LUISS

Corso di Laurea Magistrale in Gestione d'Impresa

Cattedra: Economia per il management

How the adoption of blockchain technology and oracles help companies overcome the main supply chain challenges, and how this results in a performance improvement.

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Anno Accademico 2020/2021

Index

Abstract

Purpose – This paper analyses the effects of blockchain on the resolution of supply chain challenges and on the firms' financial performance. Having the capacity to innovate and improve the performances of a firm thanks to its distributed and decentralized properties which ensure traceability, transparency, security and costs reduction. The use of blockchain can be reinforced and exploit by the introduction of oracles which consent the technology to communicate with the ecosystem improving and strengthening all its characteristics.

Design/methodology/approach – Once identified the limitations of the theoretical framework, three initial hypotheses are developed according from what emerged from the literature review and gaps. The gaps are referred to an empirical analysis of blockchain's impact on supply chain practices and business performance. Moreover, we developed three additional hypotheses following the previous ones, but analysing the higher impact that blockchain has when oracles are implemented. We developed a survey using reflective scales for all items to measure the firms' capability in the corresponding domain. The hypotheses are then tested using Structural Equation Modelling and adopting a Partial Least Squares–Path Modelling technique on a dataset composed of 156 firms.

Findings – The empirical results from our first analysis showed that blockchain positively impacts on resolving supply chain challenges, and that this resolution contributes to a financial performance improvement. Contrary to our expectations, blockchain didn't have at all a direct positive impact on business performance, so managers should take into consideration these results when applying the technology. Moreover, from the second analysis it has emerged that thanks to the adoption of certain oracles firms can benefit an improvement in the performance, both directly and trough the resolution of supply chain challenges, even tough the oracles don't improve the supply chain practices, but only their impact on performance.

Originality- This paper takes a different approach towards the study of blockchain and supply chain, by conducting an empirical analysis on the phenomenon. The research explores whether the adoption of blockchain technology impacts on both supply chain challenges and financial performance. Moreover, the research extends to the analysis of the impact of blockchain oracles adoption. This is the first empirical work to evaluate the benefits of such oracles, which can enable the firms' exploit of the blockchain technology.

Keywords: Supply chain; Supply chain challenges; Blockchain; Oracles; Business performance.

Introduction

New technologies are continuously being released and often companies aren't able to exploit them. Indeed, nowadays we speak about a new industrial revolution with the digital technologies that are part of the Industry 4.0. One of the firms' main processes affected by this revolution is supply chain, which is crucial for every firm, considered to be the main skeleton of every industry (Hughes et al., 2019). They are the most affected since traditional supply chains systems are not enough transparent and versatile for the market needs.

So it has become a necessity for firms to try and adopt new technologies, and above all these, blockchain has risen as the most revolutionary and complete technology. This thanks to its decentralized and distributive technology which allows confidentiality, integrity and availability of all transactions and data (Dutta et al., 2020). Building a trustworthy system where once that a record is added is visible to all the stakeholders and immutable, unless all the records are altered.

With this premise said, the main intent of this research is to empirically demonstrate the effects of blockchain on supply chain challenges and on the firm's performance.

Specifically we want to analyse if the blockchain is able to contrast the biggest challenges for supply chains which are growing in complexity due to the offshoring and outsourcing. Indeed, products traceability and transparency are always more challenging, and this leads firms to incur in extremely high transaction and networking costs (Bechini et al., 2008; Aung and Chang 2014). In this case blockchain technology proposes to solve these problems thanks to its properties and capability to record information in an extremely secure way.

Moreover, seeing the great potential of this technology we proceeded to analyse the impact it has on performance. In order to grow and expand their market share, firms must always renew themselves adopting new disruptive technologies (Sheel and Nath, 2019). And blockchain perfectly fits this description, indeed, it has the opportunity to decrease the total costs of a firm and so increase their turnover and financial performance, especially in the long term. Nevertheless, even tough, not directly, blockchain has the capability to indirectly improve the performances, by resolving supply chain challenges, which brings to a performance improvement. Hence, numerous studies highlighted the importance of supply chain practices in order to improve the firms' results.

Finally we enriched our study by analysing how the implementation of oracles impact on the aforementioned blockchain effects. We took into consideration those that are the most common blockchain oracles: software, hardware, inbound, outbound, and human oracles. We conducted an analysis which wants to demonstrate if through their application the effects on the resolution of supply chain challenges and performance is higher than without. Indeed oracles should allow a firm to exploit the blockchain technology thanks to their functionality to serve as a bridge between the blockchain and the entire ecosystem, allowing it to communicate with the off-chain world.

In order to conduct the analysis we gathered the data by administering a survey to an initial sample of 1200 firms, of these only 12% were valid giving us a sample of a total of 156 usable observations which is line

with other empirical studies (Bhatia and Kumar Srivastava, 2019; Shaharudin et al. 2017). To achieve the objectives of the research we used partial least squares path modelling (PLS-PM) and XL-Stat 2021.2.1 software. We started with a comprehensive analysis of the phenomenon and then looked at the eigenvalues given by the model to understand if the scale were representative; we concluded with seven supply chain challenges variables, 4 blockchain variables, and 3 business performance variables.

Once conducted the analysis, we divided the results in two analyses. In the first one we reviewed the results of the hypothesis regarding the impact of blockchain. The empirical results in this case were not completely in line with our hypothesis. Indeed, while the blockchain impacted positively on the supply chain challenges, it doesn't on the business performance. This even tough the results showed that the blockchain adoption indirectly impacts the performance through the resolution of supply chain challenges, thus confirming the importance of supply chain practices in the firms' ecosystem.
Regarding the second analysis which involved the oracles, the results show that not all oracles perform at the same way, indeed some performed very well, improving the results when implemented, while other didn't affect at all the results, since their application doesn't allow the blockchain to perform better. The greatest achievement of this analysis is that the implementation of some oracles allows the blockchain to positively impact the business performance which before was not possible. Moreover, it has emerged that no oracle increased the impact of blockchain on the resolution of supply chain challenges. In conclusion from this analysis, it has emerged that managers should focus on implementing the right oracles in order to exploit the use of blockchain.

Obviously, this study is not free of limitations, and leaves space for future research to deepen the study. Indeed, it could be possible to analyse the effects of different Industry 4.0 technologies that may have different and better results. Moreover, our study doesn't take into consideration the oracle problem based on trust, which could be explored by future research. Finally it may be interesting to conduct the analysis to observe the blockchain impact in different industries.

Literature review

Nowadays, new technologies are being released at an extraordinary rate and often companies aren't able to exploit them. Thus, given the complexity of these new technologies, which are meant to change the whole industry. One of the main processes that is affected by these technologies is supply chain (SC), which is crucial for every company since it involves every step in the life of the product, from the sourcing of raw materials to the delivery of the finished product to the market.
The supply chain management is an enormous sector and is the main skeleton of every industry (Hughes et al., 2019). And as defined by the Council of Supply Chain Management (2018), SCM "encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities." "Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies".

However, traditional SC systems are not versatile and transparent enough to accommodate the growing needs and demands of the future, leading to huge overheads in terms of error handling, costs, administration, and fraud management (Dutta et al., 2020).
This brings to the necessity for firms to adopt new technologies in order to develop and improve their supply chain management which has entered the big data era (Choi et al., 2018; Kuo and Kusiak, 2019).
In this scenario blockchain technology has emerged and has been identified as a disrupted technology that has the potential to transform the SCM through its features (Philipp et al., 2019; Gurtu and Johny, 2019).

Blockchain is an innovative, decentralized, and distributive technology, which maintains confidentiality, integrity, and availability of all the transactions and data (Dutta et al., 2020). It is a shared, open and distributed over the network ledger that can help store and record data and transactions backed by a cryptographic value across a peer-to-peer network (Choi, 2021).
Blockchain is formed through a series of connected blocks, where transactions history can be easily traced through previous blocks making the technology transparent and trustworthy. Each block contains its own unique ID and has the hash of the previous block, thus ensuring transaction security (Dutta et al., 2020). This enables a trustworthy system (Queiroz et al., 2020) where once that a record is added to the chain it cannot be edited without changing the previous records, and this can be done only with the consent of all or the majority of the involved parties. This distributed consensus mechanism is one of the most important features which makes blockchain trusted, secure, and transparent and allows its participating entities to be informed of every event and transaction by creating an irrefutable record in the public ledger, making it an extremely safe system for business operations (Dutta et al., 2020).

In the blockchain technology it has been identified the immense potential to transform every step of SC, from raw materials procurement to distribution to the consumers (Goyat et al., 2019; Babich and Hilary, 2019). Every transaction and operation can be reformed and the product journey can be made more secure and faster.

Therefore, blockchain technologies have the capacity and flexibility to be applied to different SCM contexts. For instance, tracking and providing visibility through the entire supply chain optimises the information flow and generates cost reduction (Wu et al., 2017), at the same time Mackey and Nayyar (2017) concluded that blockchains could improve the supply chain information sharing, making SCM more trustworthy and secure.

So, given the importance of this technology, one of the main objectives of this research is to investigate the following: **What is the impact of blockchain on supply chain challenges and firm performance?**

Despite these significant potential for blockchain to promote changes in all types of supply chains, and the literature interest in blockchain technology applications in SCM fields (Wang et al., 2019), the literature providing concrete application results is still at its infancy. (Queiroz et al., 2020)

Therefore, we seek to fill this literature gap by investigating the benefits that implementing blockchain technology grant the supply chain management, by developing the following research hypothesis:

Hp1: Blockchain technology implementation impacts positively on resolving supply chain challenges:

Over the course of history supply chain have emerged to meet the diverse needs of human societies, to exploit natural resources and to enable humans to engage profitably in commerce and trade. (MacCarthy et al.,2016) So, supply chain practices have evolved and adapted during time alongside with the technology and society development.

During its evolution and adaptation, it has gained more and more importance within the company, expanding its sphere of competence. In essence, Supply Chain Management integrates supply and demand management within and across companies.

Speaking of supply chain challenges (SCC) nowadays, these are always more complex, and supply chain managers, especially in the last years, have faced great changes in every direction.

Indeed, supply chains are expected to experience the heat of the global financial crises in the long term (Sanjoy Kumar Paul et al., 2021). These crises have led to the need for automation of certain services in companies (Business Wire, July 2021).

So, with the growing complexity of global supply chain related to offshoring and outsourcing, coupled with the constant development of new products, and processes, have created product safety and security challenges in various industries (Marucheck et al., 2011). There are many issues that threat supply chain's integrity, and that are more highlighted by the literature, and at the same time considered more crucial are only few. Among these, one of the biggest challenges is considered to be the traceability and transparency of the products (Francisco and Swanson, 2018; Bechini et al., 2008; Aung and Chang 2014; Opara, 2003). Indeed, Tian (2016) in his research demonstrated that traditional supply chain logistics pattern cannot match the demands of the market anymore, and so building a supply chain transparency and traceability system is becoming more and more urgent (Tian, 2016). Improving the traceability allows to combat the rising and increasing of counterfeit products that play a vital role in product manufacturing industries and which directly affects the sales and profit of the companies (Jayaprasanna et al., 2021).

As stated previously Blockchain technology is rapidly gaining more and more popularity, spreading with multiple industries exploring their capabilities and new blockchain use cases springing up on a daily basis (Phan The Duy et al, 2018).

This coincides with the growing demand of automatization and continuous improvement and optimization of SC practices, and the BT has a tremendous potential to eliminate intermediaries and to make SCM more efficient (Gurtu, A. and Johny, J., 2019). It indeed, have the potential to revolutionize trust, security, and relationship with data in the online world (Phan The Duy et al, 2018). It brings lots of enthusiasm, as experts consider it to offer enormous potential to transform the supply chain and disrupt the way we produce, market, purchase and consume goods (Dobrovnik et al., 2018).

Nevertheless, as anticipated previously, the manufacturing of goods is becoming more and more complex, also due to the increased number of intermediaries between the producer and the final consumer (Rita Azzi

et al, 2019).
Hence, there's little knowledge of the product origins, processing, or shipping journey (Van Kralingen, 2016). So, the greatest supply chain challenges become not only quantitative but also qualitative. The main challenge of the supply chain remains in the transaction costs, traceability, transparency and data management system (Abeyratne and Monfared, 2016).
Blockchains are expected to add the most value to supply chains through their extended visibility and product traceability, and this will likely be the point at which the blockchains sees large-scale deployment (Wang et al., 2019).

The blockchain gives the firm the capability to record information by authorized actors making it extremely secure through immutable and transparent transactions that are visible to all supply chain members. This by creating a block for each transaction following the product's digital footprint, from manufacturing to distribution and sale (Patel et al., 2017).
This level of transparency and visibility is essential for improving the traceability of products and ensuring product authenticity and legitimacy (Casey and Wong, 2017; Lu and Xu, 2017; Mansfield, 2017).
This is the greatest possibility to contain the commerce of counterfeit products, the use of unethical practices, and behaviours and actions by suppliers that are usually non detectable. Giving the possibility to build a sustainable supply chain (Saberi et al., 2019).
Even tough, as stated previously, real-life experimentation is still at its early stage, from the literature it appears evident the potential of blockchain technology for the development of a sustainable supply chain. This brings us on thinking the great opportunity that this technology might give to a firm, beyond resolving the main supply chain challenges, and so we hypothesize the following:

Hp2: Blockchain technology implementation impacts positively on the firms' performance.
Due to the increasing blockchain investments it is crucial to understand whether blockchain provides a competitive advantage and an improvement to the firms' performances (Lui and Ngai, 2019).
However, the existing literature provides limited evidence on the benefits of blockchain adoption and more in general of IoT technologies, since it focuses more on the development and adoption of the technologies, while scarce research addresses the impact on firm performance. One of the first to analyse the possible financial impact of these technologies have been Tang and Huang (2018) by analysing the business value of IT. This term refers to the impacts of the organizational performance of IT, including productivity enhancement, profitability improvement, cost reduction, competitive advantage, inventory reduction, and other measures for performance (Kauffman and Kriebel, 1988; Hitt and Brynjolfsson, 1996; Devaraj and Kohli, 2003). By developing this hypothesis, we intend to fill this gap and explore how the blockchain adoption impacts and improves the firms' financial performance.
The financial performance metrics are a subjective measure of how well a firm can use assets, based on its primary mode of business, and generate revenues. They also help in short-term and long- term forecasting and growth, which can be identified as financial performance analysis (Thang and Huang, 2018). In order to investigate the impact on performance researchers often exploit two methods which have been identified and

exposed by Thang and Huang (2018). One of these, which is the one we will follow in our analysis, is to adopt an accounting-based method to measure accounting performance such as market share, ROI, profits and cost savings.

With this said, it is known that in order to survive, grow, and improve their performance in their business environment, firms must constantly search for new opportunities, and introduce and adopt new and potentially disruptive technologies (Teece et al.,1997; Sheel and Nath, 2019 ; Craighead et al., 2017). The blockchain technology is one such disruptive technology that has rapidly gained traction among industry practitioners (Büyük ̈ozkan et al., 2021; Chen et al., 2019; Ji et al., 2022; Kamble et al., 2020).
From an operational perspective, blockchain has a strategic value for firms by enabling cost reduction and eliminating middlemen (Carson et al. 2018) and the findings of (Lui and Ngai, 2019) show that blockchain adoption provides an improvement in market value and stock returns meaning so, a financial improvement in the long run. So, it appears fundamental the need to eliminate middleman and automate business operation in order to gain a sustainable financial improvement. Indeed, according to Chae et al. (2018), businesses are increasing financial performance with the help of digital business strategy which digitalize their infrastructures, automate traditional industry operations, and replace the human workforce with automating business processes. This is a primary source for increase financial performance and obtain of a competitive advantage (Benitez et al. 2018; Liu et al. 2013; Peng et al. 2008). Concluding, it has been demonstrated that the adoption of blockchain technology impacts positively both on market performance and on financial performance (Bag et al., 2022).
Moreover, according to Sheel and Nath (2019) blockchain technology can indirectly lead to better firm performance by improving supply chain adaptability, alignment, agility, trust and transparency.
We propose to investigate on this theme by developing the following hypothesis:

HP3: Resolving supply-chain challenges impacts positively on the firms' performance.
As stated previously supply chain plays an always more important and fundamental role in the firm's development. Over the last few years this role has become even more central due to the economics complications. This made the environment extremely mutable and dynamic, characterized by continuous and unexpected demand variations.
With this said it appears clear that companies must invest and improve constantly their supply chain management in order to control and optimize the firm's performances.
This because thanks to an excellent SCM companies are able to become more and more competitive and increase customer satisfaction, which is their final goal (Advance Knowledge Consulting, 2022).
Nevertheless, the literature highlights the role of IT in supply chain integration that leads to an improvement of the firm's financial performance (Prajogo and Olhager, 2012; Liu et al., 2016; Qrunfleh and Tarafdar, 2014). It's shown that thanks to the enablement of collaboration and sharing data blockchain makes supply chain agile which brings to a financial performance improvement (Ngai et al., 2011). Moreover, supply chain practices play a vital role to develop sustainability and improve businesses financial performances (Iranmanesh et al., 2019).

Numerous studies investigated the effect of various SCM-related activities on organizational performances (Menor et al., 2007; Boon-itt et al., 2011; Zimon 2021) and many focus on financial performance since it reflects the success of a company's plans and operations numerically (Yang et al., 2011; Hofer et al., 2012; Feng et al., 2018). Hence financial performance can be described as the degree to which profit-oriented objectives are produced by and organization (Jum'a et al.,2021 ; 14) Among the many measures for financial performance the ones mostly used are, as anticipated previously, sales, sales growth, market growth and return on investments and assets (ROI, ROA) (Hofer et al., 2012).

Among the SCM practices and challenges analysed by the literature, the ones that have shown a higher correlation with financial performance are those regarding the transaction costs, the information sharing and quality level of information (Li et al., 2006; Cook et al., 2011). Considering that blockchain directly impacts these supply chain challenges it should indirectly improve the firms' financial performance as demonstrated by the study of Jum'a et al., 2021 it has been revealed that SCM practices significantly leads to financial performance improvement.

Blockchain oracles

In order to exploit the blockchain's impact on both the resolution of supply chain challenges and on the firm's financial performance, is necessary for a firm to adopt oracles. Indeed, the birth of these was due to the desire to expand the types of collaboration possible on blockchains.

From this we developed our second intent of the research which can be resumed by the following question:

Does the implementation of oracles allow the blockchain to perform better in terms of supply chain challenges resolution and business performance?

Speaking of oracles, their fundamental functionality is to serve as bridges between the network and the outside world, this because blockchains and smart contracts cannot access off-chain data (data from outside the network) **(Wirex, 2022).** The literature around this topic is quite scarce, indeed it mainly focuses on explaining the functionality, how they integrate the BT, and the risks that they bring. This supports the view that blockchain oracles are still a widely neglected subject, despite their crucial importance (Caldarelli G., 2022). The above-mentioned risk is given by the fact that if the oracle is vicious and gives wrong information it could compromise the whole contract. Blockchain/oracle service may be outsourced to a third party (Kamath, R. 2018), even though it doesn't completely solve the problem since the information are given by the company.

Research on the subject outlines that for some products subject to a procedural guideline, providing false information would result in fines or license revocation, (Caldarelli G. 2020) so the company has little incentive to cheat information provided on the blockchain through a trust model.

Researchers agree that, for supply chain management, there is the need for a third-party to supervise and ensure data integrity on the blockchain, their relationship should then be formalized through a "trust model", in order to be reliable and overcome the oracle problem (Caldarelli G. 2020)

With said, it is fundamental that firms overcome this problem in order to adopt oracles and maximise the blockchain potential. So, our work's intent is to go beyond the previously developed hypothesis and extent

its analysis in proving that the use of blockchain and its result are more efficient and have an higher positive impact both on supply chain challenges and on the firm's performance. Therefore, we differentiate between firms that invested in oracles and those who didn't, and so we proceeded formulating the following hypothesis:

Hp1x: For firms that invested in oracles: software (a), hardware (b), inbound information (c), outbound information (d), and human (e), the positive impact of Blockchain technology on Supply-chain challenges is higher than for those who didn't.

Hp2x: For firms that invested in oracles: software (a), hardware (b), inbound information (c), outbound information (d), and human (e), the positive impact of Blockchain on the performance is higher than for those who didn't.

Hp3x: For firms that invested in oracles: software (a), hardware (b), inbound information (c), outbound information (d), and human (e), the positive impact of Supply-chain challenges resolution on performance is higher than for those who didn't.

As stated previously, an oracle is an interface that delivers data from external data outside the blockchain, this meaning that they are third-party services that provide the blockchain with external information, serving as bridges between blockchain and the outside data (Beniiche, 2020). It's fundamental to point out that an oracle is not the data itself, but rather the layer that queries, verifies, and authenticates external data (Beniiche, 2020). There are different kinds of oracles with different characteristics and functions, that can deliver different types of data depending on what it is designed for, so depending on the requirements and industry. In this paper we focus on five of them, which are the most used and common, and after briefly describing how they work we will proceed to illustrate how they can improve the impact of blockchain on performance and supply chain challenges.

Starting with the software oracles (also known as deterministic oracles), they interact with every type of online source of information, as for example online databases, websites, and servers, and transfer it to the blockchain. Obviously, this makes them the most common and used one.

Moving on to hardware oracles, these are essential for the blockchain communication with the real world. They basically consist in devices like QR scanners, tags, and robots that transfer information form the real world and make it available to the blockchain. A concrete supply chain example could be a sensor that checks if a truck transporting goods has arrived at a loading bay. If it does, it relays the information to a smart contract that can then execute decisions based on it (Beniiche, 2020).

Then we have inbound and outbound information oracles, these are essentially the opposite. Having the first transmitting information from external sources, and the second one transmitting information to the external world.

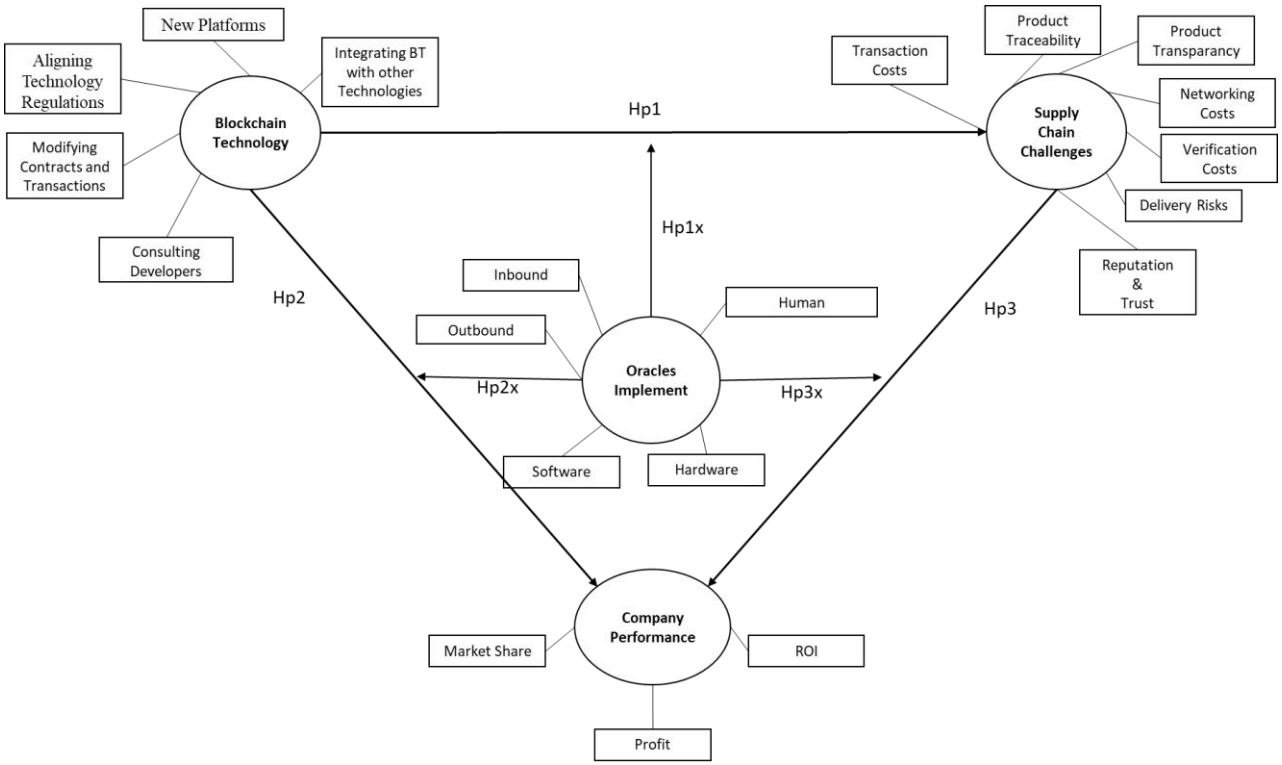
Lastly, we have human oracles. They basically consist in individuals with specialized knowledge and skills in a particular field that can research and verify the authenticity of information from various sources and translate that information to the blockchain (Beniiche, 2020). Since human oracles use cryptography to

authenticate their identity, the chances of a fraudster impersonating them and giving tampered data are extremely low, and that guarantees the validity and authenticity of the data.

Thanks to this preliminary information now it is much easier to understand why and how the blockchain impact on the firm is much higher thanks to the correct use of oracles.

This because the oracles give the chance to exploit the blockchain technology and increase all the advantages given by the use of it. Indeed, combining BCT with other relevant technologies can largely improve the benefits and enhance its features (K¨ohler & Pizzol, 2020).

Figure 1 summarizes and displays all the research hypothesis proposed in this research.



Methodology

Survey design and sample description.

In order to test our hypotheses, we gathered the primary data by designing and dispensing a survey. We then proceeded collecting information about the respondents (e.g., industry, country, size, and company type), the firms' investments in blockchain technology, the management of supply chain challenges, and their interaction with the ecosystem, as well as the firms' business performance in the last two years. The questionnaire, which was composed of eight sections and included eighty-two questions also referred to other topics than the ones analysed in this research (Naclerio, 2020). We requested feedbacks, for testing the reliability and completeness of the survey, by administering the survey to a pool of experts as professors, Ph.D., students, and managers. The questionnaire was modified and improved accordingly and its is reported in the appendix, **Table A1**. In order to collect the data we administrated the survey to firms selected through

Bureau van Dijk Electronic Publishing. In order to consider a valid sample, we checked if the firms adopted Industry 4.0 technologies as the blockchain technology and oracles. This because our research is based on the digital transformation of firms.

We submitted the survey to an initial sample of 1200 firms. We asked the companies to whom we sent the survey if it could be completed by the supply chain manager, since the research is founded on supply chain activities and improvement. When unavailable, the questionnaire was completed by other managerial figures linked to the supply chain activities, such as operations manager, logistics, sales, procurement, purchasing, and distribution. Once we obtained the majority of the responses, we proceeded to exclude those invalids, and ended up with 156 usable observations, which represent the 12% of the total companies we targeted (1200). The sample size is in line with previous empirical research in the same domain, indeed, for example, the sample size was 138 firms in Bhatia and Kumar Srivastava (2019), 150 firms in Shaharudin et al. (2017), and 141 firms in French and LaForge (2006).

Our sample's characteristics can be resumed as following: the majority (52%) have average sales over 100 million, and a workforce (53%) over 200 employees. Great part of the respondents were supply chain managers (52%), and firms mostly operated in manufacturing (36%) and retailing (23%).

Regarding the industry the majority operated in food and beverage (22%), and fashion (12%).

Table1 displays all the details regarding both the respondents and the composition of the sample.

The first approach to assess nonresponse bias was of comparing early and late respondents. In this case no significant difference was found by conducting a one-way analysis of variance (ANOVA) on all items, so nonresponse bias was not present. We didn't find any nonresponse bias also after checking trough the demographic size variables, the number of employees and sales.

We used a seven-point Likert scale to measure the items, by describing the level of agreement to a question. Where, 1 meant "not at all in agreement" and 7 meant "full agreement". Considering the importance of the difference between the items, the analysis was conducted at the original scale for all items.

Sales	#	%	Employees	#	%	Country	#	%	Company type	#	%	Professionals	#	%	Industry	#	%
< 10	11	7.0%	< 50	13	8.9%	Europe	115	73.2%	Manufacturer	56	35.7%	SC Manager	82	52.2%	Food & Beverage	34	21.7%
10-50	37	24.2%	50-99	40	25.5%	USA	25	15.9%	Wholesaler	30	19.1%	Logistics Manager	12	7.6%	Fashion & Apparel	18	11.5%
50-100	26	16.6%	100-200	20	12.7%	Asia	4	2.5%	Distributor	13	8.9%	Operations Manager	13	8.3%	Medical & Healthcare	12	7.6%
> 100	82	52.2%	>200	83	52.9%	Other	12	8.3%	Supplier	21	13.4%	Sales Manager	3	1.9%	Automobile	11	7.0%
									Retailer	36	22.9%	Production Manager	8	5.7%	Mechanic	7	4.5%
												Purchasing Manager	2	1.3%	Energy	7	4.5%
												Procurement Manager	8	5.1%	Furniture	6	3.8%
												Distribution manager	2	1.3%	E-commerce	5	3.2%
												Other	26	16.6%	Aerospace	3	2.5%
															Sport	4	2.5%
															Entertainment	4	2.5%
															Glass	3	1.9%
															Cement	3	1.9%
															Telecommunications	2	1.3%
															Luxury	2	1.3%
															Beauty & Cosmetics	2	1.3%
															Electrical and electronics	2	1.3%
															Chemical	1	0.6%
															Other	30	19.1%
Total	156	1		156	1		156	1		156	1		156	1		156	1

Table 1– Sample description

Estimation methods

To achieve the objectives of this study, we used partial least squares path modeling (PLS-PM) and the XL-Stat 2021.2.1 software. The core of PLS is a family of alternating least squares algorithms that emulate and extend principal component analysis as well as canonical correlation analysis (Henseler, J. et al., 2016). PLS-PM is a component-based estimation algorithm that aims to predict the relationships between constructs and provides their scores at the original scale (Agyabeng-Mensah et al., 2020). Furthermore, PLS-PM does not require any distributional assumption for the data (in contrast with a maximum likelihood covariance-based approach) (De Giovanni, P., 2022). This method has become a full-fledged estimator for structural equation modelling (SEM) over the past decade (Jose Benitez et al., 2020). Furthermore, PLS path modelling results can be assessed globally (i.e. for the overall model) and locally (for the measurement models and the structural model (Henseler, J. et al., 2016). Finally, PLS-PM provides less biased estimates than other approaches to structural equation modeling sample sizes lower than 200 observations, while achieving the same power above 200 observations (Chin, 2010).

These motivations underlie the use of PLS-PM in various fields of business research. Such as business administration (Jose Benitez et al., 2020), supply chain management (Colicev, A. et al., 2016), and digital transformation (De Giovanni and Cariola, 2020).

Model Assessment

According to the meaning that we give to each of our constructs, we use reflective scales for all items to measure the firms' capability in a certain domain. Therefore, we follow the procedure suggested by Colicev et al. (2016) and Agyabeng-Mensah et al. (2020) to check for the internal consistency of constructs as well as to verify both the convergent and the discriminant validity.

We started with a comprehensive analysis of the phenomenon which included eight blockchain variables, seventeen supply chain challenges variables, and six performance variables. From this we started running the model in order to understand if the scales were significant for what they represented and so respectively: Supply chain challenges, Firm's performances, and Blockchain technology.

In order to understand if the scale is representative firstly, we looked at the eigenvalues given by the model, if there was only one higher that 1.0 the scale was representative, instead if there are more eigenvalues higher than 1.0 we needed to understand which variables were not representative for the scale. In order to do so we proceeded with a one-piece analysis and looked at the correlation between the variables, and so if this number was high, we proceeded to include them, otherwise if there was a statistically divergence (at least 0.4) we excluded them from the model.

Regarding the supply chain challenges construct (SC), which were the more problematic for the model, in the first model run we had 3 eigenvalues higher than 1.0. So, we proceeded with the one-piece analysis. In the first analysis we didn't find any statistically divergent value. Indeed, we proceeded with the second supply chain challenges analysis, and here we found all the variables included between -0.381 and -0.143

except for five variables that were positive and with a divergence higher than 0.4 and so we removed them from the dataset and advanced by re-running the model with the same structure as before except for the 5 divergent variables. We repeated this procedure three times until there was only one eigenvalue higher than 1.0 and all the variables were significant for representing supply chain challenges.
From this operation we have obtained in our final model the final scale, that went from the first seventeen analysed dimensions to seven of them that are all extremely significant and related to supply chain challenges.
These are *Transaction Costs* (SC1), indeed the cost of carrying out an exchange which in certain situations be extremely high. *Product Traceability* (SC2) which is the capability to identify, track and trace elements of a product as it moves along the supply chain. *Product Transparency* (SC3) when companies know where and how their goods are produced, based on reliable data, and then communicate that knowledge both to internal and external stakeholders. *Networking Costs* (SC4) the process of building and modelling a supply chain to better understand the costs and time associated with bringing goods to market with the resources and locations available. *Delivery Risks* (SC5) the chance that a counterparty may not fulfil its side of the agreement by failing to deliver the underlying asset of a contract. *Verification Costs of Suppliers and Third Parties* (SC6) the process of confirming that a supplier or third party the company wishes to contract with is both legitimate and reliable. *Reputation and Trust* (SC7) which are always more important since great part of decision making is based on them.

Regarding the Business Performance construct (BP), we make use and revise the scales developed by Bhatia and Kumar Srivastava (2019), since they consider both economic and environmental components when studying performance within the context of Supply Chain (De Giovanni, P. 2022). Alongside these revised scales, we also considered other traditional ones like market share and return on investments (ROI) since they are usually included by many contributors (e.g. Agyabeng-Mensah et al., 2020).
Once grouped the scales we had a total of six variables, even tough, also in this case running the model we had more than one eigenvalue over 1.0 so we proceeded with the same one-piece analysis mentioned above. From this we found that in total three of the variables were statistically divergent and so we proceeded to eliminate it. Therefore, our final scale includes in total three items. *Market share* (BP1), which indicates a firm's performance and size. *Profits* (BP2), which informs on a firm's capacity to generate financial value. *ROI* (BP3), which indicates a firm's capacity to recover investments through economic outcomes.

Finally, regarding the Blockchain construct (B), due to the newness of this technology, there is a lack of research on scale development. Therefore, we propose hereby a measurement scale according to the ingredients emerged from the literature review with the purpose of exploring the practices that managers adopt when implementing this technology (De Giovanni, P. 2022). The first development of the scale consisted in seven blockchain adoption indicators, but once running the model for several times, following the procedure above mentioned we ended with five significant variables. The first of these relates to working with blockchain developers (B1) in order to implement the technology within the business model. Then, we

included the actions finalised in modifying the management of contracts and transactions (B2), like for example the use of smart contracts, and the developing of new exchanging platforms for the business(B3). Finally, we have the last two variables which consist in integrating blockchain technologies with other new or current digital technologies (B4) and aligning the technology requirements with the regulations. These last two indicators are fundamental both for the good output of the integration, and especially for the full exploitation of its potential.
In **Table 2** are exposed the final items' list and allows for the detection of the cross-loadings associated with each construct. As displayed by the **Table 2** all items have loadings over 0.6 and so constitute important items in term of content validity.

So, once we had the final model it was necessary to analyse its goodness, and this has been done thru the ad hoc goodness of fit index (GoF) which is equal to 0.806 and therefore acceptable since it must be over 0.8. In **Table 3**, are displayed the construct reliability indexes and it shows that all of them are higher than the threshold 0.7. This highlights the strengths of our constructs in term of internal consistency (De Giovanni, P. 2022). Furthermore, we assess the convergent validity by evaluating the outer loadings and applying the Average Variance Extracted (AVE) criterion. The results found are exposed in the **Table 3**, and they demonstrate that the AVE for each construct take values close to the recommended threshold of 0.5 (Chin,2010). So, the overall convergent validity can be considered as satisfactory. Finally, the comparison between the AVE and the squared correlation among the constructs informs on the discriminant validity, which reflects the difference of a construct comparatively to the others Furthermore, each item belonging to a certain construct should have a higher loading than the loadings associated to the other constructs (De Giovanni, P. 2022). According to the developments illustrated our model meets both of these criteria. Summarily, we achieve satisfactory levels of internal consistency, convergent validity, and discriminant validity. Consequently, the structural model can be considered as valid and subsequently analysed.

	Supply Chain Challenges	Business Performance	Blockchain
Transaction Costs	0.674		
Product Traceability	0.755		
Product Transparency	0.806		
Networking Costs	0.653		
Delivery Risks	0.787		
Verification Cost of Suppliers and Third Parties	0.739		
Reputation and Trust	0.677		
Market share		0.830	
Profits		0.836	
ROI		0.820	
Consulting developers			0.838
Modifying the management of contracts and transactions			0.792
New platforms			0.805
Aligning the technology requirement with the regulations			0.802
Integrating blockchain technologies with other digital technologies			0.819

Table 2. Summary of cross loadings.

Index of composite reliability	Average variance Extracted (AVE)	Construct	Blockchain	SC Challenges	Performance
0,871	0,658	*Blockchain*	1,000	0,412	0,052
0,853	0,532	*SC Challenges*	0,412	1,000	0,170
0,772	0,686	*Performance*	0,052	0,170	1,000

Table 3. Inter-construct squared correlations and reliability measures.

Results and discussions.

Analysis I

In this section are showed the empirical results of the first three hypothesis. The general outcomes of our final model, as stated previously, shows a relative goodness-of-fit index of 0.806. The results from this first *Analysis I* are displayed in the **Table 4** in which we report the result "Supported" when a research hypothesis is empirically confirmed or "Not Supported" otherwise.

Regarding the first hypothesis **H1** is supported (coef. = 0.642 and p-value < 0.01) confirming and highlighting that blockchain implementation for a firm, impacts positively on resolving and improving the supply chain challenges. Contrary to this result **H2** finds no support (coef. = -0.062 and p-value >0.52) but as seen having a high p-value, the result is not statistically significant and so this result must be carefully

examined in a case-by-case basis, due to its low robustness. So, from our analysis has emerged that blockchain doesn't have direct impact on the firms' performances. Moving on to our third hypothesis **H3** (coef. = 0.452 and p-value< 0.01) and so it is confirmed and statistically relevant, it has a positive and significant support by the analysis. Meaning that the resolution of supply chain challenges positively impacts positively on the firms' financial performance.

Research hypotheses	Coefficients	Results
H_1: Blockchain technology implementation impacts positively on resolving supply chain challenges	0.642***	Supported
H_2: Blockchain technology implementation impacts positively on the firms' performance	*-0.062#*	Not supported
H_3: Resolving supply chain challenges impacts positively on the firms' performance	0.452***	Supported

****p=value<0.01; **p=value<0.05; *p=value<0.1;# italic values are not significant*

Table 4. Results of the research hypothesis

Analysis II Hypothesis testing of the blockchain oracles.

In this section, we focus on the analysis of the blockchain oracles, that is, that if the firms proceed to adopt blockchain oracles the positive impact of blockchain on supply chain challenges and on the firm performance is higher. To carry out this analysis, whose result are displayed in **Table 5**, we start by distinguishing the sample between firms that adopted and implemented oracles and firms that only adopted blockchain, but no oracles were implemented.

As stated in the methodology, we had a total of 156 usable observations, and we distinguished the two groups by using a dummy variable, we did this procedure for each one of the single oracles, so we tested the three hypotheses (Hp1x, Hp2x, and Hp3x) for every single oracle: software, hardware, inbound, outbound, and human/social oracles.

Software Oracles.

Starting with the software oracles, the 62% (97) of the sample adopted the oracle while 59 firms didn't. From the multigroup (1) analysis, for **Hp1X** it has emerged that there is no significant difference between adopting or not software oracles (Δcoef.= 0.015 and p-value> 0.089) meaning that the implementation of software oracles on blockchain doesn't have a higher impact on resolving supply chain challenges. Moving on to our second hypothesis, as the first, it revealed to be not significant **Hpx2** (Δcoef. =0.014 and p-value > 0.96), therefore the implementation of software oracles doesn't give any higher impact on the firms' performances compared to the solely blockchain adoption. Finally, regarding the third hypothesis **Hpx3** (Δcoeff.0.394 and p-value <0.1), there is a significant difference between the implementation of software oracles and not. Meaning so, that the resolution of supply chain challenges has a higher impact on performance when software oracles are adopted. In conclusion, the indirect effects of implementing software oracles are statistically different and significant (Δcoef. 0.26 and t-value > 2).

Hardware Oracles.

Regarding the hardware oracles 95 (61%) of the analysed firms adopted them while 61 of them didn't. The multigroup analysis (2) shows that hardware oracles implementation works better than the previous one. Indeed, while the first hypothesis **Hpx1** (Δcoef. = 0.060 and p-value >0.59) showed that there isn't a significant difference between adopting or not the oracle for the resolution of supply chain challenges. The second and third hypothesis results, **Hpx2** (Δcoef. = 0.587 and p-value < 0.01) and **Hpx3** (Δcoef. = 0.468 and p-value < 0.05) show a significant difference between the implementation of hardware oracles and not, meaning that its impact on the firms' performances is higher as it is the impact of the resolution of supply chain challenges on performance. As previously, also in this analysis, the indirect effect is statistically different significant (Δcoef. = 0.29 and t-value > 2).

Inbound Oracles

The third type of oracle we analyse are the inbound oracles. These were adopted by the 57% (89) of the sample. The multigroup analysis (3) shows results similar to the ones given by hardware oracles implementation. Indeed, the first hypothesis is not supported since there was not a significant difference between the implementation and not in resolving supply chain challenges **Hpx1** (Δcoef. = 0.06 and p-value > 0.57). As the previous analysed oracle, the second and third hypothesis are supported since they show a significant difference between the implementation of inbound oracles and not **Hpx2** (Δcoef. = 0.52 and p-value < 0.01), **Hpx3** (Δcoef. = 0.51 and p-value < 0.01). The indirect effect is considered significant (Δcoef. = 0.31 and p-value > 2), therefore the group that adopted inbound oracles performed best.

Outbound Oracles and Human Oracles

Finally, we will now analyse the results given by the multigroup analysis (3,4) including outbound and human oracles. We analyse these two together since they reported the same results.

Outbound oracles are the ones which the majority of the sample implemented with a percentage of 70% (109), on the contrary Human oracles have been the ones least implemented with only 46% (72) of the sample adopting them.

In this case for both of the oracles, none of the hypothesis were supported. No significant difference has emerged from our analysis. Indeed, for the outbound oracles we found **Hpx1** (Δcoef. = 0.01 and p-value > 0.39), **Hpx2** (Δcoef. = 0.27 and p-value > 0.31) **Hpx3** (Δcoef. = 0.12 and p-value > 0.59 For the human oracles the multigroup test showed **Hpx1** (Δcoef. = 0.12 and p-value >0.2), **Hpx2** (Δcoef. = 0.02 and p-value > 0.92), and **Hpx3** (Δcoef. = 0.05 and p-value > 0.8).

In conclusion, these two oracles are the only ones where also the indirect effects are not significantly different.

Research hypotheses	Coefficients	Results
***H*$_{1x}$*: For firms that invested in oracles the positive impact of Blockchain technology on Supply-chain challenges is higher than for those who didn't.*		
Software	*0.02*$^{\#}$	Not Supported
Hardware	*0.06*$^{\#}$	Not Supported
Inbound	*0.06*$^{\#}$	Not Supported
Outbound	*0.01*$^{\#}$	Not Supported
Human	*0.12*$^{\#}$	Not Supported
***H*$_{2x}$*: For firms that invested in oracles the positive impact of Blockchain on the performance is higher than for those who didn't.*		
Software	*0.01*$^{\#}$	Not Supported
Hardware	*0.59****	Supported
Inbound	*0.52****	Supported
Outbound	*0.27*$^{\#}$	Not Supported
Human	*0.02*$^{\#}$	Not Supported
***H*$_{3x}$*: For firms that invested in oracle the positive impact of Supply-chain challenges resolution on performance is higher than for those who didn't.*		
Software	*0.39**	Supported
Hardware	*0.47***	Supported
Inbound	*0.51****	Supported
Outbound	*0.12*$^{\#}$	Not Supported
Human	*0.05*$^{\#}$	Not Supported

****p=value<0.01; **p=value<0.05; *p=value<0.1;# italic values are not significant*

Table 5. Results of the oracles research hypothesis

Discussion and managerial insights

Managerial insights from Analysis I

For the first three hypothesis in our first Analysis I the empirical results demonstrate that the implementation of blockchain technology impacts positively on resolving supply chain challenges, and that this resolution contributes in a financial performance improvement. These results are in line with the present literature (Queiroz et al., 2020; Gurtu and Johny, 2019; Sheel and Nath, 2019; Wu et al., 2017) showing the benefits brought to the supply chain management by blockchain adoption.

Regarding these challenges it is interesting how the results given show that the blockchain have a high impact on them. Hence, it will be possible for a firm adopting the blockchain technology, to improve those that from the literature emerge to be the main supply chain practices (Lui and Ngai, 2019; Chae et al. 2018). Indeed, it would improve the traceability and transparency of the product thanks to its capacity to inalienably store the path of goods along the entire life cycle of a product. Thus, reducing all those costs linked to the verification of the supplier and more in general of the whole network and transaction costs.

Moreover, our results shows that the improvement of all these practices directly improve the reputation and trust gained by the firm adopting the blockchain. Interestingly, the results show that the resolution of the supply chain challenges has a positive impact on the increase of the firms' financial performances. This

result supports what is theorized by the literature and in other research. (Iranmanesh et al., 2019; Zimon 2020; Menor et al., 2007) Indeed, our results emphasise the vital role played by supply chain management in a firm, giving the possibility, if adopted the right practices, to highly increase a firm's market share and profits.

When it comes to blockchain directly impacting business performance, our findings reveal that the implementation of this technology does not positively influence the performance. From a managerial point of view, firms that are investing in blockchain adoption should be aware that it isn't certain that this will transform in an improvement of the performance. This result contrasts with the empirical studies of Ko et al. (2018) and Lui et al. (2019) which show a positive link between blockchain and performance. Moreover, our results are in line with other studies present in the literature among them there are Kouhizadeh et al. (2020), and van Hoek (2019), and De Giovanni (2022). Where it is highlighted the not so clear blockchain adoption implications regarding business performance.

Nevertheless, firms can see their financial performance improving indirectly from the blockchain adoption. Meaning that, as stated previously, trough the resolution of supply chain challenges, firms can see their performance improve.

Managerial insights from Analysis II.

When investigating in blockchain oracles, our findings reveal the possible higher positive impacts of blockchain on supply chain challenges and performance. To our knowledge, this is the first empirical study analysing how the implementation of oracle impacts on the blockchain adoption.

Not consistent with our expectations, only in some cases the implementation of oracles, consented the blockchain adoption to amplify and improve its results. In order to well explain the results we must singularly analyse each oracle we studied. Starting with the ones who have the best overall results, we have the inbound oracles. In this case they guarantee an improvement in the performance both directly and indirectly, meaning that trough the adoption of these oracles firms may increase the impact of the blockchain on the performance which previously wasn't positive and also increase the performance through the resolution of supply chain challenges. This gives managers the opportunity to improve the financials and exploit the use of blockchain. For the second category of oracles, the hardware oracles, performed similarly to the previous one, increasing the performance of blockchain both on the financial aspect and on the supply chain management impact on performance. So, it gave the same results as the inbound but with a slightly lesser difference. The third and last oracles that performed positively are the software ones. It has emerged that they only indirectly impact positively the financial performance, through the resolution of supply chain challenges.

Finally, we can group the last two oracles since they gave the same results. Indeed, for both outbound and human oracles, no significance difference has emerged. So these don't impact positively neither on the resolution of supply hain challenges, nor on the financial performance.

Meaning that the adoption or not of these don't bring any type of advantage, among those studied, to a firm.

In conclusion from this second analysis, it has emerged that the implementation of oracles, contrary to our

expectations, won't improve the resolution of the supply chain challenges, but surprisingly in some cases, with some oracles it gives the opportunity o improve a firm's financial performance both directly and indirectly. We define it surprisingly since with the sole adoption of blockchain this wasn't possible.
From what emerged from our research managers should focus their efforts in implementing the right oracles, because some of them won't produce any consistent result. Indeed, it is important to underline how the outbound oracles, which were the ones that performed worst, were the most adopted by our sample. So, it will be crucial for managers choose wisely which blockchain oracle to adopt in order to exploit this technology and see an improvement in supply chain management and performance.

Theoretical contributions

This study connects three research areas, which are, supply chain, blockchain technology, and blockchain oracles, and focuses on these targets.
The first, consists of studying those that are considered to be the biggest and toughest supply chain challenges firms face in their supply chain management. This study enriches the literature by highlighting these challenges and explaining why are crucial for a firm.
The second focus and contribution to the literature is the empirical analysis on the impact that blockchain technology has on the supply chain. Indeed, blockchain is meant to be revolutionary for all sectors, guaranteeing a great help in resolving the challenges that supply chain face. This because of its properties such as a distributed and decentralized system that allows to improve transparency, traceability, and reduce all those that are the networking costs, giving a firm and its products higher reliability. So, these technologies propose to solve many of the concerns emerged by the literature (Queiroz and Wamba, 2019; Villa, 2001).
The third theoretical contribution focuses on the adoption of blockchain oracles. In this case, to our knowledge, there was no empirical study present in the literature. The oracles that are a blockchain implementation that allows the technology to communicate with the outside world, and so giving the possibility to exploit this technology in all of its uses. In present literature it is affirmed how these oracles work, and most importantly what are the main issues and problems derived by their application. With this contribution we don't analyse these issues but directly focus on the positive effects they bring, and in what manner they implement and complete the use of blockchain technology.

Conclusions

This research analyses the effects that blockchain technology and blockchain oracles exerts on the supply chain management and on a firms performance.
Considering the always more common use of blockchain and all the variety of the possible application this study's objective is to investigate in which terms it affects the resolution and improvement of the main supply chain challenges firms face and the possible benefits, in terms of financial performance that firms may gain. Furthermore, this study implements these blockchain given benefits by analysing in which manner does the adoption of oracles affect them. So, whether there is a positive correlation and whether this

translates into a greater increase in the resolution of supply chain challenges and improvement of financial performance.

Our findings reveal that the blockchain is an extremely effective technology to combat the main difficulties and problems regarding the supply chain practices. When implementing blockchain technology all the supply chain is impacted, and it gains great benefits. Specifically, it gains properties such as transparency and traceability of the product meaning that the origin and the journey of the product can be completely traced and therefore no shady actions can be committed. Moreover, the blockchain adoption guarantees great results in terms of cost reduction. Indeed, many costs are directly linked with the supply chain and trough blockchain adoption firms may improve and reduce all the networking and transaction costs, being able to wisely chose producers and products. All of this directly affects the reputation of the firm gaining trust by all the stakeholders involved, and therefore giving a great image of the firm.

When it comes to business performance, our findings show that the blockchain adoption does not influence it positively at all. Having no direct impact in improving performance. Nevertheless, the results show that blockchain indirectly improves financial performance over time. Indeed, the resolution of supply chain challenges results in a financial performance improvement. These results indicate that firms, when implementing blockchain technology, must focus on the supply chain practices, so that once the main challenges are surpassed and improved, firms will see a great performance improvement.

Finally, in our research we analysed the impact of oracles implementation, and in which manner does these affect the results given by blockchain application. Therefore, we verified the difference in performance and resolution of supply chain challenges when blockchain is adopted and when blockchain is implemented with oracles. We proceeded by distinguishing the oracles and then proceeded to analyse how each one of them performed. In our research we included the most common oracles used by firms, and they are: software, hardware, inbound, outbound, and human. These performed differently, having as the ones that gave the best results the inbound and hardware oracles that not only improved the impact positively of the resolution on supply chain challenges on performance but also the direct impact of blockchain on performance, which as stated previously with the sole blockchain was not positive at all. Then we have the software oracles that only improved the effect of blockchain on performance indirectly with no other positive correlations. Finally, we have the outbound and human oracles that didn't performed positively at all, giving no significant impact neither on the supply chain challenges nor on the performance, and so useless for a firm in these circumstances.

This study is obviously not free of limitations, and they are hereby reported in order to increase interest and participation and inspire future research in this trending and strategic topic. The greatest limitation of this research is that it focuses solely on blockchain and its derivates as the digital technology to improve supply chain practices and firms' performances. Nevertheless, there are many other technologies that belong to the Industry 4.0 that can surely have different and greater impact on the analysed aspects. So, a possibility could be to reuse the parameters used in this research by analysing the effects of implementing other technologies. For instance, the use of Internet of Things (IoT) systems that can complete the use of blockchain technology,

by capturing all the important information in a certain environment. Furthermore, the use of Big Data, which is gaining always more popularity, in order to optimize the supply chain challenges and consequently improve the performances by reducing the monitoring costs and the verification costs of suppliers.
Regarding the second Analysis, a limitation of this study is that we shape the research not considering the "oracle problem" which is already partially present in the literature but which should have a more in-depth study. Moreover, an interesting analysis may be conducted following the steps of this research and substituting the oracles with another technology that can be combined to the blockchain as for example AI which is gaining more and more popularity and utility and it would be interesting to study the effects when implemented by a firm.
Finally it may be interesting to conduct the analysis differentiating between the several industrial sectors to observe the different impact of blockchain.

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Appendix

Construct	Item	Question
Blockchain.		***In the last two years, our companies invested in blockchain by***
	B1	Consulting developers
	B2	Modifying the management of contracts and transactions
	B3	Developing tokens*
	B4	Developing new platforms
	B5	Initiating new training programs*
	B6	Aligning the technology requirement with regulations
	B7	Integrating blockchain technologies with other digital technologies
Supply Chain Challenges		***In the last two years, our company has successfully managed the following Supply chain challenges:***
	SC1	Transaction costs
	SC2	Product traceability
	SC3	Product transparency
	SC4	Networking costs
	SC5	Delivery risks
	SC6	Verification Cost of suppliers and third parties
	SC7	Reputation and trust
	SC8	Counterfeit products*
	SC9	Regulatory compliance*
	SC10	Complex supply chain contracts*
	SC11	Security and privacy issues*
	SC12	Environmental restrictions*
	SC13	Management of reverse logistics flows*
	SC14	Identification of green suppliers*
	SC15	Design of proper incentives for suppliers*
	SC16	Supply chain visibility*
	SC17	Price competition*
Business Performance (BP)		***In the last two years, our company has performed in terms of:***
	BP1	Market share
	BP2	Profits
	BP3	ROI
	BP4	Cost savings*
	BP5	Environmental impact*
	BP6	Cost for energy*
Table A1. Questionnaire		**Note(s):** *Excluded from our analysis

Extended Abstract

Nowadays, new technologies are being released at an extraordinary rate and often companies aren't able to exploit them. Thus, given the complexity of these new technologies, which are meant to change the whole industry. One of the main processes that is affected by these technologies is supply chain (SC), which is crucial for every company since it involves every step in the life of the product, from the sourcing of raw materials to the delivery of the finished product to the market.

Nevertheless, traditional SC systems are not versatile and transparent enough to accommodate the growing needs and demands of the future, leading to huge overheads in terms of error handling, costs, administration, and fraud management (Dutta et al., 2020). In this scenario blockchain technology has emerged and has been identified as a disrupted technology that has the potential to transform the SCM through its features. (Philipp et al., 2019; Gurtu and Johny, 2019).

Blockchain is an innovative, decentralized, and distributive technology, which maintains confidentiality, integrity, and availability of all the transactions and data (Dutta et al., 2020). It is a shared, open and distributed over the network ledger that can help store and record data and transactions backed by a cryptographic value across a peer-to-peer network (Choi, 2021).

So, the first objective of this study can be synthesised by the following research question:
What is the impact of blockchain on supply chain challenges and firm performance?

Despite the significant potential for blockchain to promote changes in all types of supply chains, and the great literature interest in blockchain technology applications in SCM fields (Wang et al., 2019), the literature providing concrete application results is still at its infancy. (Queiroz et al., 2020) Therefore we seek to fill this literature gap by conducting an empirical analysis that investigates the benefits that implementing blockchain grants to the supply chain practices by developing our first hypothesis:
Hp1: Blockchain technology implementation impacts positively on resolving supply chain challenges.

Supply chain practices have evolved and adapted during time alongside with the technology and society development. During its evolution and adaptation, it has gained more and more importance within the company, expanding its sphere of competence.
Speaking of supply chain challenges (SCC) nowadays, these are always more complex, and supply chain managers, especially in the last years, have faced great changes in every direction. Indeed, supply chains are expected to experience the heat of the global financial crises in the long term (Sanjoy Kumar Paul et al., 2021). These crises have led to the need for automation of certain services in companies (Business Wire, July 2021). There are many issues that threat supply chain's integrity, and that are more highlighted by the literature, and at the same time considered more crucial are only few. Among these, one of the biggest challenges is considered to be the traceability and transparency of the products (Francisco and Swanson, 2018; Bechini et al., 2008; Aung and Chang 2014; Opara, 2003). Indeed, Tian (2016) in his research demonstrated that traditional supply chain logistics pattern cannot match the demands of the market

anymore.
As stated previously Blockchain technology is rapidly gaining more and more popularity, spreading with multiple industries exploring their capabilities and new blockchain use cases springing up on a daily basis (Phan The Duy et al, 2018).
This coincides with the growing demand of automatization and continuous improvement and optimization of SC practices, and the BT has a tremendous potential to eliminate intermediaries and to make SCM more efficient (Gurtu, A. and Johny, J., 2019). The blockchain gives the firm the capability to record information by authorized actors making it extremely secure through immutable and transparent transactions that are visible to all supply chain members.
Even tough, as stated previously, real-life experimentation is still at its early stage, from the literature it appears evident the potential of blockchain technology for the development of a sustainable supply chain. This brings us on thinking the great opportunity that this technology might give to a firm, beyond resolving the main supply chain challenges, and so we hypothesize the following:

Hp2: Blockchain technology implementation impacts positively on the firms' performance.

Due to the increasing blockchain investments it is crucial to understand whether blockchain provides a competitive advantage and an improvement to the firms' performances (Lui and Ngai, 2019). However, the existing literature provides limited evidence on the benefits of blockchain adoption and more in general of IoT technologies, since it focuses more on the development and adoption of the technologies, while scarce research addresses the impact on firm performance, so with the development of this hypothesis we intend to fill this gap. One of the first to analyse the possible financial impact of these technologies have been Tang and Huang (2018) by analysing the business value of IT, including productivity enhancement, profitability improvement, cost reduction, competitive advantage, inventory reduction, and other measures for performance (Kauffman and Kriebel, 1988; Hitt and Brynjolfsson, 1996; Devaraj and Kohli, 2003).

It is known that in order to survive, grow, and improve their performance in their business environment, firms must constantly search for new opportunities, and introduce and adopt new and potentially disruptive technologies (Teece et al.,1997; Sheel and Nath, 2019 ; Craighead et al., 2017). The blockchain technology is one such disruptive technology that has rapidly gained traction among industry practitioners (Büyük ̈ozkan et al., 2021; Chen et al., 2019; Ji et al., 2022; Kamble et al., 2020). From an operational perspective, blockchain has a strategic value for firms by enabling cost reduction and eliminating middlemen (Carson et al. 2018) and the findings of (Lui and Ngai, 2019) show that blockchain adoption provides an improvement in market value and stock returns meaning so, a financial improvement in the long run.
Finally, according to Sheel and Nath (2019) blockchain technology can indirectly lead to better firm performance by improving supply chain adaptability, alignment, agility, trust and transparency, so we propose to investigate this theme by developing the following hypothesis:

HP3: Resolving supply-chain challenges impacts positively on the firms' performance.

As stated previously supply chain plays an always more important and fundamental role in the firm's development. Over the last few years this role has become even more central due to the economics complications. This made the environment extremely mutable and dynamic, characterized by continuous and unexpected demand variations. So, it appears clear that companies must invest and improve constantly their supply chain management in order to control and optimize the firm's performances. The literature highlights the role of IT in supply chain integration that leads to an improvement of the firm's financial performance (Prajogo and Olhager, 2012; Liu et al., 2016; Qrunfleh and Tarafdar, 2014). It's shown that thanks to the enablement of collaboration and sharing data blockchain makes supply chain agile which brings to a financial performance improvement (Ngai et al., 2011). Moreover, Numerous studies investigated the effect of various SCM-related activities on organizational performances (Menor et al., 2007; Boon-itt et al., 2011; Zimon 2021) and many focus on financial performance since it reflects the success of a company's plans and operations numerically (Yang et al., 2011; Hofer et al., 2012; Feng et al., 2018).

Among the SCM practices and challenges analysed by the literature, the ones that have shown a higher correlation with financial performance are those regarding the transaction costs, the information sharing and quality level of information (Li et al., 2006; Cook et al., 2011). Considering that blockchain directly impacts these supply chain challenges it should indirectly improve the firms' financial performance.

We then proceeded to extend our study by analysing the measure in which oracles consent to exploit the blockchain's impact on supply chain and on performance. Indeed, from this, we developed our second intent of the research which can be resumed by the following question: **Does the implementation of oracles allow the blockchain to perform better in terms of supply chain challenges resolution and business performance.**

The fundamental functionality of oracles is to serve as bridges between the network and the outside world , this because blockchains and smart contracts cannot access off-chain data (data from outside the network) (Wirex, 2022). The literature around this topic is quite scarce, indeed it mainly focuses on explaining the functionality, how they integrate the BT, and the risks that they bring. This supports the view that blockchain oracles are still a widely neglected subject, despite their crucial importance (Caldarelli G., 2022).

So, our work's intent is to go beyond the previously developed hypothesis and extent its analysis in proving that the use of blockchain and its result are more efficient and have an higher positive impact both on supply chain challenges and on the firm's performance. Therefore, we differentiate between firms that invested in oracles and those who didn't, and so we proceeded formulating the following hypothesis:

Hp1x: For firms that invested in oracles: software (a), hardware (b), inbound information (c), outbound information (d), and human (e), the positive impact of Blockchain technology on Supply-chain challenges is higher than for those who didn't.

Hp2x: For firms that invested in oracles: software (a), hardware (b), inbound information (c), outbound information (d), and human (e), the positive impact of Blockchain on the performance is higher than for those who didn't.

Hp3x: For firms that invested in oracles: software (a), hardware (b), inbound information (c), outbound information (d), and human (e), the positive impact of Supply-chain challenges resolution on performance is higher than for those who didn't.

As seen from the hypotheses we focus on five oracles which are the most used and common: Starting with the software oracles, they interact with every type of online source of information, as for example online databases, websites, and servers, and transfer it to the blockchain.
Moving on to hardware oracles, these are essential for the blockchain communication with the real world. They basically consist in devices like QR scanners, tags, and robots that transfer information form the real world and make it available to the blockchain.
Then we have inbound and outbound information oracles, these are essentially the opposite. Having the first transmitting information from external sources, and the second one transmitting information to the external world.
Lastly, we have human oracles. They basically consist in individuals with specialized knowledge and skills in a particular field that can research and verify the authenticity of information from various sources and translate that information to the blockchain (Beniiche, 2020).

Methodology

In order to test our hypotheses, we gathered the primary data by designing and dispensing a survey to a total of 1200 firms selected through Bureau van Dijk Electronic Publishing. Once excluded the invalid responses we ended up with 156 usable observations. The sample size is in line with other empirical research in the same domain, present in the literature (Bhatia and Kumar Srivastava 2019; Shaharudin et al. 2017).
Regarding the sample characteristics, more than half had average sales over 100 million, and over 200 employees, and the majority of the answers were given by supply chain managers.
In order to measure the items of the questionary a seven-point Likert scale was used by describing the level of agreement to a question. Indeed, 1 meant "not at all in agreement" and 7 meant "full agreement".

Estimation methods

To achieve the objectives of this study, we used partial least squares path modeling (PLS-PM) and the XL-Stat 2021.2.1 software. PLS-PM is a component-based estimation algorithm that aims to predict the relationships between constructs and provides their scores at the original scale (Agyabeng-Mensah et al., 2020). Furthermore, PLS-PM does not require any distributional assumption for the data (in contrast with a maximum likelihood covariance-based approach) (De Giovanni, P., 2022).

Model Assessment

According to the meaning that we give to each of our constructs, we use reflective scales for all items to measure the firms' capability in a certain domain. Therefore, we follow the procedure suggested by Colicev et al. (2016) and Agyabeng-Mensah et al. (2020) to check for the internal consistency of constructs as well as to verify both the convergent and the discriminant validity.

We started with a comprehensive analysis of the phenomenon which included eight blockchain variables, seventeen supply chain challenges variables, and six performance variables. From this we started running the model in order to understand if the scales were significant for what they represented. In order to understand if the scale is representative firstly, we looked at the eigenvalues given by the model, and secondly through a one-piece analysis looked at the correlation between the variables, which it needed to be statistically divergent (over 0.4).

Regarding the supply chain challenges construct (SC) we started with seventeen dimensions and after running the model until the eigenvalues were satisfactory we ended up with seven significant dimensions and strictly related to supply chain challenges. These are: Transaction Costs (SC1), Product Traceability (SC2), Product Transparency (SC3), Networking Costs (SC4), Delivery Risks (SC5), Verification Costs of Suppliers and Third Parties (SC6), and Reputation and Trust (SC7).

Regarding the Business Performance construct (BP), we make use and revise the scales developed by Bhatia and Kumar Srivastava (2019). Alongside these revised scales, we also considered other traditional ones like market share and return on investments (ROI) since they are usually included by many contributors (e.g. Agyabeng-Mensah et al., 2020).

We had a total of six variables, even tough, also in this case running the model we had more than one eigenvalue over 1.0 so we proceeded with the same one-piece analysis mentioned above. From this we found that in total three of the variables were statistically divergent and so we proceeded to eliminate it. Therefore, our final scale includes in total three items. Market share (BP1), Profits (BP2), and ROI (BP3).

Finally, regarding the Blockchain construct (B), due to the newness of this technology, there is a lack of research on scale development. Therefore, we propose hereby a measurement scale according to the ingredients emerged from the literature review with the purpose of exploring the practices that managers adopt when implementing this technology (De Giovanni, P. 2022). The first development of the scale consisted in seven blockchain adoption indicators, but once running the model for several times, following the procedure above mentioned we ended with five significant variables. The first of these relates to working with blockchain developers (B1) then the actions finalised in modifying the management of contracts and transactions (B2), and the developing of new exchanging platforms for the business(B3). Finally, we have the last two variables which consist in integrating blockchain technologies with other new or current digital technologies (B4) and aligning the technology requirements with the regulations.

So, once we had the final model it was necessary to analyse its goodness, and this has been done thru the ad hoc goodness of fit index (GoF) which is equal to 0.806 and therefore acceptable since it must be over 0.8.

Results and discussions.

Analysis I

This section provides the empirical results of the first three hypothesis testing by considering the entire sample. Regarding the first hypothesis **H1** is supported (coef. = 0.642 and p-value < 0.01) confirming and highlighting that blockchain implementation for a firm, impacts positively on resolving and improving the supply chain challenges. Contrary to this result **H2** finds no support (coef. = -0.062 and p-value >0.52) but as seen having a high p-value, the result is not statistically significant and so this result must be carefully examined in a case-by-case basis, due to its low robustness. So, from our analysis has emerged that blockchain doesn't have direct impact on the firms' performances. Moving on to our third hypothesis **H3** (coef. = 0.452 and p-value< 0.01) and so it is confirmed and statistically relevant, it has a positive and significant support by the analysis. Meaning that the resolution of supply chain challenges positively impacts positively on the firms' financial performance.

Hypothesis testing of the blockchain oracles.

In this section, we focus on the analysis of the blockchain oracles, that is, that if the firms proceed to adopt blockchain oracles the positive impact of blockchain on supply chain challenges and on the firm performance is higher.

Regarding the analysis of the first hypothesis, **Hpx1**, it has emerged that here is no significant difference between adopting or not any of the considered oracles. Meaning that the implementation of oracles on blockchain doesn't have a higher impact on resolving supply chain challenges.

Moving on to our second hypothesis, **Hpx2**, the oracles performed differently. Indeed it has emerged that there is a significant difference only for hardware and inbound oracles while software outbound and human oracles' hypothesis wasn't supported. Finally, regarding the third and last hypothesis of our research, **Hpx3**, which indicated that the resolution of supply chain challenges has a higher impact on performance, it has emerged that software, hardware, and inbound oracles have a significance difference between the adoption or not.

Discussion and managerial insights

Managerial insights from Analysis I

When considering the entire sample in our first Analysis I the empirical results of the hypothesis testing, demonstrate that the implementation of blockchain technology impacts positively on resolving supply chain challenges, and that this resolution contributes in a financial performance improvement. These results are in line with the present literature (Queiroz et al., 2020; Gurtu and Johny, 2019; Sheel and Nath, 2019; Wu et al., 2017) showing the benefits brought to the supply chain management by blockchain adoption. Hence, it will be possible for a firm adopting the blockchain technology, to improve those that from the literature emerge to be the main supply chain practices (Lui and Ngai, 2019; Chae et al. 2018). Indeed, it would improve the traceability and transparency of the product thanks to its capacity to inalienably store the path of goods along the entire life cycle of a product. Thus, reducing all those costs linked to the verification of the

supplier and more in general of the whole network and transaction costs.
Moreover, our results shows that the improvement of all these practices directly improve the reputation and trust gained by the firm adopting the blockchain. Interestingly, the results show that the resolution of the supply chain challenges has a positive impact on the increase of the firms' financial performances. This result supports what is theorized by the literature and in other research (Iranmanesh et al., 2019; Zimon 2020; Menor et al., 2007).
When it comes to blockchain directly impacting business performance, our findings reveal that the implementation of this technology does not positively influence the performance. From a managerial point of view, firms that are investing in blockchain adoption should be aware that it isn't certain that this will transform in an improvement of the performance. This result contrasts with the empirical studies of Ko et al. (2018) and Lui et al. (2019) which show a positive link between blockchain and performance.

Managerial insights from Analysis 2.
When investigating in blockchain oracles, our findings reveal the possible higher positive impacts of blockchain on supply chain challenges and performance. To our knowledge, this is the first empirical study analysing how the implementation of oracle impacts on the blockchain adoption.
Not consistent with our expectations, only in some cases the implementation of oracles, consented the blockchain adoption to amplify and improve its results.
Indeed, no oracle implementation consents an improvement in resolving supply chain challenges, while regarding the positive impact of blockchain on financial performance, only two of them are effective, precisely the hardware and inbound oracles. Improving directly the impact on performance which without their implementation was not possible. Moreover regarding the third and last hypothesis, showed that was the one where in overall the oracles performed better. With software, hardware and inbound oracles consenting a higher impact of the resolution of supply chain challenges on the firms' financial performance.
From what emerged from our research managers should focus their efforts in implementing the right oracles, because some of them, such as outbound and human oracles, won't produce any consistent result.

Theoretical contributions
This study connects three research areas, which are, supply chain, blockchain technology, and blockchain oracles, and focuses on these targets.
The first, consists of studying those that are considered to be the biggest and toughest supply chain challenges firms face in their supply chain management. This study enriches the literature by highlighting these challenges and explaining why are crucial for a firm.
The second focus and contribution to the literature is the empirical analysis on the impact that blockchain technology has on the supply chain. Indeed, blockchain is meant to be revolutionary for all sectors, guaranteeing a great help in resolving the challenges that supply chain face.
The third theoretical contribution focuses on the adoption of blockchain oracles. In this case, to our knowledge, there was no empirical study present in the literature. The oracles that are a blockchain

implementation that allows the technology to communicate with the outside world, and so giving the possibility to exploit this technology in all of its uses.

Conclusions

This research analyses the effects that blockchain technology and blockchain oracles exerts on the supply chain management and on a firms performance.

Considering the always more common use of blockchain and all the variety of the possible application this study's objective is to investigate in which terms it affects the resolution and improvement of the main supply chain challenges firms face and the possible benefits, in terms of financial performance that firms may gain. Furthermore, this study implements these blockchain given benefits by analysing in which manner does the adoption of oracles affect them

Our findings reveal that the blockchain is an extremely effective technology to combat the main difficulties and problems regarding the supply chain practices. When implementing blockchain technology all the supply chain is impacted, and it gains great benefits. When it comes to business performance, our findings show that the blockchain adoption does not influence it positively at all. Having no direct impact in improving performance. Nevertheless, the results show that blockchain indirectly improves financial performance over time by resolving supply chain challenges.

Finally, in our research we analysed the impact of oracles implementation, and in which manner does these affect the results given by blockchain application. Therefore, we verified the difference in performance and resolution of supply chain challenges when blockchain is adopted and when blockchain is implemented with oracles.

We proceeded by distinguishing the oracles and then proceeded to analyse how each one of them performed. In our research we included the most common oracles used by firms, and they are: software, hardware, inbound, outbound, and human. These performed differently, having as the ones that gave the best results the inbound and hardware oracles that not only improved the impact positively of the resolution on supply chain challenges on performance but also the direct impact of blockchain on performance, which as stated previously with the sole blockchain was not positive at all. Then we have the software oracles that only improved the effect of blockchain on performance indirectly with no other positive correlations. Finally, we have the outbound and human oracles that didn't performed positively at all, giving no significant impact neither on the supply chain challenges nor on the performance, and so useless for a firm.

This study is obviously not free of limitations, and they are hereby reported in order to increase interest and participation and inspire future research in this trending and strategic topic. The greatest limitation of this research is that it focuses solely on blockchain and its derivates as the digital technology to improve supply chain practices and firms' performances.

Regarding the second Analysis, a limitation of this study is that we shape the research not considering the "oracle problem" which is already partially present in the literature, but which should have a more in-depth study. Moreover, an interesting analysis may be conducted following the steps of this research and

substituting the oracles with another technology that can be combined to the blockchain as for example AI which is gaining more and more popularity and utility and it would be interesting to study the effects when implemented by a firm.

Finally it may be interesting to conduct the analysis differentiating between the several industrial sectors to observe the different impact of blockchain.