that a triple helix (TH) approach consisting of the collaboration between government, academia, and firms in a specific territory (Leydesdorff & Etzkowitz, 1998) can help with understanding innovative I4.0 technologies in firms and facilitating their diffusion (Cucculelli et al., 2022; Reischauer, 2018).

Recognising the lack of knowledge of BCT in Italian firms evidenced in Chapter III and the reliance of BCT adopters on providers' and consultants' knowledge of BCT in Chapter IV, the objective of this study is to suggest measures to increase the understanding of BCT in firms of the Marche Region by leveraging on TH actors. In this study, BCT is considered as one of the I4.0 technologies (Subic et al., 2018). In the Marche Region, many firms struggle to understand and implement I4.0 technologies (Cucculelli & Lena, 2017). The regional government is engaged in fostering the diffusion of I4.0 in firms of its territory and supports it concretely with tenders (Regione Marche, 2023a). Particularly, BCT has recently drawn the region's attention and has been addressed in both its technological road map (Regione Marche, 2021a) and Smart Specialisation Strategy (S3) (Regione Marche, 2023b).

(2022). A triple helix approach for the diffusion of blockchain technology against counterfeiting of Made in Italy products in SMEs of the Marche Region. International Journal of Current Science Research and Review.

Indeed, this study is part of an innovative PhD programme created by the University of Macerata, in Italy, and promoted by the Marche Region to strengthen the relationship between academic research and the local firms' needs, as part of the POR FSE 2014/2020 Axis 1- P.I. 8.1- R.A. 8.5 which is financed with European funds[24].

The measures suggested in this paragraph for the diffusion of I4.0, including BCT, in firms of the Marche Region, leverage collaborations between existing local TH actors and other innovation intermediaries that were individuated through an analysis of the regional context. Moreover, an explorative survey of local innovative firms that are part of an exemplary innovation cluster is conducted to strengthen the findings. The survey is based on the theoretical framework.

5.1.1 Theoretical framework

The term "Industry 4.0" was first proposed in 2014 referring to the fourth industrial revolution (Colombo et al., 2014), enabled by a group of technologies that interconnect machines and equipment through the internet into automatic and intelligent networks (Pech & Vrchota, 2020b). I4.0 technologies include big data analytics, augmented reality, simulations, collaborative robots, 3D printing, horizontal and vertical integration, the IoT, cloud storage and computing, and cybersecurity (Masood & Sonntag, 2020). I4.0 technologies enable firms, especially SMEs, to adopt new business models (Moeuf et al., 2020) and gain competitive advantages (Bravi & Murmura, 2021; Masood & Sonntag, 2020). Factors that limit the diffusion of I4.0 in firms are mainly related to the small size of the firms (Ghobakhloo et al., 2022; Pech & Vrchota, 2020b) and the lack of finances and specialized support in obtaining new technologies (Ingaldi & Ulewicz, 2019), technical and digital knowledge (Masood & Sonntag, 2020), and non-technical competencies (Cimini et al., 2020).

Among the I4.0 technologies, BCT has recently emerged (Subic et al., 2018). BCT is transversal to all the other I4.0 technologies since it can be

24 Università di Macerata, 2018, "Dottorati innovativi a caratterizzazione industriale", https://www.unimc.it/it/dottorato-di-ricerca/phd-e-ricerca-applicata/dottorati-innovativi-a-caratterizzazione-industriale

used together with each one of them (Fernández-Caramés et al., 2019; P. W. Khan et al., 2020). However, firms' digitalisation is a prerequisite for the adoption of BCT (Garrard & Fielke, 2020), missing which the adoption is hindered (de Boissieu et al., 2021; Sternberg et al., 2020). Moreover, the lack of clear regulations on BCT might discourage firms from using it (Alkhudary et al., 2020; Baharmand et al., 2021). Finally, BCT is still not well known to firms: Caldarelli et al. (2021) stated that training by an expert consultant is crucial for the successful adoption of BCT in firms, while an Italian provider of BCT services interviewed by Compagnucci et al. (2022) declared that firms, especially SMEs, need support in understanding which kind of BCT solution to adopt.

Collaboration can be a source of value co-creation in an I4.0 context (I. S. Khan et al., 2022) and encourages firms to adopt I4.0 business models (Cucculelli et al., 2022). The TH explains the positive effect of collaboration between academia, government, and firms in the economic development of territories (Leydesdorff & Etzkowitz, 1998). Academia generates basic scientific knowledge for industrial innovation (Gunasekara, 2006) and can help firms in their technological transformation also by training skilled managerial figures who have a strong effect on the rate of diffusion of digital technologies (Andrews et al., 2018). Governments play a key role by funding universities (A. Abbas et al., 2019) and making policies that support the adoption of I4.0 in firms (Luthra et al., 2020), whereas a lack of governmental support can hinder it (Pourmehdi et al., 2022). On BCT specifically, Compagnucci et al. (2022) suggest that national and regional institutions should support the adoption of BCT solutions through financial and organizational measures, promoting both the tools used to favour collaboration between firms, academia, and other institutions and those adopted to support the implementation of innovation.

Within a regional TH, some public and private organisations can facilitate the flow of knowledge and innovation. These are innovation intermediaries whose basic functions include process coordination and matchmaking between innovation seekers and potential solution providers, knowledge and finance brokering, and testing (Stewart & Hyysalo, 2008). They facilitate the exchange and the building of new knowledge, create opportunities for experimentation, and help form partnerships between private and public actors around common goals (Katzy et al., 2013). Since innovation intermediaries increase knowledge and resource flows amongst TH institutions and the rest of civil society (Barrie et al., 2019), a growing number of innovation policies rely on publicly-funded innovation intermediaries to provide knowledge-intensive services to firms, particularly SMEs (Russo et al., 2019).

5.1.2 Method

This study uses triangulation of data (Yin, 2018) by combining different sources, specifically second-hand qualitative data from a literature review, with data retrieved from the Web on the Marche region's policies, and first-hand data from an explorative qualitative survey.

A literature review was conducted to collect evidence on the relationship between the diffusion of I4.0 and TH. A search on Scopus was conducted in September 2022 using the keywords 'Industry 4.0' and 'triple helix' in the title, abstract, and keywords fields of peer-reviewed research papers. The search string used was the following: TITLE-ABS-KEY ("industry 4.0" AND "triple helix") AND (LIMIT-TO (DOCTYPE , "ar")). All years of publication were included to increase the inclusivity of results. Articles written in English were selected to avoid comprehension issues and increase the replicability of results by the international research community. The search gave only 13 results, showing that evidence on the topic of I4.0 and TH is scarce. All the articles retrieved are recent and demonstrate a growing interest in the relationship between I4.0 and TH: one was published in 2018, one in 2020, two in 2021, and nine in 2022. The abstracts and, when possible, the content of the papers were read to search for recurring themes. All the papers state that TH can help with the implementation and diffusion of I4.0. Table 1 shows the results highlighting the role attributed to the TH concerning I4.0.

Table 13 The scientific literature on the relationship between TH and I4.0

Author(s) and date of publication	**Methodology**	**Role of Triple Helix (TH) for Industry 4.0 (I4.0)**
(Reischauer, 2018)	Conceptual	Objective of policy-driven innovation discourse around I4.0.
(Steenkamp, 2020)	Conceptual	Create entrepreneurial leadership for innovation.
(Capetillo et al., 2021)	Case study	Evolving into a Penta Helix to foster the diffusion of I4.0 in firms.
(Majumdar et al., 2021)	Survey	Help overcome barriers to the implementation of I4.0 technologies in firms.
(AlMalki & Durugbo, 2022)	Interviews	Promote and enhance the co-evolution of institutions with technological I4.0 advances.
(Carayannis et al., 2022)	Conceptual	Offer references on how knowledge and innovation could proceed in co-evolution in the context of a knowledge economy.
(Costa et al., 2022)	Conceptual	Help develop teaching-learning processes which use I4.0 technologies.
(Cucculelli et al., 2022)	Survey	Counterbalance the lower propensity of family managers to adopt I4.0 business models.
(I. S. Khan et al., 2022)	Case study	Increase collaborative capabilities in an I4.0 ecosystem context.
(Lepore et al., 2022)	Case study	Enable innovation ecosystems for developing I4.0 solutions.
(D. Liu & Zhu, 2022)	Case study	Lead to a knowledge spillover effect in the field of I4.0 smart factories.
(Ojubanire et al., 2022)	Conceptual	Foster industrial I4.0 transformation.
(Tataj et al., 2022)	Case study	Help understand key success drivers that enable science parks to deliver outstanding results in I4.0.

Following a qualitative approach, the context of the Marche Region was analysed concerning the diffusion of I4.0 technologies, including BCT, among firms of the region, and policies addressing firms' innovation, by retrieving information from secondary sources and subjectively selecting the kind of information considered relevant for the topics addressed in terms of I4.0 and collaborations linked to the TH. Institutions and policies relevant to the diffusion of I4.0, such as the Marche Region's S3 for the two last programming periods (Regione Marche, 2019, 2023b), and tenders (Regione Marche, 2023a) were individuated by accessing the Marche Region's institutional website (Regione Marche, 2023d) and the Marche Innovazione website (Regione Marche, 2023c) on the 8th of October 2022. The Marche Innovazione website is the regional portal for disseminating and developing strategies for intelligent, sustainable, and inclusive economic growth in the region. It includes sources to the regional S3 and tenders of the two programming periods divided by research and development (R&D), investments, and internationalization. Additionally, web searches were conducted using the keywords "Industria 4.0 Regione Marche" between the 8th and 12th of October 2022, which allowed to recover institutional reports regarding the digital transformation of firms in the Marche Region (Camera di Commercio delle Marche & Università Politecnica delle Marche, 2021; Camere di Commercio d'Italia, n.d.; Ministero delle Imprese e del Made in Italy, 2023; Regione Marche, 2021b).

An explorative qualitative survey was sent on the 25th of October 2022 by sending an anonymous semi-structured questionnaire to all the firms with an active membership of the Fondazione Cluster Marche[25], which is a Foundation representing the Technology Clusters in the Marche Region. The Foundation's members were contacted for the survey since they are innovative firms located in the Marche Region that know or use I4.0 technologies and are valuable sources of information on the implementation of I4.0 technologies in business processes.

The questionnaire was built following a continuous feedback process with two experts in qualitative research methods, an expert in I4.0 technologies, and the representatives of the Fondazione Cluster Marche who

25 Fondazione Cluster Marche, https://cluster-marche.it/

gave the final approval to the questionnaire's content before sending it. The questionnaire was not piloted before this study. The questionnaire was in Italian language because it was addressed to native Italian speakers.

The questionnaire was sent by a representative of the Fondazione Cluster Marche via e-mail and was self-administered as the respondents filled it in themselves (Bruschi, 2005). Of the 149 firms to which the questionnaire was sent, seven compiled it, between the 25th and the 27th of October 2022.

The questionnaire's first section collected generic information about the firms, such as the size and economic activity classification. The second asked the respondents to state what I4.0 technologies were used in the firms and their knowledge and use of BCT. The third assessed the collaborations that the firms have or had concerning I4.0 technologies, dividing the collaborations per type and territorial level of collaboration partners. The fourth and final section addressed the respondents' perceived usefulness of some measures for the diffusion of I4.0 in firms in the Marche Region, leaving open questions for them to suggest initiatives additional to those indicated.

5.1.3 Results of the analysis of the Marche Region's context, key institutions, and policies

The Marche Region's economy is mostly based on clusters of SMEs (Cutrini et al., 2013). Cappelli (2020) noted that these firms specialised in the classic industries of the Made in Italy, for example, those of timber, furniture, leather, footwear, and household appliances. However, in these industries, the technological advantage gained does not always translate into an economic advantage due to the lack of complementary skills and assets. Indeed, many firms in the Marche Region struggle to understand and implement I4.0 technologies (Cucculelli & Lena, 2017). A 2021 report of the Osservatorio Impresa 4.0 (Camera di Commercio delle Marche & Università Politecnica delle Marche, 2021) found that the firms in the Marche Region show significant delays in the adoption of I4.0 technologies due to their limited size. Indeed, most of them are micro-sized enterprises (94%), followed by small and medium (5.7%), and large (0.1%) (Regione Marche, 2021b). Moreover, the report states that the delay is also caused by the lack of specific technical skills in firms and the lack of collaborations with developers of new technologies. Another factor causing the delay is the firms' low level of digital knowledge and skills (Micozzi et al., 2020). Regarding BCT in particular, the firms' size seems to influence the level of knowledge on BCT as it is for other I4.0 technologies. A survey conducted in 2019 revealed that 80% of SMEs did not know about BCT, 16% knew it superficially, and only 4% understood it deeply, whereas larger firms showed higher levels of awareness and deep knowledge (Bianchini & Kwon, 2020). The lack of awareness of BCT among Italian firms was confirmed in the same year by a survey from the Italian Ministry for Economic Development (MiSE & IBM, 2019). A more recent survey by Bracci et al. (2022) found that Italian SMEs are quite aware of the existence of BCT but their level of knowledge is limited and the adoption rate is very low.

In the context of the region, some key institutions may help to increase the knowledge and adoption of I4.0 technologies, including BCT, in firms. The authors of the 2021 report by the Osservatorio Impresa 4.0 (Camera di Commercio delle Marche & Università Politecnica delle Marche, 2021) state that a synergistic and complementary relationship between Punto Impresa Digitale (PID) (Camere di Commercio d'Italia, n.d.), Digital Innovation Hubs (DIHs), and Competence Centers can be leveraged in the Marche Region to help firms achieve a higher level of digitalisation and usage of I4.0 technologies. PID are an initiative of the Italian trade unions Camera di Commercio and Unioncamere offering a series of services and opportunities for firms such as basic courses on I4.0 and specific training, consultancy, or direct assistance to support digitization. DIHs are knowledge brokers that support firms and connect them with public and private actors such as universities, research centres, service providers, and corporations (Crupi et al., 2020). Competence Centers are public-private partnerships that were created by the Italian government to carry out guidance and training activities for firms on I4.0 as well as support them in the implementation of innovation, industrial research, and experimental development projects through I4.0 technologies (Ministero delle Imprese e del Made in Italy, 2023). Another institution which was not mentioned in the report but could have a role in the diffusion of I4.0 in the Marche Region is the Fondazione Cluster Marche, which represents the Technology Clusters in the Marche Region. Technology Clusters are aggregations of companies, universities, and research institutes that work together to promote excellence in research and innovation. The purpose of the Fondazione Cluster Marche is to enhance the capabilities of the Marche Region innovation system through the development of collaborative research and technology transfer activities. The Fondazione Cluster Marche is one of the partners of i-Labs[26], a laboratory which represents the physical centre of the regional Collaborative Platform on I4.0. Inside the laboratory, researchers and entrepreneurs develop, apply, and share solutions useful for improving production systems, to ensure rapid evolution towards I4.0. The i-Labs offers orientation and consultancy activities, research and development, training for companies towards I4.0 technologies, including BCT, and help firms in participating in national and regional tenders. These services are offered in cooperation with DIHs, Competence Centres, academia, and technology providers.

As for the policies, an important role in the diffusion of I4.0 in firms in the Marche Region could be played by the regional Smart Specialisation Strategy (S3) (European Commission, 2023), which aims to invest European community funds to build comparative advantages and sustainable growth in the long term by using the existing territorial resources and production capacities (Foray et al., 2011). The first S3 plan of the Marche Region for the period 2014-2020 (Regione Marche, 2019) contributed to an increase in the propensity of regional companies to invest in R&D activities, innovate, collaborate with the academia, develop R&D and/or activities for innovation, and increase the number of placements of highly qualified personnel. Compared with the first S3 plan, the new regional S3 plan 2021-2027 (Regione Marche, 2023b) emphasises the role of I4.0 for economic development and notes the delay in firms in the Marche Region in the adoption of these innovative technologies. Nevertheless, the new plan states that the effective implementation of the S3 requires the involvement of the research and innovation actors present in the Marche Region, for which a TH approach could be beneficial.

In the process of entrepreneurial discovery, the region has organized meetings with the stakeholders of the TH to identify needs and innovation trajectories. In particular, concerning the S3 for 2021-2027, blockchain is

26 i-Labs, https://ilabsindustry.it/

presented among the innovative trajectories identified. Indeed, new needs have emerged concerning new approaches based on technologies for authenticity, management, tracking and traceability also from a BCT perspective. The technology is presented as linked to competencies regarding digital technologies and engineering while the main market driver of this technology is related to inclusion and social innovation. Finally, the Marche Region expressed its interest in BCT with Regional Law number 36 of 2020 (Consiglio Regionale delle Marche, 2020), which states that the region promotes the use of a multifunctional IT platform based on BCT for registering and managing funds and tenders, tracing the typical products of firms of the Marche territory, and rewarding citizens for their participation to public endeavours.

5.1.4 Survey results

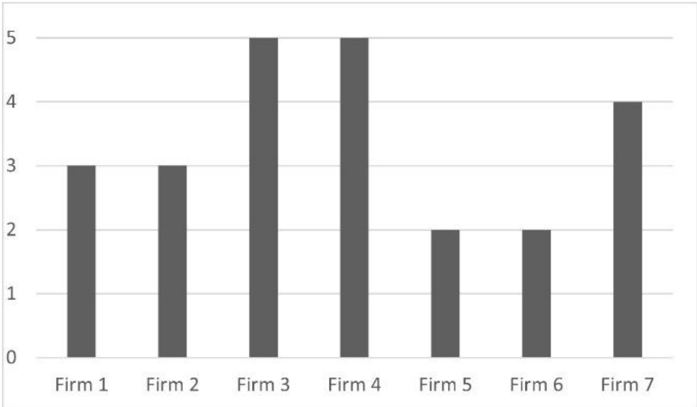
To provide an empirical basis for the measures suggested in this paper for the diffusion of I4.0 technologies in local firms, a questionnaire was sent to the 149 firms that are members of the Fondazione Cluster Marche, to which seven of them responded. Four of them are large-sized, one is medium, and two are small. The recently updated ATECO 2007 classification of economic activities by Istat (Istat, 2022) was used to classify the firms by sector. Four are manufacturers, one is in the sector of agriculture, forestry, and fishing, one offers services to firms, and one conducts professional, scientific, and technical activities (Table 14).

Table 14 Size and ATECO sector

Firm n.	**Size**	**Sector (ATECO 2007)**
1	Large	C - Manufacturing
2	Large	C - Manufacturing
3	Large	C - Manufacturing
4	Large	A - Agriculture, forestry, and fishing
5	Medium	C - Manufacturing
6	Small	S - Other service activities
7	Small	M - Professional, scientific, and technical activities

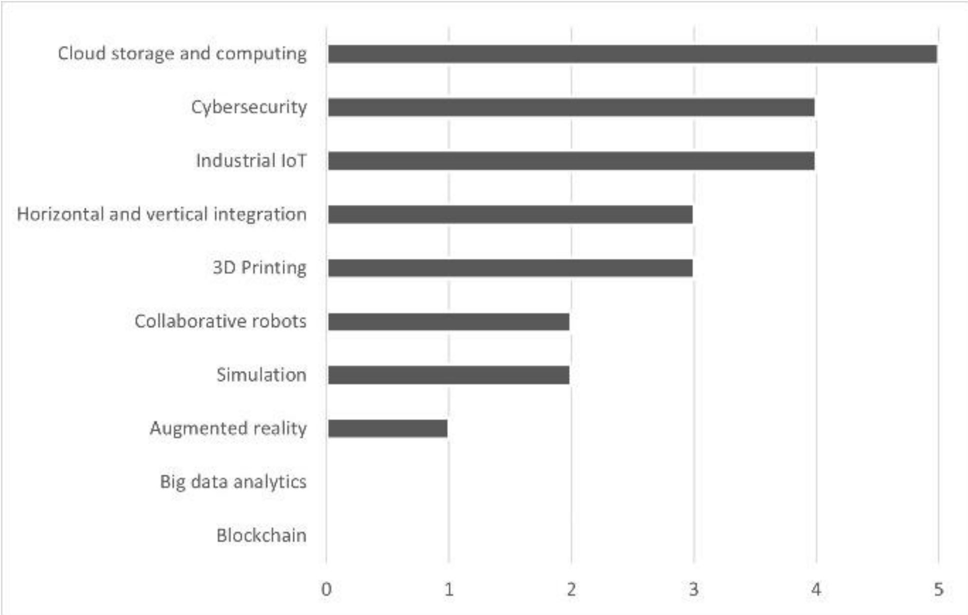
To demonstrate that the firms surveyed were indeed familiar with innovative technologies, they were asked to state how many I4.0 technologies they were currently using. Figure 5 shows that the firms surveyed use at least two and at most five of the nine I4.0 technologies; bigger firms generally use more I4.0 technologies than smaller ones, except for Firm 7.

Figure 5 Number of I4.0 technologies used



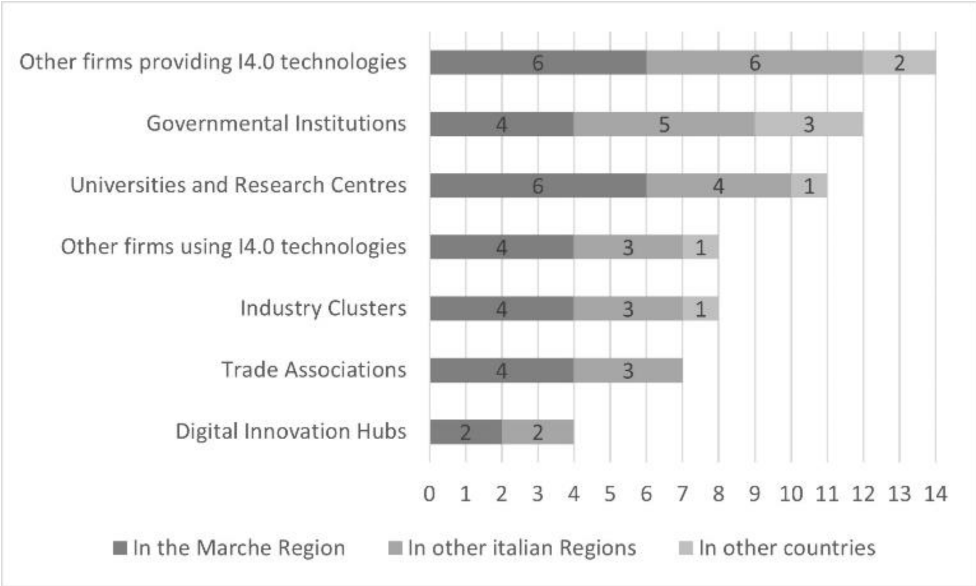
As seen in Figure 6, the firms use especially cloud storage and computing, cybersecurity, and industrial IoT, followed by horizontal and vertical integration and 3D printing, and finally collaborative robots, simulation, and augmented reality. None uses big data analytics, i.e., techniques for managing large amounts of data through open systems that allow forecasts or predictions. All the firms surveyed declared knowing BCT but none of them used it. Only one firm among those surveyed, which is large-sized, has analysed the potential use of BCT in its business processes, specifically for supply chain traceability.

Figure 6 Most used I4.0 technologies



The firms surveyed collaborate with different kinds of actors from the Marche Region, other Italian Regions, and other countries. Small-sized firms report having more collaborations than larger firms. The number of collaborations was counted per type of collaboration (Figure 7): most are concentrated at the regional (30 collaborations) and national (26) levels, while collaborations in other countries are marginal (eight). A higher number of collaborations are with providers of I4.0 technologies (14), governmental institutions (12), and universities and research centres (11). Lower levels of collaboration are with other firms using I4.0 technologies (eight), Industry Clusters (eight), and Trade Associations (seven). Collaborations with Digital Innovation Hubs are the least present (four) and there is an absence of collaborations with trade associations and DIHs located in other countries. The firms reported no other kind of collaboration in addition to those presented in the answers.

Figure 7 Total number of collaborations by kind of collaborator and territorial level



The firms surveyed were asked to rate the importance of some measures for increasing the knowledge and adoption of enabling I4.0 technologies, including BCT, among firms in the Marche Region (Figure 8). Networking activities both with academia and other firms using I4.0 technologies were considered the most useful. Receiving more funding for the implementation of I4.0 technologies in firms was rated as quite useful by five firms out of seven, and very useful by the remaining two. Raising awareness about I4.0 technologies and training activities on them were rated as less useful overall but still of relevant importance. Lastly, given the lack of clear regulations on BCT, the firms rated the usefulness of clear laws on the business uses of BCT for its diffusion. The answers were mixed, with three firms considering clear regulations not useful and the other three considering them useful, while one firm did not know what to answer. The firm which was exploring the application of BCT in its business processes considered clear regulations to be very useful. The firms were also given the possibility to suggest additional measures: firm number two proposed "common projects" and firm number three added "skills development in young people".

Figure 8 Perceived usefulness of measures for increasing the knowledge and adoption of I4.0 technologies including BCT

5.1.5 Discussion

The qualitative analysis of the economic context based on scientific papers and reports showed that firms in the Marche Region struggle to adopt I4.0 technologies. Factors hindering the implementation of these innovative technologies are the small size of firms and the lack of technical knowledge and collaborations with technology providers. However, the small firms interviewed for this study use I4.0 technologies as much as the bigger firms do. Indeed, as the 2021 report of the Osservatorio Impresa 4.0 stated, the limited size of firms is not an insurmountable obstacle to the implementation of I4.0 technologies (Camera di Commercio delle Marche & Università Politecnica delle Marche, 2021). Instead, collaborations are a driver for the use of I4.0: the firms surveyed for this study collaborate especially with other firms providing I4.0 technologies, leveraging on the providers' technical expertise to use these innovative technologies. Moreover, they have a high number of collaborations with universities and research centres, confirming their role as knowledge and innovation generators (Gunasekara, 2006), and with governmental institutions, which confirms the importance of government support to firms for innovation (A. Abbas et al., 2019; Luthra et al., 2020). This collaboration between firms, universities, and government may indicate the existence of a TH approach that allows the firms surveyed to be innovative. Although the collaborations are mostly with universities and governments in the Marche Region and other Italian regions, international collaborations are present too, confirming the importance of international ties and networking for innovation.

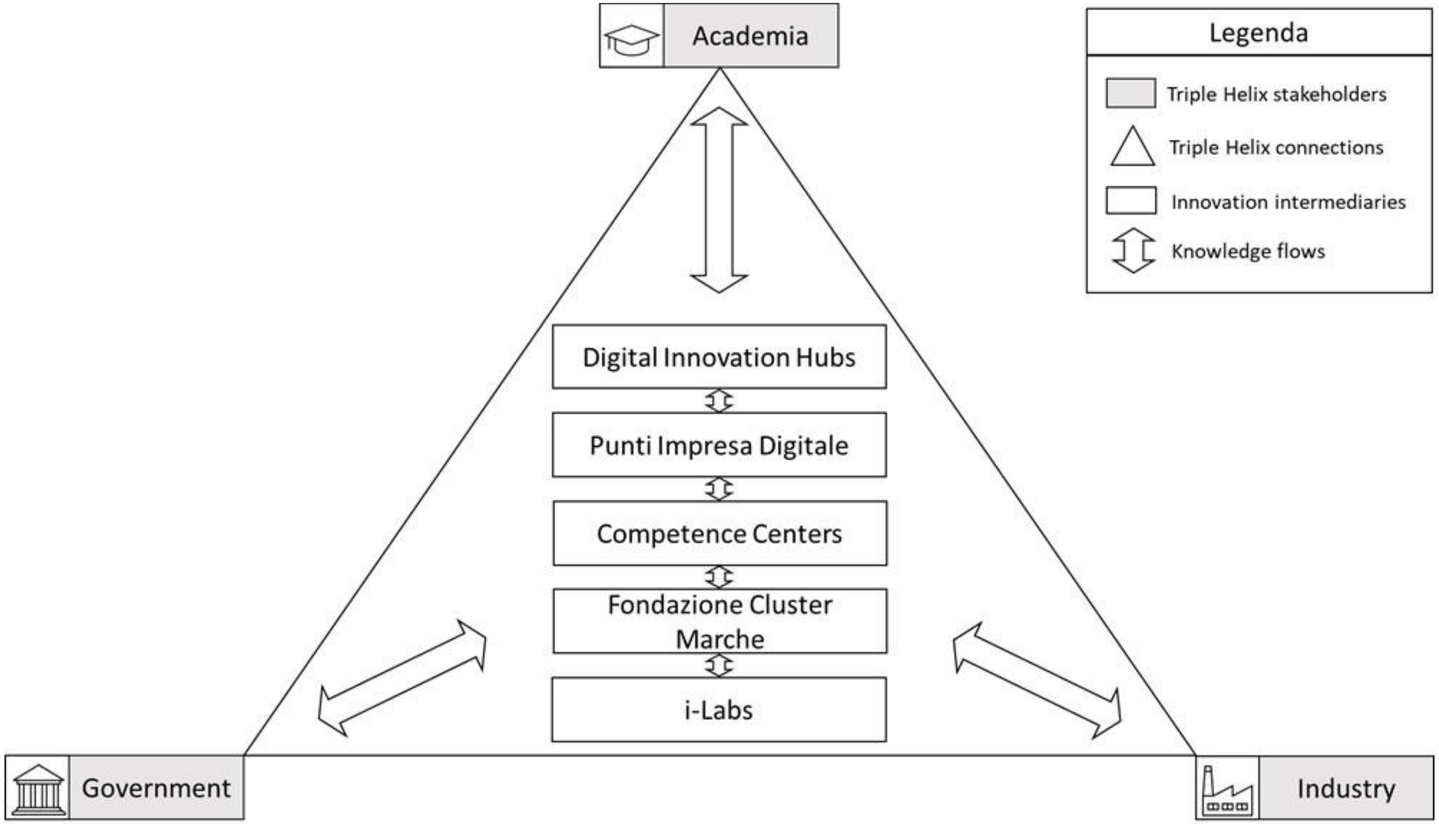
The firms surveyed also reported having strong ties with other firms using I4.0 technologies, industry clusters, and trade unions, showing the importance of being part of networks of actors with similar objectives and needs. However, in this case, the collaborations were mainly with Italian actors, which may indicate a lack of interest in, knowledge of, or access to the possibility of collaborating with firms, industry clusters, and trade unions in other countries. Moreover, it is surprising that the firms interviewed do not collaborate much with Italian DIHs and at all with European DIHs since these are knowledge brokers that help firms implement innovative technologies and intermediaries that help them create collaborations with governments, academia, and other firms.

As for the usefulness of different measures for the local diffusion of I4.0 technologies, the firms interviewed considered very or quite useful the networking activities with other firms using I4.0 technologies and with academia, and they underlined the importance of government support with funding opportunities. This reinforces the validity of a TH approach for the diffusion of I4.0 technologies in the Marche Region, promoting collaborations and networking, indeed, one of the surveyees mentioned the need for collaboration in projects on I4.0. Raising awareness and training activities were found just slightly less useful. These activities are conducted not only by universities and governments but also by trade unions and industrial clusters, with which the firms surveyed collaborate. Again, it is notable that firms do not collaborate much with Italian DIHs and at all with European DIHs, whose activities supporting firms involve raising awareness and training on innovative technologies.

Finally, BCT has been addressed in the literature as the new pillar of I4.0 technologies (Subic et al., 2018). The firms interviewed know BCT but only one of them studied its concrete applications to its business processes. This may be related to the novelty that this technology represents for Italian firms (Bianchini & Kwon, 2020). Firms were asked in the questionnaire to rate the usefulness of having clear regulations on BCT, of which the absence has been found as a barrier to its adoption in firms (Alkhudary et al., 2020; Baharmand et al., 2021). The responses were mixed, however, the firm which had studied the implementation of BCT in its business processes considered clear regulations to be very important.

This research was driven by the limited implementation of I4.0 technologies in firms in the Marche Region and thereby aims to suggest measures to promote the adoption of these technologies, including BCT, in the regional context. The findings suggest that a TH approach could be useful to foster the diffusion of I4.0 technologies in firms in the Marche Region, leveraging on local actors. Figure 9 shows how the TH model would work in the Marche Region. It identifies institutions in its territory that may be part of a TH to support the diffusion of these innovative technologies. Innovation intermediaries such as DIHs, PID, Competence Centers, Fondazione Cluster Marche, and i-Labs are placed at the centre of the TH. These not only share knowledge with each other but also transfer to and receive knowledge from the typical stakeholders involved in the regional TH, namely academia, government, and industry, and intermediate the knowledge flow between these actors through collaborations which could be leveraged to spread the diffusion of I4.0 technologies in firms in the Marche Region. The TH model proposed is based on both an analysis of the economic context in the Marche Region and empirical evidence from the survey of seven innovative local firms that use I4.0 technologies, that was conducted to collect these firms' opinions on what other firms may need to effectively adopt these technologies.

Figure 9 The TH model proposed to increase knowledge and adoption of BCT in firms of the Marche region



Based on the results of the study, some measures to increase the diffusion of I4.0 in local firms can be suggested. In the perspective of raising awareness on I4.0 technologies, policymakers may want to continue fostering a TH approach by helping strengthen the collaboration between some key institutions in the Marche Region: Punto Impresa Digitale (PID), Digital Innovation Hubs (DIHs), Competence Centers, Fondazione Cluster Marche, and i-Labs. These could have the role of innovation intermediaries, i.e., institutions that connect firms with governmental institutions and academia in the regional TH.

The survey evidenced a lack of collaboration with DIHs, despite their role as connectors among the three helices. DIHs can help firms with the practical implementation of I4.0 technologies and regional institutions by adjusting financial and training incentives to the needs of different firms. Additionally, DIHs can connect firms and institutions with other intermediaries around Europe to facilitate international access and exchange of knowledge, allowing them to gather experiences and best practices from other European contexts on the implementation of I4.0 technologies. Both policymakers and DIHs need to make firms more aware of the possibility of using DIHs to access knowledge from all around Europe. On one hand, policymakers need to reinforce the role of existing DIHs and give them more visibility with entrepreneurs. On the other hand, DIHs should organize events with firms and institutions of different European countries that already use Industry 4.0 technologies and BCT and are willing to share their direct experience, so that firms in the Marche Region can appreciate the value that DIHs can provide them.

As for the policies, an important role in the implementation of a TH for the diffusion of I4.0 has been individuated in the S3. The involvement of the key intermediaries in the Marche Region in the S3 must be fostered by policymakers to facilitate its implementation.

However, caution is mandatory before generalising this study's results. Indeed, although the seven surveyed firms' expertise, based on the practical implementation and use of I4.0 technologies, is relevant to the objective of this study, their limited number and high level of digitalization make them not representative of all the firms in the Marche Region.

5.2 A look into the future: integrating blockchain in the context of smart cities for supply chain traceability[27]

In the previous paragraph, it was suggested that TH institutions and innovation intermediaries have the task of helping firms in the Marche region to understand the benefits and limitations of BCT for supply chain traceability. Further, in the current paragraph, it is argued that these institutions should adopt a long-term view on the development of BCT for supply chain traceability and understand how this can be embedded in the territory, especially in digitalised urban areas such as smart cities where information coming from supply chains could be provided to stakeholders in the smart city context such as citizens, authorities, and firms, transparently.

Smart cities are urban areas infused with the digital technologies of I4.0, which were primarily created for the industry sector and later applied to cities, enabling both smart factories and smart cities (Correia et al., 2022). These technologies are used in smart cities to enhance citizens' lives efficiently and are transforming the way we live and work and are ushering in a new era of efficiency, sustainability, and economic growth. A smart economy allows firms to organise their business processes within the larger context of the city (Ismagilova et al., 2019).

Integrating BCT for supply chain traceability in smart cities presents a transformative approach to enhancing transparency, efficiency, and security in urban management. The concept revolves around utilizing blockchain's decentralized and immutable ledger system to track and verify the authenticity and movement of goods within a city. This integration is particularly significant in the context of smart cities, where the emphasis is on leveraging technology for improved urban governance and quality of life. BCT can greatly improve supply chain management in smart cities by enhancing transparency, traceability, and security, while also enabling real-time tracking of goods and improved decision-making (Karale & Ranaware, 2019). Since BCT in smart cities can increase data integrity and availability

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27 This paragraph is based on a) Lepore, D., Testi, N., & Pasher, E. (2023). Building inclusive smart cities through innovation intermediaries. Sustainability; b) Testi, N., Marconi, R., & Pasher, E. (2023). Exploring the potential of blockchain technology for citizen engagement in smart governance. Open Res Europe.

(Lepore et al., 2023), blockchain-based supply chain systems in smart cities can record detailed product information throughout their lifecycle in a secure and accessible manner (Bhushan et al., 2020). Additionally, the use of BCT-enabled smart contracts in supply chain transactions, as demonstrated in various studies, offers a secure and efficient way to manage procurement, traceability, and payment transactions (Raj et al., 2022). Blockchain is just one of the I4.0 technologies with which it can be used in synergy to bring more transparency and efficiency to supply chains in the context of smart cities.

Vertical and horizontal system integration are two strategies enabled by Industry 4.0 technologies that firms and smart cities can use to make supply chains more agile. Vertical integration refers to the integration of systems within the factory or smart city, while horizontal integration involves connecting with external parties through shared platforms (Erboz, 2017). This horizontal integration allows for automated value creation within the smart city (Safiullin et al., 2019). The IoT has enabled objects to be connected to the internet, allowing them to collect and exchange data, as well as be sensed, identified, and controlled remotely. This has led to the emergence of Industry 4.0 and smart cities, as it has enabled firms and cities to turn objects into agents of data collection and monitoring, and in turn, has provided decision-makers with data to support their decisions and take action (Correia et al., 2022). The IoT in smart cities can be used for real-time tracking of goods (Kshetri, 2018), providing real-time information on their availability (Karale & Ranaware, 2019). Citizens can actively engage in reporting counterfeited or harmful products through smart city platforms (Majeed et al., 2021). BCT and the IoT together can improve transparency and traceability in food supply chains, a critical aspect of urban living (Tripathi et al., 2023), by enabling the final customer to access a tamper-proof history of the product, including the farming, harvesting, production, packaging, conservation, and transportation processes (Arena et al., 2019).

BCT and the IoT can also provide real-time indicators for quality factors like humidity and temperature, helping to prevent contamination during events like disease outbreaks (Kshetri, 2018). BCT can also improve security and privacy in IoT systems in smart cities (Ejaz & Anpalagan, 2019), thereby enhancing the security and efficiency of smart city supply chains (Z.

Yu et al., 2022). The IoT has enabled the collection and analysis of large amounts of data (i.e., big data) in both industries and smart cities. Cloud computing is used as an on-demand network that provides access to shared IT resources such as servers, storage, and applications (Sunyaev, 2020). However, due to the large amount of data generated by the IoT, edge and fog computing are becoming increasingly necessary (Dogo et al., 2019). Edge computing allows data analysis to be performed where the data is created, reducing latency (Shi & Dustdar, 2016), while fog computing acts as a mediator between the edge and the cloud, deciding which data should be sent to the cloud and which should remain local (Lom et al., 2016). AI algorithms can process large amounts of data to detect patterns and features that would otherwise go unnoticed (Luckey et al., 2021).

Nevertheless, the IoT and databases have made firms and smart cities more vulnerable to cyber-attacks (Alibasic et al., 2017). BCT can help to increase data integrity and availability and protect against data vulnerability (K. Abbas et al., 2021b).

However, as Bagloee et al. (2021) noted, managing complex supply chains in urban areas can be challenging. Data integration between existing supply chain traceability software and blockchain can be difficult and expensive. Also, smaller players in city logistics and urban freight may have a lower capacity to use digital technologies, further complicating the implementation of such systems.

When integrating BCT in a smart city, some considerations must be made concerning the kind of blockchain solution to adopt. In the hypothetical scenario in which a municipality used BCT to store data that are then made available to all the smart city's stakeholders, permissioned blockchains could be more suited, compared to the permissionless (public) type. While the latter allows for more transparency and is truly distributed, it also suffers from a lack of control on the blockchain and scalability, compared to the former. Consortium blockchains might provide a better solution when compared both to permissionless and private blockchains because they mitigate some of the risks of private blockchains by removing centralized control and sharing it among multiple parties (Cui et al., 2019). As Bai et al. (2022) explain, the reasons for employing a consortium blockchain in smart city governance are twofold. First, as the population and the number of digitally connected infrastructures continue to grow, the blockchain must be efficient and scalable, which hinders the application of permissionless blockchains. Second, multiple organizations will be involved, rendering private blockchains unsuitable. Therefore, consortium blockchains provide an ideal balance between the need for scalability, efficiency, and collaboration among various stakeholders in the smart city context, which is an opinion shared by Bruneo et al. (2018).

Another technical aspect to be considered is the kind of consensus algorithm to use in blockchain-enabled smart governance. The consensus algorithm plays a vital role in BCT, particularly in ensuring public participation and maintaining the system's security and efficiency. Given BCT's low scalability limit, Bai et al. (2022) highlight the importance of real-time interaction and the complexity of involving public users, calling for a low-latency and cost-efficient consensus protocol. For blockchain applications in smart cities, Marsal-Llacuna (2020) proposes the use of the PoA consensus algorithm as a solution to the challenge of low scalability. Indeed, despite its security issues, PoA may be more suitable for semi-decentralized systems (E. Tan et al., 2022) such as smart cities governed by municipalities and other institutions.

Despite the potential of integrating BCT and smart cities, some general challenges need to be addressed. As a relatively new technology, aspects such as performance, security, and scalability remain uncertain (Deng & Ouyang, 2021). Moreover, both BCT and smart cities are in their infancy and require significant research efforts for integration (Majeed et al., 2021). Tiwari & Batra (2021) identify challenges related to the integration of BCT in smart city ecosystems. One of the primary challenges, also mentioned by Scekic et al. (2019), is scalability, as data sets in smart cities can be of enormous sizes. Garcia-Font (2020) proposes using IPFS decentralized cloud storage in smart cities for off-chain storage of data, while only the data's hashes are uploaded to the blockchain for reference. Another critical challenge, according to Tiwari & Batra (2021), is maintaining unique identification for all participating nodes. Since nodes are identified by unique sets of public-private keys, and the security of these keys is of vital importance, a compromise by a cybercriminal or a careless holder can have severe consequences.

CONCLUSIONS

This Thesis focuses on the application of BCT in firms, particularly SMEs, of the Marche Region to explore how it can enhance their competitiveness in both domestic and international markets.

Recent studies have analysed the potential of BCT in various fields beyond cryptocurrency. BCT is particularly relevant for supply chain traceability, allowing firms to store and share immutable product traceability data, and thus enhancing transparency, building trust, identifying counterfeit products, and increasing consumer trust and loyalty.

BCT can play a significant role in supply chains of Made in Italy products by valorising them, protecting them from counterfeiting, and combating "Italian-sounding". However, despite its potential benefits, there is still a gap between theoretical advantages and empirical evidence of BCT's effectiveness. Several high-profile blockchain projects have faced challenges or failed, reflecting difficulties in practical implementation.

This Thesis intends to bridge this gap by providing empirical evidence from real BCT implementations in Italian supply chains.

The objective is to understand the advantages and challenges of the potential adoption of BCT for supply chain traceability in SMEs of the Made in Italy in the Marche region.

The research adopts a strong empirical approach, employing qualitative methodologies like interviews and surveys to gather real-world evidence. The Thesis also aims to cover the technical, economic, and legal aspects of BCT adoption through an interdisciplinary approach, offering practical, evidence-based insights for managers and policymakers in the Marche region.

Summary of the findings

Chapter I of the Thesis provides a comprehensive introduction to BCT, explaining its functionality, utility, and how it compares with centralized databases. It delves into the specifics of blockchain-enabled tools such as smart contracts, decentralized applications, and non-fungible tokens, highlighting their features and limitations. A key focus of the chapter is the exploration of the conditions under which blockchain databases are preferred over centralized ones, noting that blockchains are often adopted to eliminate the need for trust and intermediaries in data sharing between stakeholders.

However, the chapter reveals a paradox in this adoption: while blockchain is designed to remove the need for trust, the validity of data input by external sources (oracles) often requires pre-existing trust and possibly trusted intermediaries for verification.

Additionally, the chapter addresses one of the major limitations of BCT, which is its lack of scalability. This issue is explored within the context of the BCT trilemma, which impacts all blockchains. The scalability limitations of BCT are addressed through various solutions, each compromising trust to some extent.

Off-chain storage, where data is stored outside the blockchain and only hashes are kept on-chain, increases scalability but raises concerns about data access and centralization. The most studied and used consensus algorithms like PoW, PoS, and PoA offer trade-offs between scalability, decentralization, and security. For example, PoW ensures security and decentralization but limits scalability, while PoS and PoA offer greater scalability at the expense of decentralization and security.

Blockchain architectures, classified as permissionless (public), permissioned (private, consortium), also balance scalability, control, and privacy. Permissionless blockchains, like Bitcoin, are decentralized and secure but less scalable. In contrast, permissioned blockchains are more scalable but less decentralized and secure, with consortium blockchains offering a middle ground.

Hybrid architectures, involving multiple interconnected blockchains, propose a solution for scalability and decentralization but face interoperability challenges. The overall power dynamics within these networks can shift, potentially centralizing initially decentralized structures.

All these solutions tend to reintroduce elements of centralization and the need for intermediaries, thus challenging the fundamental principles of BCT.

Chapter II reviews the topic of BCT for supply chain traceability, focusing on its business and management implications.

The study's review of academic literature highlights a growing interest in this field, particularly in the agri-food and pharmaceutical sectors due to concerns over food contamination and counterfeit medicines.

Through the literature review, two main themes are identified.

The first theme regards the benefits of using BCT in supply chains, which are categorized into three sub-themes: the enhancement of transparency and its positive effect on trust among supply chain stakeholders; the increase in consumer trust regarding the product's originality and safety; the improvement in supply chain effectiveness, resilience, performance, and sustainability.

The second theme explores the drivers and barriers to firms' intention to adopt BCT for supply chain traceability. While BCT is desired for enhancing data transparency and thereby improving trust and accountability in supply chains, compliance with regulations, fraud detection, and increasing resilience, performance, and sustainability, significant barriers to its adoption include a lack of digital knowledge, insufficient resources, unclear regulations, governance challenges, privacy concerns, and technical issues of blockchains. Consumer preference for products traced with BCT and their willingness to pay a premium are potential income sources, but evidence on this is scarce and conflicting.

The main advantage of BCT-enabled traceability over centralized systems could be its role in enabling trust among supply chain stakeholders, which is a significant driver for its adoption. However, the increased transparency could also lead to concerns about data confidentiality.

Permissioned blockchains, offering differentiated access rights, have been suggested to protect sensitive information, but their effectiveness and governance challenges are still to be fully understood. Moreover, permissioned blockchains might not effectively enable trust due to their lower decentralization, potentially making them less desirable than centralized databases.

Further, the reliability of data uploaded to a blockchain is a critical concern. The information can be inaccurate due to human error or manipulation before being uploaded. Using IoT devices for automatic data collection and uploading has been proposed to enhance reliability, but further research is needed on how to prevent the manipulation of these devices by malicious actors.

Finally, the chapter highlights that while BCT promises to address certain problems of centralized supply chain traceability systems, particularly the issue of lack of trust among stakeholders, there remains a notable gap in empirical evidence demonstrating the benefits of BCT for supply chain traceability, particularly when weighing against the costs and risks involved. Indeed, more than half of the articles reviewed are conceptual, focusing on the potential advantages and disadvantages of BCT from a theoretical perspective.

Empirical research is limited and does not compare BCT with centralized supply chain traceability solutions. This creates uncertainty about the actual value of BCT compared to its implementation costs and existing solutions.

While some studies indicate cost reduction and real-time monitoring as benefits of BCT, it's unclear if these outcomes are exclusive to BCT or achievable with existing centralized solutions too.

Additionally, the indirect benefits of BCT, such as incentivizing digitalization and the use of smart contracts for automation, could be achieved without BCT.

Recognising both the potential of BCT applied to supply chain traceability for firms of the Made in Italy and the lack of evidence on the topic, the first study of **Chapter III** focuses on collecting firsthand data through expert interviews with managerial and technical staff from Italian SMEs using BCT for supply chain traceability of Made in Italy products and tech companies providing this technology.

The interviews confirm that BCT enhances transparency and accountability in supply chains, leading to increased trust among stakeholders. However, in cases where trust is already established, BCT may not add significant value, especially in shorter food supply chains.

BCT's role in anti-counterfeiting is beneficial for protecting the Made in Italy brand and involves stakeholders in verifying product originality.

Additionally, transparency through BCT can lead to increased revenues, as consumers value and are willing to pay more for products with transparent traceability.

A key application of BCT in this context is for B2C marketing, allowing SMEs to tell the story of their products, enhancing consumer perception of the reliability and quality of their Made in Italy products.

The assumption behind this application is backed by some studies that found a positive effect of BCT-enabled traceability on consumers' purchasing intentions and willingness to pay a premium. However, depending on how the researchers conducting these surveys and experiments described the application of BCT for supply chain traceability to participants in their studies, their perception could have been biased into considering only the advantages and not the limitations of BCT-enabled traceability.

Finally, findings from this study on the use of BCT for supply chain traceability in firms of the Made in Italy evidenced that the use of smart contracts for storing traceability event hashes and

Challenges in the adoption of BCT include a lack of clear legal frameworks, standardization issues, and insufficient knowledge about BCT among companies. Effective communication about the benefits of BCT is crucial for its adoption. NFTs are not widely used due to their negative reputation and technical constraints.

Technical solutions involve using off-chain storage for scalability and data confidentiality but raises concerns about centralization and control by data managers and exposes the stakeholders to the risk of data loss.

Different blockchain architectures, like consortium and public blockchains, offer various advantages, with some providers using a hybrid approach for better transparency and cost predictability. Third-generation public blockchains are used for more scalability but at the expense of decentralisation and security of the blockchain network.

Risks of data unreliability arise from human error, fraudulent manipulation, and the potential for displaying false information. Providers recommend using IoT for automatic data collection to minimize human intervention errors.

The notarization of the producer's declaration is a common practice, but it doesn't guarantee the data's reliability before blockchain entry. Some solutions allow supply chain partners to autonomously upload data using smart contracts, enhancing accountability but not ensuring reliability. Italian adopters predominantly use the producer's declaration method, influenced by factors like cultural barriers and a focus on marketing.

Risks also emerge from the use of centralized apps to display traceability information, prompting some providers to adopt DApps for greater trustworthiness, as these run on public blockchains and offer open-source, immutable code.

The chapter provides managerial implications, guiding SMEs in understanding if they need a BCT solution and which solution fits their needs.

Firms should assess the trust among stakeholders in their supply chains. If trust is lacking, BCT is useful for data sharing among multiple parties without relying on a trusted third party for data handling. This focus on trust enhancement through BCT is particularly leveraged for B2C marketing purposes.

Further, the second study of the chapter investigates through a survey the opinions of Italian adopters on the usefulness of BCT for supply chain traceability, particularly in B2C marketing contexts. The respondents, primarily from micro-sized companies, were from sectors emblematic of the Made in Italy, like agri-food, furniture, and fashion.

The survey results indicate that most adopters perceive BCT as positively influencing customer trust, brand awareness, and the willingness of customers to pay a premium for BCT-traced products, which are areas of B2C marketing related to brand awareness and loyalty. However, this positive influence seemed to not significantly impact the number of products sold.

The findings suggest that while BCT positively affects areas related to B2C marketing, its influence on trust among supply chain partners and efficiency is less pronounced.

Additional benefits noted were promoting genuine Italian products, increasing transparency, and aiding in compliance with future digital product passport legislation.

Interestingly, only a minority of adopter have direct access to performance data of the BCT service, with some reliant on providers for data access. This raises concerns about the reliability of data and the adopters' capacity to assess the impact of BCT on their business accurately.

Only two respondents actively use performance data for business decision-making, suggesting a lack of awareness or accessibility of crucial data.

Looking ahead, most respondents intend to continue using BCT services for traceability, driven by customer demand and upcoming legislation. However, the continuation for some is contingent on cost factors, indicating that while BCT is seen as beneficial, its practical application and long-term viability are still being evaluated by these firms.

This cautious approach reflects a broader need for understanding BCT's tangible benefits and aligning them with business goals and regulatory requirements.

Chapter IV explores the dynamic capabilities (DCs) as enablers, and legal challenges as barriers, to the adoption of BCT for supply chain traceability in Italy.

The first study presented in the chapter contributes to understanding the intersection between DCs and BCT adoption of BCT for supply chain traceability in Italian firms. The research applies the DCs theory and, through interviews with six Italian firms of the Made in Italy that use BCT in their supply chain, the study reveals how these companies learned about and adopted BCT and how they adapted their operations to the new technology.

The findings show that most firms were introduced to BCT through external sources like seminars, webinars, or consultants, indicating a reliance on external expertise for identifying technological opportunities.

In seizing these opportunities, firms predominantly leaned on consultants to choose appropriate BCT providers.

Consultants emerge as key facilitators in the adoption process, acting as knowledge brokers and aiding in technology integration. However, this reliance also suggests a potential lack of in-house understanding of BCT and its applications. While consultants can provide valuable guidance, firms should be cautious of over-reliance, especially considering potential conflicts of interest.

Interestingly, the educational background of the firms' owners or CEOs appears to play a positive role in the successful adoption of BCT. Higher education levels, combined with an openness to innovation, seem to positively influence BCT adoption.

As for the phase of transforming to adapt to BCT, no significant transformation of internal capabilities or processes was required for BCT use, mainly due to BCT providers' involvement in implementation.

The second part of the chapter discusses the legal challenges around BCT as potential barriers to its implementation and diffusion in firms, with a focus on BCT for supply chain traceability.

The exploration of BCT, smart contracts, and NFTs across Europe, Italy, and the Marche Region reveals a legal framework grappling with the integration of BCT.

The primary challenge is aligning BCT with existing laws, particularly the GDPR in the EU. The GDPR's emphasis on data privacy clashes with the immutable and decentralized nature of blockchains, leading to significant challenges in legal compliance. The GDPR's challenges for BCT include its principles of the right to erasure and data minimization, which conflict with blockchain's inherent features like data immutability. Possible solutions include permissioned blockchains, which offer a more controlled environment conducive to GDPR compliance, and off-chain storage, allowing for data modification or deletion while maintaining blockchain benefits.

At the EU level, there is a lack of specific legal frameworks for BCT, with the EC mainly focusing on fostering a pro-innovation environment while ensuring legal certainty. The EC's European Blockchain Regulatory Sandbox is an example of this approach, supporting projects to increase legal clarity for BCT innovations, including public sector applications on the European Blockchain Services Infrastructure.

In Italy, the legislation's definition of DLTs and smart contracts under DL 135/2018 offers some regulatory clarity but also reveals gaps, particularly in addressing permissioned DLTs where data modification is possible.

Regarding smart contracts, Italy's legal system has attempted to define them broadly, but this generic approach may be ineffective in practical legal contexts.

The legal landscape for NFTs remains ambiguous, with ongoing debates about their classification under existing legal categories. European Parliament resolutions and the EC's proposed regulation on crypto-assets markets address DLT but lack specificity regarding NFTs.

In terms of traceability, particularly in the food sector, the EU's regulations mandate traceability requirements, but the integration of BCT into these systems poses legal and technical challenges. BCT could enhance traceability but requires legal and digitalization strategies to align with food law.

Overall, the legal challenges of BCT in Europe, Italy, and the Marche Region reflect a need for more precise legal guidelines and frameworks. This evolving legal landscape calls for collaboration among firms, policymakers, legislators, and researchers to navigate and address the complexities of integrating blockchain into existing legal structures.

Chapter V, recognising that knowledge on the use of BCT for supply chain traceability in Italian firms is scarce and heavily influenced by providers and consultants, argues that TH actors and innovation intermediaries should be involved in the diffusion of knowledge on BCT in firms of the Marche region to foster its adoption.

The study explores the application of a Triple TH model to enhance the understanding and adoption of BCT among the other I4.0 technologies, in firms of the Marche region. This TH approach, which emphasizes collaboration among academia, government, and industry, emerges as a framework to address the challenges that SMEs face in integrating I4.0 technologies, BCT included.

The research methodology combines a literature review, an analysis of the regional context and policies, and a targeted survey of innovative local firms.

The research findings highlight a general awareness of BCT among firms in the Marche Region, but its actual implementation remains limited. Also, firms value networking activities with academia and other firms that are already utilizing I4.0 technologies. Moreover, the firms recognize the importance of governmental support in terms of funding and incentives for implementing I4.0 technologies.

The proposed TH model for the Marche region positions innovation intermediaries, such as DIHs, PID, Competence Centers, Fondazione Cluster Marche, and i-Labs, at the centre of the TH collaboration. These intermediaries facilitate the flow of knowledge and foster collaborative initiatives between academia, government, and industry. Also, innovation intermediaries, and DIH specifically, connect regional firms with broader European networks for gaining access to a wider array of knowledge and best practices in the field of I4.0 technologies.

One key observation from the survey is the underutilization of DIHs by the firms, despite their potential role as connectors, which indicates a possible gap in awareness or accessibility regarding the services offered by DIHs. To address this, the study suggests that both policymakers and DIHs need to enhance the visibility and perceived value of DIHs among regional firms. For instance, organizing events and workshops that bring together firms, technology providers, and other European stakeholders could demonstrate the practical benefits of engaging with DIHs.

Another significant aspect highlighted by the study is the role of the S3 in fostering the adoption of I4.0 technologies in the region. The involvement of key intermediaries in the implementation of the S3 is crucial for its success. This involvement can facilitate the dissemination of I4.0 technologies and support the region's economic development through technological innovation.

Finally, the chapter argues about the necessity for TH actors to adopt a forward-looking vision that aligns with the evolving landscape of urban digitalization, by integrating BCT within smart cities, specifically for enhancing supply chain traceability. The integration of BCT in smart cities is a transformative step towards ensuring transparency, efficiency, and security in urban management systems. Such integration can significantly enhance the management of supply chains, offering real-time tracking, improved decision-making, and enhanced transparency.

The IoT facilitates the connection and data exchange among various entities both in I4.0 and smart city, paving the way for real-time tracking and management of goods.

When combined with BCT, it can enhance food supply chain traceability, a critical aspect in urban settings. This combination ensures data integrity and offers real-time quality indicators essential for maintaining food safety standards.

However, integrating BCT in smart cities for supply chain traceability is not without challenges.

Technical considerations include choosing the appropriate type of blockchain, with consortium blockchains emerging as a suitable choice for smart city governance due to their balance between scalability, efficiency, and collaborative governance.

The choice of consensus algorithm is also crucial, with PoA being proposed for its suitability in semi-centralized systems like smart cities.

Also, the early development stage of both BCT and smart cities necessitates considerable research and development efforts, which in turn require a collaborative effort involving various stakeholders.

The TH model, promoting cooperation between government, academia, and industry, can play an important role in facilitating this integration.

Final considerations on the usefulness of blockchain for traceability of Made in Italy products

BCT, invented in 2008, was designed to facilitate P2P exchanges of value across network nodes without relying on intermediaries like banks to confirm transaction accuracy and guarantee their permanence and immutability once registered. This technology shifts trust from interpersonal relationships to the deterministic outcomes of the blockchain's protocol and the immutability of transactions stored on the blockchain. Blockchains, thus, eliminate the need for both interpersonal trust among peers exchanging value and intermediaries acting as trusted third parties.

An interesting feature of blockchains is their ability to store strings of text within P2P transactions. This capability paves the way for using blockchains to store data in a manner that is immutable and transparent. Consequently, since 2015, BCT has been proposed as a potential solution to foster trust-less data exchanges in many sectors plagued by trust deficits among parties. The applications proposed for BCT are so diverse and far from its original cryptocurrency application, that BCT has been considered as a solution seeking problems to solve.

In recent years, there has been increasing academic interest in BCT as a means to enhance transparency in supply chains. The idea is for companies to upload traceability data about their products onto a blockchain, making this information immutable and accessible to stakeholders, thereby addressing the issues of information asymmetry and lack of transparency typical of centralized traceability systems. This approach aims to enable trust building in supply chains, especially in light of growing consumer and regulatory concerns about frauds exploiting the opacity of increasingly globalized and complex supply chains. The expectation is that BCT would mitigate issues related to the lack of transparency and trust in centralized supply chain traceability systems by making such data immutable and visible to all supply chain stakeholders, including partners, certifiers, authorities, and customers, without needing a third party to store and validate this information.

However, in the context of BCT-enabled supply chain traceability, two primary issues emerge.

Firstly, the traceability data stored on the blockchain are sourced from oracles like supply chain partners, who might provide inaccurate data due to error or deceit. Therefore, these oracles need to be reliable. Additionally, intermediaries as trusted third parties may still be required to verify the accuracy of the data. This situation creates a paradox in BCT adoption for supply chains: while BCT is sought to eliminate the need for trust and intermediaries, it paradoxically requires pre-existing trust among supply chain partners and the involvement of intermediaries for its implementation. However, if trust already exists among partners or reliable third parties are available to validate the traceability data, then the necessity for BCT becomes questionable.

Secondly, blockchains face scalability challenges, making it impractical to store large volumes of data. Proposed solutions like off-chain storage, specific consensus algorithms, and permissioned blockchains reintroduce a degree of centralization in a system initially designed to be decentralized, potentially compromising the blockchain network's security and the foundational BCT principle of trust elimination.

The question then arises: can BCT truly meet the expectations set for it in supply chain traceability? The lack of empirical studies leaves this answer uncertain, though scepticism regarding BCT's ability to fully eliminate the need for trust is reasonable.

While BCT might not completely remove the need for trust in supply chains, it has been suggested as a mechanism for fostering trust in the traceability of Made in Italy products by making data immutable and accessible to stakeholders.

Italian BCT service providers for supply chain traceability predominantly use off-chain storage. This approach poses risks such as data loss and may undermine stakeholder confidence in the perpetual availability and auditability of traceability data. Therefore, BCT's role in enhancing trust in supply chains might be limited.

Furthermore, the prevalent practice of using centralized apps by providers to display traceability data introduces risks of incorrect data presentation, either intentionally by providers or due to hacking. Utilizing DApps could potentially mitigate this issue.

Third-generation public blockchains are frequently employed in BCT services for tracing Made in Italy products to improve scalability. However, this choice is contentious as such blockchains use consensus algorithms like Proof of Stake (PoS) and Proof of Authority (PoA), which, while enhancing scalability, reduce decentralization and security. This reduction in security could facilitate hacker attacks.

Additionally, the motivation for Italian adopters to utilize BCT in supply chain traceability primarily revolves around its use as a B2C marketing tool. The underlying assumption is that consumers prefer and are willing to pay more for BCT-traced products. Although some surveys and experimental evidence support this assumption, participant bias cannot be ruled out if only the benefits and not the limitations of BCT-enabled traceability were highlighted.

Further, empirical evidence presented in Chapter III shows that Italian firms adopting BCT in their supply chains heavily depend on consultants and providers for knowing and implementing BCT. There is a concern that these firms may not be fully informed about BCT's limitations in enhancing supply chain trust, given the potential conflict of interest where consultants and providers might emphasize benefits over drawbacks.

Interestingly, while adopters recognize B2C marketing advantages of using BCT for supply chain traceability, many lack direct access to performance data of the blockchain service and do not use this data for business decision-making. This could suggest either an inability to interpret the data or its irrelevance. Despite these challenges, most adopters plan to continue using BCT services in the foreseeable future.

Finally, the absence of clear legal frameworks at European, Italian, and regional levels in Marche presents additional risks for firms using BCT, smart contracts, and NFTs.

Therefore, the Thesis advocates for a Triple Helix (TH) approach in the Marche Region to enhance local firms' understanding of BCT for supply chain traceability. This approach could diminish the disproportionate influence of consultants and providers and offer unbiased knowledge to firms.

In conclusion, while BCT seems to bring opportunities for enhancing trust and transparency in supply chains, its effective implementation requires careful consideration of its limitations, scalability issues, and the balance between decentralization and security. This makes informed decision-making, clear legal frameworks, and collaborative TH approaches crucial in the adoption of BCT.

Managerial implications

This thesis offers businesses detailed insights into BCT for supply chain traceability, aiding them in strategic decision-making.

The primary recommendation is for SMEs with limited budgets for digital innovation to first focus on digitalizing their supply chains and adopting proven Industry 4.0 technologies, such as RFID for tracing or QR codes and NFCs on product labels for consumer information access, before considering BCT. This is due to the current lack of conclusive evidence on the benefits of BCT adoption.

However, if firms identify BCT as a potential solution for enhancing trust among stakeholders in data management, they should seek unbiased information from sources like public universities, government institutions, innovation intermediaries, and BCT adopters.

Firms must also consider the inherent trade-offs in blockchain technology, known as the BCT trilemma: the impossibility of achieving scalability, decentralization, and security simultaneously. Therefore, if a proposed blockchain service emphasizes scalability, firms should be aware that it may compromise decentralization and security, potentially failing to build trust among stakeholders.

After implementing BCT, firms should insist on getting direct access to performance data from their blockchain service provider, so that they can assess the service's effectiveness at any moment.

Additionally, understanding the legal implications of using BCT is crucial. Firms should consider the type of data being stored on blockchains, whether it's on-chain or off-chain, and the nature of the blockchain they want to use (e.g., permissionless or permissioned, private or consortium, hybrid), as these factors influence data management responsibilities and compliance requirements.

Policy implications

Regarding policy implications, the study highlights the absence of clear legal frameworks for using BCT in supply chain traceability.

Policymakers are encouraged to establish a regulatory environment that is adaptable enough to foster experimentation with BCT-based applications.

This approach should promote collaborative projects that bring together various academic and non-academic stakeholders, facilitating the exchange of knowledge and the development of effective market and societal solutions. Governmental support through public funding and institutional backing can expedite this process.

Alongside these regulatory efforts, governments should also focus on educating and enhancing citizens' and firms' understanding of BCT and its application in supply chain traceability.

Future research

Research on BCT is still at an early stage and the supposed benefits and costs of this innovative technology, when applied to supply chain traceability, are yet to be proven.

This Thesis provides some interesting insights based on empirical qualitative studies.

However, these are based on the few firms that accepted to be interviewed or surveyed, thus, the results cannot be generalised.

Future research should adopt an interdisciplinary and empirical approach involving technical and socio-economic perspectives to analyse more case studies of real long-term applications of BCT for supply chain traceability.

As Compagnucci et al. (2022) state, the challenges for the application of BCT to supply chains are multifaceted and complex and necessitate a comprehensive approach that considers technical, operational, regulatory, and collaborative aspects to successfully leverage BCT in supply chain management and beyond.

First, benchmarking of the costs and benefits of using BCT compared to other existing centralised software for supply chain traceability is needed, also considering the technical aspects of the different BCT solutions that firms could use. This benchmarking should be based on real implementations of BCT in firms, possibly on longitudinal case studies to follow the implementation of BCT in firms and the associated costs and benefits throughout time. This would give companies relevant insights to understand the profitability of the different blockchain solutions and what profit margin they need to cover the costs of implementing BCT in their supply chain.

Secondly, research must explore how the absence of clear legal frameworks affects the adoption of BCT for supply chain traceability, the use of smart contracts, and NFTs. This should include a comparative analysis across different countries to understand the broader regulatory impact.

Finally, there is a need to rigorously test the assumption that consumers prefer and are willing to pay more for BCT-traced Made in Italy products. While existing studies suggest this assumption may be true, the lack of rigour and transparency in their methodology calls for caution. Future studies should offer participants a comprehensive and balanced understanding of BCT, including both its potential and limitations, so that participant responses are not skewed by biases in the information provided.

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