ADOPTION OF BLOCKCHAIN TECHNOLOGIES IN THE PHARMACEUTICAL SUPPLY CHAIN TO COMBAT THE DISTRIBUTION OF FALSIFIED MEDICINAL PRODUCTS FOR HUMAN USE

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Executive Summary

In recent years, companies worldwide have come to the conclusion that supply chain management (SCM) is the key to staying competitive and profitable in their respective markets. However, supply chain has various unresolved issues due to increased complexity caused by globalization. Companies struggle with not knowing the origin of their inbound materials, where their stock is at all times downstream, and with a lack of visibility into demand, orders, and supply. All this, due to lack of traceability and transparency across partners, leaving companies with fragmented information, unable to make informed decisions.

To mitigate these challenges, many different technologies have been adapted and implemented in the supply chain domain. Some of these are Internet-of-things (IoT), radio-frequency identification (RFID) tags, sensors, bar codes, GPS tags and chips, which facilitate the tracking of products, packages and shipping containers. Recently, experts are adding blockchain technologies (BT) to the list. The concept of blockchain, introduced in 2008 and also known as distributed ledger technologies, refers to a distributed data infrastructure or a method for data recording using crypto-analytic hash function. These infrastructures are peer-to-peer distributed networks consisting of nodes that are secure, append-only, immutable and updated only through peer consensus. It can therefore be used as registry and inventory systems for the recording, tracing, monitoring and transacting of assets such as financial, legal, physical or electronic. Moreover, these technologies allow to securely share information with other organizations, identity management, and verification of sustainability in a secure manner.

In the pharmaceutical supply chain (PSC), the lack of product tracing and tracking along the supply chain allows for counterfeited drugs to reach the final consumer and have deathly consequences. The World Health Organization (WHO) blames the billion-dollar trade of falsified medicinal products for tens of thousands of deaths every year. The PSC is composed of various different actors needed to carry the products to the consumers, relying mostly on paperwork for partner interaction. This creates inefficiencies and security breaches that allow for the falsified products to enter the legal PSC. Some initiatives, such as Mediledger and PharmaLedger, have started to develop solutions based on blockchain technologies in order to solve this problem. However, in order to truly achieve the benefits desired, the solutions need to have a wide adoption from the players in the PSC. While conducting the literature review, it was clear that there were no holistic guidelines on how to make this a reality. Naturally, the main research question found to guide this research is "How can blockchain technology initiatives in the PSC stimulate blockchain technologies' adoption to combat the distribution of falsified medicinal products for human use?".

It was found that falsified ingredients or products can enter the PSC at any stage when transaction of ownership of the product occurs between the actors involved in the chain, since there are no robust mechanisms in place to verify the activities. Accord-

ing to the literature, blockchain technologies offer the right features to not only verify the origin of the product by immutably recording this information, but it also allows to track product transactions. The solution requires an identification mechanism such as RFID tags or bar codes, the use of smart contracts, and a recording platform based on blockchain technology. There are already a few initiatives around the globe developing and offering the technology, but wider adoption needs to happen to reap the true benefits.

In this thesis, the barriers and drivers impacting the adoption of blockchain technology in the PSC were found and classified according to the chosen Technology, Organization, and Environment (TOE) framework. This framework was chosen due to its wide use in studying firm level acceptance of technology adoption, and its proven robustness. Seven experts were interviewed to choose their five most important drivers and barriers per each of the TOE categories.

In order to understand the most important drivers and barriers from the perspective of the actors involved in the pharmaceutical industry, an online questionnaire was built following the Bayesian Best-Worst Method (BWM) and distributed to the target population. The BWM was chosen since it proved to be the best one according to literature due to being less data-intensive, more user-friendly, and able to generate the most reliable results when compared to other methods. The questionnaire gathered 21 responses that allowed to derive the local and global weights of all the 15 barriers and 15 drivers, using the Bayesian BWM.

The most important category of barriers was found to be Technology as well as the most important category of drivers. In both cases, Organization came in close second, and then Environment as third. Despite this result, Customer safety (an Environmental driver) made the first five of the most important drivers showing that the pharmaceutical industry truly puts consumer and patient's well-being at the top of their priorities.

In order to attract more participants, it was suggested that blockchain technology providers focus primarily on designing and improving the solution according to the found priorities regarding the Technological context. Thereupon, they should advertise it to companies according to the insights given by the conclusions of the Organizational and Environmental context. This means building a simple, secure, and interoperable solution that allows for traceability of products. The swaying of upper management with a strong business case that shows reduction of costs and improved patient safety is also a key priority. Finally, it is important to involve as many stakeholders as possible, including the governments. This will ensure that all the intended users of the technology will be heard and, consequently, ease its adoption. It was also understood that countries or regions with policies that encourage the adoption of blockchain technologies are an important implementation driver, as it is a highly regulated industry.

In conclusion, this study resulted in a novel set of drivers and barriers that influence the adoption of blockchain technologies in the PSC to combat the distribution of falsified medicinal products for human use. Furthermore, the ranking of these factors using the Bayesian BWM, allowed to provide meaningful recommendations to blockchain technology initiatives that pursue wider adoption of their solutions in the pharmaceutical market.

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INTRODUCTION

With the increase of globalization, companies see themselves involved in more complex supply chains that have to withstand intense competition, cost pressures, a demand for shorter time to market, and volatile demand patterns. Supply Chain Management (SCM) can be defined as "the planning and management of all activities involved in sourcing and procurement, conversion, and all Logistics Management activities" including the "coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers." (Gibson, Mentzer, & Cook, 2005). Therefore, organizations have realised that effective SCM is the key to staying competitive and profitable (S. Li, Ragu-Nathan, Ragu-Nathan, & Subba Rao, 2006).

Technology has contributed greatly for the improvement and development of SCM in all its aspects and processes, from demand to supply, including planning and execution. In the previous decades, SCM has moved from material requirement planning (MRP) to manufacturing resource planning (MRP II), to enterprise resource planning (ERP), and more recently to advanced supply chain planning and optimization (APS/APO) (Banerjee, 2018a). All these systems are technology dependent.

Even though the adoption of these systems brought many benefits for organizations, there are still a number of supply chain challenges that remain to be solved such as lack of traceability and transparency (Azzi, Chamoun, & Sokhn, 2019), and lack of real-time visibility into demand, orders, and supply (Banerjee, 2018a). Companies struggle with knowing not only where their stock is at all times outside the organizations' network but also where the raw materials for their products have been. As there is a lack of connectivity across different systems from the different players in the supply chain, companies are left with fragmented information, unable to make informed decisions (Banerjee, 2018b).

Many technologies have been adapted and implemented in the supply chain domain that have helped with the mentioned problems. Technologies such as Internet-of-things (IoT), radio-frequency identification (RFID) tags, sensors, bar codes, GPS tags and chips, make tracking the locations of products, packages and shipping containers much easier (Kshetri, 2018). Nowadays, experts are also adding blockchain technologies to the list since it brings benefits such as securely sharing information with other organizations, the possibility of identity management, verifying sustainability, and a higher degree of flexibility (Casino, Dasaklis, & Patsakis, 2019). Blockchain is a network of members connected through a distributed ledger technology. It records information, such as transactions and logistics events, as blocks that are immutable and secure, and chronologically maintain the data blocks across transactions (Banerjee, 2019). One of its more promising advantages is that it is distributed, meaning that the information is stored and verified by the nodes in the blockchain. Depending on the type of base architecture of the blockchain, the verification system might be set up in different manners such as demanding that every node approves of the transaction or allowing that a majority of approvals is sufficient. The same applies to the hierarchy of nodes, as in some consensus mechanisms nodes have different rankings compared to the others but it can also be decided that no node has more power than the others. This allows for different set ups which can be adapted depending on the purpose of the blockchain based application.

Therefore, studying the possibilities of adopting blockchain technologies to address supply chain challenges is a logical next step.

1.1. LITERATURE REVIEW

1.1.1. SUPPLY CHAIN MANAGEMENT CHALLENGES

Companies are attributing more importance to supply chains since it has become clear that it has a significant impact on their overall bottom line. Supply chain related activities have the potential to save costs and drive efficiency in all industries, as well as provide a competitive advantage if adapted to the evermore demanding consumer.

According to Banerjee (2019), today, customers and end consumers ask for, among others, the ability to trace the origin of each product, to have customized product features, a more flexible but also more environmentally friendly deliveries, all while demanding the lowest price possible. He also presented the supply chain challenges across industries and various SC domains. The seven challenges found were product/order tracking in real-time; product traceability/recall/anti-counterfeiting are all problems stemming from lack of access to real-time information; Agri supply chain is very complex and lengthy and keeping track of all the information has no solution yet; the Digital automotive industry presents new challenges with connected and autonomous cars which deals with sensitive information that also has no solution; Digital homes and offices benefits are enabled by sharing information among different services and devices, once again the safe sharing of information across the supply chain has no mature solution; Transparency in distribution industry is still a problem especially in ship and debit claims which could be solved with a trustworthy inter-company technology which does not exist; and finally Manufacturing systems still struggle with having real time data sharing and reliable digital twins which are only possible with a trustworthy and transparent mechanism.

It is also important to take into account how the COVID-19 pandemic affects the supply chain challenges and what it represents for SCM. It seems that the main lesson to learn is to create transparency and visibility across the multi-tier supply chain closest to real-time as possible (Alicke, Azcue, & Barriball, 2020). Which companies still struggle to execute due to lack of cross-company communication and information sharing. Other challenges put forward by Alicke et al. (2020) are gaps between supply and real-time demand as information from the customers' customer is not available or is too slow; collaborating with partners is difficult; and real-time visibility and tracking of products in transit is crucial to be able to plan capacity accordingly. Overall, companies should digitize their SCM as much as possible by building single sources of truth and work closely with partners which is a challenge as secure and transparent information sharing lacks a proven mechanism. Awad, Pareek, Shah, and Schott (2020) also puts forward the challenges the pandemic brought to businesses using traditional ERPs and that are making companies searching for improved ones. The challenges include the need to digitalise supply chains and smart manufacturing as well as finance, procurement and human resources functions in order to increase real-time visibility and automation, use fewer workers, and being able to make more informed decisions. Another challenge is the changing consumer and go-to-market trends of omni-channel distribution, e-commerce, and its consequences such as an increase in returns. Finally, the prevalent issue of collaboration in supply chain is mentioned. The demand for an open and collaborative ecosystem across multiple organizations still has no solution in traditional ERPs.

Azzi et al. (2019) sheds light on the challenges of verifying product data accuracy and reliability in consumer goods' supply chains. When these suffer breaches such as bacteria breakouts or product contamination it is of the utmost importance that products are recalled as fast as possible as to not cause harm to consumers. Nowadays, to have verified products strenuous auditing needs to be performed to the involved companies. This could be tackled by an increase in transparency and traceability in manufacturing supply chains, however, this requires a secure way to share and storage data which is not readily available. Dabbene, Gay, and Tortia (2014) focus on traceability issues in the food supply chain, and define it the term as "the ability to guarantee that products “moving” along the food supply chain (FSC) are both tracked and traced". The issues found are the ability to recall products in food crisis management, the difficulty in tracing bulk products, the ability to verify quality and preserve identity, and the capability to prevent fraud and counterfeit products. Dabbene et al. (2014) defended that coupling traceability with other tools, such as production planning and logistics, can bring a significant improvement to the whole supply chain. However, it does not provide a solution on how to share and store this information across the network.

1.1.2. BLOCKCHAIN TECHNOLOGIES

The concept of Blockchain was first introduced in 2008 with the published article "Bitcoin: A Peer-to-Peer Electronic Cash System" by Nakamoto (2008). Blockchain technologies, also known as distributed ledger technologies, refers to a distributed data infrastructure or a method for data recording using crypto-analytic hash function (Wang, Han, & Beynon-Davies, 2018). Blockchains are peer-to-peer distributed networks consisting of nodes that are secure, append-only, immutable and updated only through peer consensus (Wang, Singgih, Wang, & Rit, 2019). They are another application layer that run on top of the internet protocols enabling transactions that do not require a trusted third party. Blockchain can also be used as registry and inventory systems for the recording, tracing, monitoring and transacting of assets such as financial, legal, physical or electronic (Walport, 2015).

In a blockchain system, a "block" is created when a list of transactions is recorded onto a ledger over a given period. As each transaction happens, it is recorded in a block with a timestamp. Then, each block created is connected to the blocks before and after it in chronological order (Nakamoto, 2008). The blocks are mathematically chained together through a hashing function. A hash is a digital fingerprint of data in order to attach it within the blockchain (Wang et al., 2019).

Once the blocks are locked in the chain they are unchangeable, this means they cannot be deleted or altered in any way by a single party. In fact, the verification and management of the blocks is done using automation and shared governance protocols. It is conducted by the different computers, or users, participating in the blockchain network, also known as blockchain nodes. When a new transaction or an edit to an existing transaction enters a blockchain, normally the majority of the nodes must execute algorithms in order to verify and evaluate the authenticity and history of the proposed single block. If the majority of the nodes agree that the history and signature are valid, then the new block is accepted into the ledger and, consequently, a new block is added to the chain (Nakamoto, 2008). No single node can control the data in the network and the entire data infrastructure is visible to all parties. It is important to mention as well that the ratio of nodes required to approve a transaction is defined by each blockchain structure. This means that it could be required that the majority of the nodes accept the transaction, but it could also be established that two thirds approve it, or any other way the specific blockchain defines this process.

With this way of verification, data can be effectively secured on the blockchain ledgers. This means, the bigger the network, the more tamper-resistant the blockchain will be. Being a decentralized and distributed peer-to-peer data storage mechanism, the risk of a single point of access failure or manipulation is decreased. Furthermore, this setup based on cryptographic security ensures the integrity of the data, as each transaction requires a digital signature with the private key of the sending node, which is only in its possession. On the other hand, the public key of each user in the network is visible to everyone as transactions are announced publicly in the chain. At the same time, privacy is maintained by keeping these public keys anonymous (Nakamoto, 2008). The unique value of blockchain technologies is that it creates a self-correcting system that does not need a third party to enforce the rules as it is all executed through consensus (Wang et al., 2019).

Many authors have now recognized the power of blockchain technologies in other aspects of society (Swan, 2015; Wust & Gervais, 2018; Carson, Romanelli, Walsh, & Zhumaev, 2018). Carson et al. (2018) present six categories of blockchain use cases that address two important needs, also seen in section 1.1.1, namely record keeping of static information, and transactions of tradeable information. For the first one, blockchain offers a static registry, identity-related information, and smart contracts. "Smart contracts" are “blockchain transactions that go beyond simple buy/sell transactions, and may have more extensive instructions embedded into them” which are then automatically enforced as the conditions are met (Swan, 2015). For the second one, blockchain also offers the possibility for dynamic registry, payment infrastructure, and others such as solutions combining the previous use cases.

It is also important to understand that blockchains can be permissioned or permissionless, based on the permissions granted to the participant of read, write or commit. Based on the ownership of the data infrastructure, they can be private or public (Carson et al., 2018). Permissioned blockchains are hosted on private computing networks, with controlled access and editing rights. Public blockchains, like Bitcoin, have no central authority and are regarded as enablers of total disruptive disintermediation (Carson et al., 2018). The most widely known permissioned blockchains are Hyperledger Fabric and R3 Corda (Wust & Gervais, 2018). Carson et al. (2018) defends that, based on these characteristics, the private and permissioned architecture is the most scalable for commercial purposes. They argue that dominant players can maintain their positions as central authorities to capture and share value, while participants can get the value of securely sharing data while automating control of what is shared, with whom, and when.

Blockchain Technologies in Supply Chain Management

Even though cryptocurrency represents the more considerable percentage of blockchain networks, researchers have branched out to study the usage of the technology in other domains (Wust & Gervais, 2018). Casino et al. (2019), for example, found eight blockchain-based applications apart from the financial one in their literature review. The applications include Privacy and Security, Education, Health, Governance, as well as Supply chain which was classified as a subcategory of Business and Industry.

For the purposes of this research, the focus is blockchain applications in Supply Chains and SCM. According to the literature, the industry is already investing millions of dollars in the technology as it is believed it will greatly impact supply chains and help in its management, posing new and exciting opportunities for companies around the world (Treiblmaier, 2018).

Wang et al. (2018) conducted a literature review to identify the drivers for the adoption on blockchain, the areas in supply chain where it brings the most value, and the challenges for its diffusion. They found that Trust is the most influential factor driving interest in blockchain applications to SCM. As blockchain presents a solution to store data in a single "shared source of truth", companies expect it to offer seamless network, entire visibility and symmetric information. Followed by the driver of public safety and security, where blockchain can help prevent corruption and fraud. They found four areas to which the technology brings the most value, such as smart contracts, and improved data security for information sharing. The barriers are related mostly to organizational and user-related issues, such as reluctancy to change in order to keep business models stable. There are also some technological challenges as well as operational challenges, such as making the complexity of implementing blockchain in the supply chain environment, and governance issues.

Both Wang et al. (2019) and Queiroz, Telles, and Bonilla (2019) investigated the benefits and application of blockchain technologies in supply chain, as well as the challenges and where the disruptions are most likely to occur in the supply chain. The first group of researchers adopted sensemaking theory to gauge foresights via expert interviews. The findings go in line with the ones presented in the previous chapter. The benefits are improving visibility, ensuring secure information sharing and building trust, and allowing for operational improvements. The most likely areas of penetration include the extended visibility and traceability, the simplification, digitalisation and optimisation of SC operations, smart contracts, trust building, and disintermediation. As for the challenges, there are confidence and related necessity issues, cultural, procedural, governance and collaboration challenges, data input and information-sharing barriers, technological and network interoperability issues, and finally, concerns about cost, privacy, legal and security matters. The second group of researchers performed a systematic literature review. They found that blockchain integration in SCM is still in its early stages, apart from the electric power industry who seem to have a more mature understanding with the use of smart contracts. Moreover, the disintermediation provided by blockchain applications has the potential to disrupt traditional industries (e.g. health care, transportation and retail).

Focusing on the applications of blockchain in order to achieve the supply chain objectives, Azzi et al. (2019) presents the benefits of adopting the technology, but also the associated challenges. They argue that to build a blockchain-based supply chain, actors need to consider selecting a blockchain according to different key criteria notably: Throughput, latency, capacity and scalability; implementing a dual storage architecture to handle large amount of data, without degrading the blockchain performance; choosing the tracking devices based on the main product criteria they want to track or monitor; choosing the communication protocol based on the speed, data rate, communication range, power consumption, cost or any criteria deemed essential in the supply chain environment; trying to fill the security vulnerabilities found in the communication protocol to provide a secure and reliable traceability system; and finally, create a secure tracking environment beginning by authenticating the system tracking devices and making sure all transferred or collected data is encrypted and signed. Kshetri (2018) looked into multiple case studies in order to research the role of blockchain to address the key SCM objectives of cost, quality, speed, dependability, risk reduction, sustainability and flexibility. Various mechanisms are shown involving the technology, especially allied to Internet of Things (IoT), and blockchain's role to validate individuals' and assets' identities.

Queiroz and Fosso Wamba (2019) focused on the adoption challenges of blockchain in the supply chain in India and the USA, by developing their own technology acceptance model. They found that adoption of blockchain in SCM is still at its infancy, that facilitating conditions are important for the diffusion of the technology, and that it varies from country to country. They also found that trust of supply chain stakeholders is only influential of behavioral expectations for blockchain adoption only in India.

Other authors focus in the applications of blockchain in food supply chains. Tian (2016) combines RFID (Radio-Frequency Identification) technology to blockchain in order to establish a traceability system in agri-food supply chains. It was able to cover the whole process of data gathering of every link in the supply chain "from farm to fork". This brings visibility and trust to consumers, farmers and distributors. In their turn, Kamilaris, Fonts, and Prenafeta-Bold (2019) present an overview of the many ongoing projects and initiatives including their maturity level. It is understood that blockchain is a promising technology to help tackle transparency issues in the supply chain but challenges involving accessibility, governance, technical aspects, policies and regulatory frameworks hinder its diffusion.

In table 1.1, the features of blockchain technologies that will add value to the supply chain players that were gathered during the literature review are presented. Following this, table 1.2 shows the benefits that blockchain technologies bring to the supply chain.

Table 1.1: Blockchain features.

Source	**Feature**
Wang et al. (2019); Nakamoto (2008); Azzi et al. (2019)	Immutability
Wang et al. (2019); Nakamoto (2008)	Decentralized
Wang et al. (2019); Nakamoto (2008)	Distributed
Nakamoto (2008); Carson et al. (2018); Wang et al. (2019) Kamilaris et al. (2019)	Data-recording method / single source of truth
Nakamoto (2008); Azzi et al. (2019)	Based in cryptographic security
Nakamoto (2008)	Verification system
Walport (2015); Nakamoto (2008)	No third party required
Nakamoto (2008)	Privacy
Swan (2015); Kshetri (2018); Tian (2016); Brody (2021); Banerjee (2018a, 2018b); Faccia and Petratos (2021); Tönnissen and Teuteberg (2018); Mann, Potdar, Gajavilli, and Chandan (2018); Haddara, Norveel, and Langseth (2021)	Interoperability / Ability to support other systems and solutions
Carson et al. (2018)	Permission / permissionless
Carson et al. (2018)	Private / Public

Table 1.2: Blockchain benefits in SCM due to its features.

Blockchain Benefits in Supply Chain Management
Trust
Security
Visibility
Traceability
Transparency
Real-time information
Accurate information
Automatic smart contracts
Cost savings
Efficiency and productivity
Improve supplier and customer relationships

1

1.2. RESEARCH PROBLEM

The globalisation of supply chains makes their management more difficult. Blockchain technologies, as a distributed ledger technology, poses great opportunities in addressing these problems as it ensures transparency, traceability, and security (Saberi, Kouhizadeh, Sarkis, & Shen, 2018).

A specific type of supply chain that could benefit immensely from blockchain adoption would be the pharmaceutical one. The production of counterfeit drugs worldwide is increasing at an alarming rate, which is becoming a critical issue, largely driven by the growth of online pharmacies and market places in general (Haq & Esuka, 2018; Raj, Rai, & Agarwal, 2019). This issue affects especially the developing countries since legitimate drugs may be too costly for the population, however, higher-income countries are also a high targeted market since it poses lucrative margins (Alarcón-Jiménez, 2015). The World Health Organization (WHO) blames the billion-dollar trade of falsified medicinal products for tens of thousands of deaths every year (Hastig & Sodhi, 2020).

Medicinal products for human use are "any substance or combination of substances presented as having properties for treating or preventing disease in human beings; or any substance or combination of substances which may be used in or administered to human beings either with a view to restoring, correcting or modifying physiological functions by exerting a pharmacological, immunological or metabolic action, or to making a medical diagnosis" (The European Parliament and the Council of the European Union, 2001). In 2011, the European directive 2001/83/EC on the Community code relating to medicinal products for human use was amended in order to prevent the entry of falsified medicinal products into the legal supply chain by introducing the definition of "falsified medicinal product" to distinguish from other illegal medicinal products, and from products infringing intellectual property rights. Therefore, according to The European Parliament and the Council of the European Union (2011) falsified medicinal product is "any medicinal product with a false representation of: (a) its identity, including its packaging and labelling, its name or its composition as regards any of the ingredients including excipients and the strength of those ingredients; (b) its source, including its manufacturer, its country of manufacturing, its country of origin or its marketing authorisation holder; or (c) its history, including the records and documents relating to the distribution channels used". Therefore, not all falsified products are counterfeited, but all counterfeited products are falsified.

The pharmaceutical supply chain (PSC) has many different players through which the drugs have to pass by until they reach the customer. Since nowadays the information is not shared seamlessly between systems, manufacturers cannot follow their products downstream, drug regulatory authorities have no visibility on the full supply chain, recalls are expensive and complex, and companies cannot follow-up on patients. Another issue is verifying the origin and authenticity of raw materials in order to manufacture the drugs right from the start (R. Kumar & Tripathi, 2019; Hastig & Sodhi, 2020). This means that falsified products can enter legal supply chains easily posing great risks to the consumers. Ensuring the quality control of the transport of these products is also a pain point as it requires complex and strict environmental control (Bocek, Rodrigues, Strasser, & Stiller, 2017). Nowadays, companies use IT systems which are not compatible with each other, relying mostly on paperwork for partner interaction which poses many inefficiencies (Hastig & Sodhi, 2020). Therefore, the pharmaceutical sector is eager to solve these issues as they represent a threat to both patients and its reputation. Moreover, solving them presents potential cost savings and increased operational efficiency.

Several digital technologies have already been put in place in the attempt to find solutions to combat fake medicines in the drug supply chain, which stems mostly from the lack of visibility and traceability across the supply chain.

Due to the global use of mobile phones that every year have enhanced integrated capacities such as GPS, sensors, cameras and internet, wireless and mobile driven technologies are used as an anti counterfeiting solution. They serve as a base for mobile authentication services, verification technology, track and trace solutions, pill image recognition tools and mobile pedigree (Mackey & Nayyar, 2017). Some of the advantages of the mobile platforms are lower costs of infrastructure, user-friendliness and can provide real-time analysis when combined with cloud platforms. However, they rely on regulatory enforcement for manufacturers to adhere, and adoption by different users in the supply chain which can lead to interoperability between actors and increased disparate sources of data.

One of the most mature technologies implemented in various industries in SCM is Radio Frequency Identification (RFID) which is often used with Internet of Things (IoT) in order to connect to a network and transmit identification information (Rejeb, Simske, Rejeb, Treiblmaier, & Zailani, 2020). RFID and related standards (such as electronic product codes [EPCs]) are based on a technology that allows automatic tracking and identification of items using tags and electromagnetic fields that electronically store information. Before, bar codes were used which were quite susceptible to counterfeit whereas RFID technology uses a tag with a unique identification information of the tagged-object and transmits data through radio waves or wireless channels to a reader without needing line-of-sight or physical contact to scan it (Juels, 2005). Due to these features, RFID is also used to tackle the lack of traceability along the supply chain (Raj et al., 2019). However, there is still a problem of adoption, interoperability and integration between different companies, standardization issues, costs and time taken for implementation, despite efforts to governmental requirements to have a traceability system based on RFID technology (Mackey & Nayyar, 2017).

With the increase of online selling of drugs, two new categories of solutions have been growing focused on consumers and point-of-sales in order to mitigate cybercriminal activities and counterfeiting (Rejeb et al., 2020). These are machine learning algorithms and online verification solutions including website seals and verification services. Although these show great promise, the two solutions lack investment and wide adoption in order to find if they are truly effective.

From the literature, it is clear that blockchain has attracted a growing interest from the pharmaceutical industry as an answer to its supply chain challenges (Tan et al., 2020; Abu-elezz, Hassan, Nazeemudeen, Househ, & Abd-alrazaq, 2020; R. Kumar & Tripathi, 2019; Raj et al., 2019). As mentioned before, blockchain provides a decentralised ledger where all the nodes in the network can see and validate the transactions. Furthermore, with its consensus algorithm, only validated information is stored eliminating the possibility for duplicated information. Applied to the PSC, the products can be identified, for example, with global trade item number (GTIN), expiry date, and serial number, which can then be accessed and tracked by everyone connected to the blockchain network (Aich, Chakraborty, Sain, Lee, & Kim, 2019). These blockchain features allow traceability and visibility across the supply chain which consequently prevent drug counterfeiting incidents (Abu-elezz et al., 2020; R. Kumar & Tripathi, 2019; Raj et al., 2019). Another feature made possible by blockchain is smart contracts. It is a digital form of contract that is self-executing and stored in the form of codes in the blockchain. When the specified conditions are met, the contract is fulfilled without any middle man necessary. When combined with the use of sensors, smart contracts can ensure the quality control of the transport of the drugs without needing paper in order to prove that the regulations were followed (A. Kumar, Choudhary, Raju, Chaudhary, & Sagar, 2019; Tan et al., 2020). It also solves other issues such as payment delays, and overall brings trust to the supply chain. Another issue blockchain is being used to solve is the recall of defective and/or potentially unsafe products from the market (Wu & Lin, 2019). This is an often expensive and complex process where transparent information and quick actions are necessary. Therefore, with blockchain technologies recall can be made more efficient with a temper-proof registry.

All these features bring more accountability, traceability, visibility and security to the supply chain which is crucial since flaws in this particular supply chain can lead to deadly consequences for the consumers of the distributed drugs (A. Kumar et al., 2019; Fernando, Meyliana, & Surjandy, 2019). However, blockchain technologies are still in its infancy and still face many barriers of adoption (Abu-elezz et al., 2020). The lack of full understanding of their advantages, clear guidelines on how to implement, and outdated regulatory bodies are a few of the reasons that have led to a narrow adoption of these technologies (Raj et al., 2019; Abu-elezz et al., 2020).

In this section it is understood that, from all the problems existing in the PSC, the falsification of medicinal products for human use is the issue that poses the greatest risk to the population. At the same time, it is shown that the features provided by blockchain technologies are ideal to combat this problem. Therefore, in order to better scope the research and produce more meaningful insights, the study will focus on how can companies offering blockchain technologies attract the different players in the PSC to combat the distribution of falsified medicinal products for human use.

1.3. RESEARCH OBJECTIVE

To address the gap in literature mentioned, the main goal of this research is:

To describe how blockchain technology initiatives in the pharmaceutical supply chain can stimulate blockchain technologies' adoption to combat the distribution of falsified medicinal products for human use.

In order to reach this goal, other sub-objectives should be reached first:

- Identify how the falsified medicinal products for human use enter the legal PSC;
- Identify how can blockchain technologies combat the distribution of falsified medicinal products for human use;

- Identify the barriers and drivers influencing the adoption of blockchain technologies in the PSC to combat the distribution of falsified medicinal products for human use;
- Identify the most important drivers and barriers to adopt blockchain technologies in the PSC to combat the distribution of falsified medicinal products for human use;
- Provide recommendations on how to overcome the most important barriers leveraging the most important drivers to stimulate blockchain adoption in the industry.

Once these are completed, the main objective should be able to be fulfilled.

1.4. Research Questions

In order to achieve the objectives, different research questions are proposed. The main research question has the aim to also answer the main objective:

How can blockchain technology initiatives in the PSC stimulate blockchain technologies' adoption to combat the distribution of falsified medicinal products for human use?

In order to gather sufficient information and data to answer the main research question, several sub-questions (SQs) were formulated. These are, in turn, related to the sub-objectives presented in the previous section.

- **SQ1: How can blockchain technologies combat the distribution of falsified medicinal products for human use?**

This question will answer sub-objectives one and two. It is important to answer this question to understand where are the weaknesses in the PSC that allows for these products to reach the final consumer, and how can blockchain technologies assist in solving these weaknesses.

The first part of answering this question will focus on finding a scheme of the PSC that can show all the stakeholders involved in the legal PSC. This will be based in the existing literature on the subject in order to find the most complete model not only with the players of the supply chain but also with the stakeholders that are affected and involved by the manufacturing and distribution of these falsified products. Furthermore, it will be understood where are the weaknesses in the PSC that allow for the falsified products to enter the legal supply chain. The second part will focus on understanding how can blockchain technologies be used to prevent this problem and what initiatives are already developing and offering this solution. This will be done resorting to the existing literature on the subject.

- **SQ2: What are the barriers and drivers influencing the adoption of blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use?**

Based on the knowledge gathered in the first sub-question, the study will focus on gathering a set of barriers and a set of drivers that influence the adoption of blockchain technologies in the PSC to combat the distribution of falsified medicinal products for human use. The research will focus on the firm level acceptance of this type of technology. Therefore, the two most widely accepted models for IT adoption in the literature are the diffusion on innovation (DOI) theory, and the technology, organization, and environment (TOE) framework (Oliveira, Thomas, & Espadanal, 2014). TOE framework is actually consistent with the DOI theory and therefore researchers have argued that they are very closely related (Baker, 2012). The context of technology from TOE is implicitly the same idea as the DOI theory, and DOI's external and internal organizational characteristic are similar as TOE's measures in the organizational context (Oliveira et al., 2014). However, the TOE framework is considered to be more complete as it includes the environment context, which the DOI theory does not provide, hence being better suited to explain intra-firm innovation adoption (Oliveira & Martins, 2011). Therefore, the TOE framework has been chosen to answer the second sub-research question.

In order to find the information to populate the framework, a literature review will be done. This review will not only focus on the barriers and drivers of blockchain technologies adoption in the PSC to bring traceability and visibility in the supply chain, but also in supply chains in general where this topic has been addressed. This is important as many lessons and experiences from other supply chains can be used in the pharmaceutical industry. At the same time, the research can be extended to the drivers and barriers to the implementation of other technologies in the PSC since there could be factors that could apply to blockchain adoption as well.

This will result in an extensive list of barriers and drivers found in the literature that will be classified according to the TOE framework. In order to narrow the barriers and drivers down, interviews will be performed with experts in the pharmaceutical industry and/or in the blockchain industry to ask what are their top five barriers and drivers that influence the adoption of blockchain technologies in the PSC to combat the distribution of falsified medicinal products for human use.

- **SQ3: What is the relative importance attributed to each driver and barrier influencing the adoption of blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use?**

Once the two previous sub-research questions are answered, a set of barriers and a set of drivers will have been identified per category of the TOE framework. These six lists will serve as a foundation to build a survey that will allow to answer the third sub-question (SQ3) by following the Bayesian Best-Worst method (BWM). This method is a multi-criteria decision making (MCDM) method, that is able to rank the barriers and drivers with less pairwise comparison matrices and with more consistent results than other tools such as the Analytical Hierarchy Process (AHP) (Rezaei, 2015). For this study in particular, the Bayesian BWM will be used as there are multiple decision-makers and this method calculates the optimal weights of each criterion (Mohammadi & Rezaei, 2020). This means the researcher does not have to obtain the criteria weights of each decision-maker first separately and aggregate the weights afterwards using arithmetic mean, which can be prone to outliers and provides limited information to decision-makers (Mohammadi & Rezaei, 2020). To collect the preferences, an online questionnaire will be designed following the BWM method. Consequently, it will be shared with relevant stakeholders in the pharmaceutical industry, and experts in the field of supply chain digitalization and blockchain in order to collect enough responses. Once this step is fulfilled, the data can be analysed in order to answer the question.

- **SQ4: How can blockchain technology initiatives overcome the most important barriers to adopt blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use, while leveraging the most important drivers, to stimulate adoption?**

By answering the previous sub-research question a ranking of the barriers and of the drivers will be found using the MATLAB program developed by Mohammadi and Rezaei (2020). Based on these rankings, an analysis will be able to be performed and enough information will be gathered in order to answer the fourth sub-question. Hence, meaningful insights will be provided on how to overcome the most important barriers while leveraging the most important drivers to the players offering blockchain technologies in the PSC to further diffuse the technology.

Finally, the main research question will be answered as a natural consequence of answering all the four sub-questions.

1.5. RESEARCH APPROACH AND FRAMEWORK

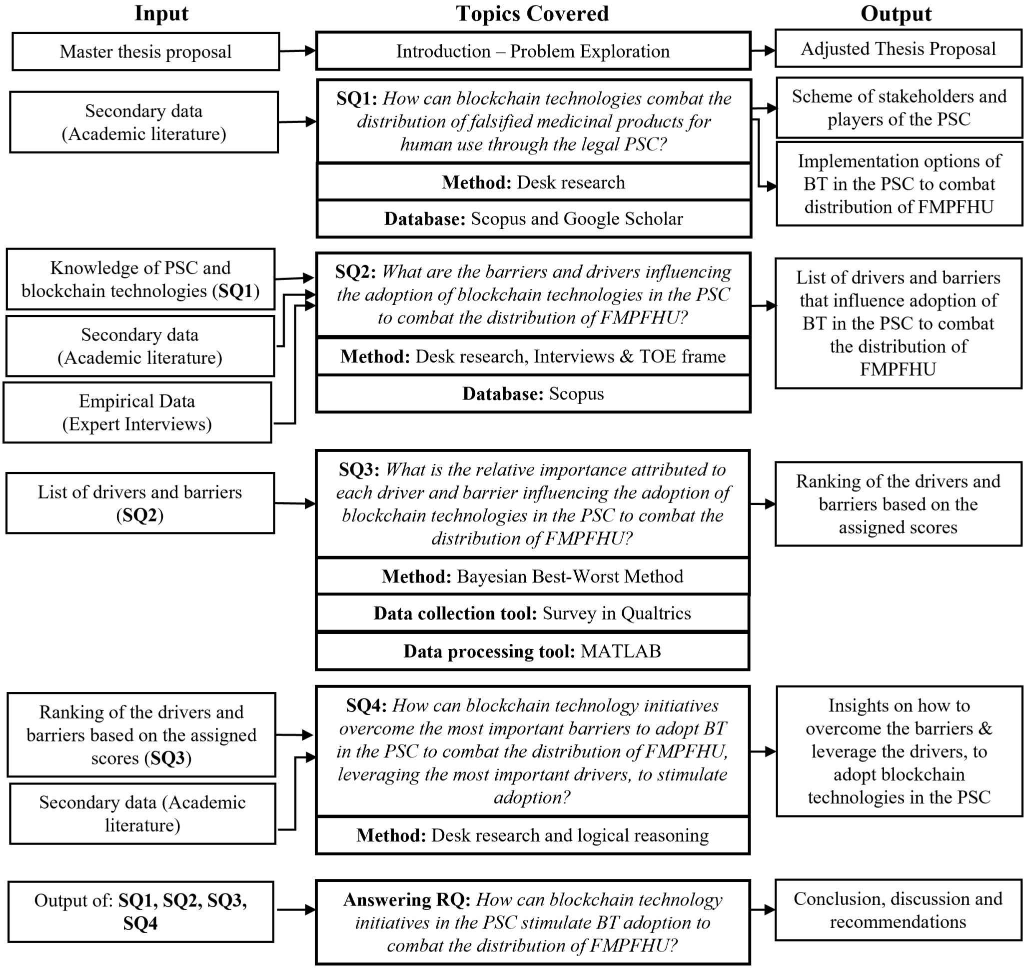

Figure 1.1: Research Flow and outline

1.6. Scientific Relevance

As mentioned in section 1.2, one of the main problems of the PSC is the distribution of falsified medicines for human use which has deathly consequences. While pursuing solutions to tackle this problem, some companies have found that blockchain technologies would be a promising investment due to their innovative features such as traceability, immutability, and security.

When conducting the literature review in chapter 2, it was found that the articles published on the use of blockchain technologies in the PSC are very recent, starting in 2017, and not extensive, 27. These were divided into explaining the potential of using blockchain based solution to combat the distribution of counterfeited medicines, and the rest on proposing concrete implementation architecture set-ups to combat this problem.

Furthermore, in the literature review conducted in chapter 3, no papers were found on the implementation drivers and barriers of blockchain technologies in the PSC nor on giving recommendations to blockchain technology providers to attract more players in the PSC.

Hence, it can be asserted that the present study contributes to an unexplored area of study of blockchain technologies and the pharmaceutical supply chain.

2

Context

In this following chapter, the first sub-question "How can blockchain technologies combat the distribution of falsified medicinal products for human use through the legal pharmaceutical supply chain?" will be answered through conducting a literature review. With this chapter and sub-question the aim is to understand three key points. The first one is how is the PSC operating with all its important and relevant stakeholders as well as its actors. The second point is to understand, in this architecture, how can counterfeiting occur. Finally, the third point is to understand how can blockchain prevent and address the distribution of falsified medicinal products in the PSC, and which are the initiatives developing or already offering the solution.

2.1. Literature Review

In order to find meaningful articles to answer the first sub-question the following approaches were followed.

2.1.1. The Pharmaceutical Supply Chain Review method

In order to find relevant literature to understand the PSC a systematic literature review was performed using the following funnel approach:

Table 2.1: Funnel approach to find articles related to the PSC

#	Terms (Query string)	Refined by	Articles
1.1	TITLE-ABS-KEY ("pharm*" AND ("supply chai*" OR "supply networ*" OR "logistics networ*")) AND TITLE-ABS-KEY ("actors" OR "stakeholders")	Language: English	246
1.2	TITLE-ABS-KEY ("pharm*" AND ("supply chai*" OR "supply networ*" OR "logistics networ*")) AND TITLE-ABS-KEY ("actors" OR "stakeholders") AND TITLE-ABS-KEY ("review" OR "literature stud*")	Language: English	50
1.3	TITLE-ABS-KEY ("pharm*" AND ("supply chai*" OR "supply networ*" OR "logistics networ*")) AND TITLE-ABS-KEY ("actors" OR "stakeholders") AND TITLE-ABS-KEY ("review" OR "literature stud*")	Language: English; Relevant title and abstract	11
2.1	TITLE-ABS-KEY ("pharm*" AND ("supply chai*" OR "supply networ*" OR "logistics networ*")) AND TITLE-ABS-KEY ("inf* flo*" OR "inf* exchange")	Language: English;	36
2.2	TITLE-ABS-KEY ("pharm*" AND ("supply chai*" OR "supply networ*" OR "logistics networ*")) AND TITLE-ABS-KEY ("inf* flo*" OR "inf* exchange")	Language: English; Relevant title and abstract	2

This research was done in February 2022, using Scopus as its main repository. For the first iteration, the keywords chosen aimed at scoping the research in order to return articles related to PSC, therefore the term "pharm*" was used in order to be able to search all words starting with "pharm" such as "pharmaceutical", "pharmaceutic" or "pharma", adding the "supply chain" terms and their synonyms such as "logistic network*". In order to specify that the articles needed to focus on its "actors" and "stakeholders" those two terms were added. After this, to further refine the search the terms "review" and "literature stud*" were added so that only studies that had done literature reviews and, therefore, looked into more studies on the topic would turn up. Following this step the fifty articles' titles and abstracts were scanned in order to choose the most suitable ones, which finally amounted to eleven. Articles that did not have at least an initial focus on explaining the PSC were not considered.

After this first search, a secondary search was made adding the terms "information flow" and "information exchange" and derivatives of these terms. This was important to find articles that focus on the flows between the different parties of the PSC, to understand its specificities. This search yielded thirty-six articles from which two were found relevant.

It is also important to mention that in both searches only articles that were available in full-text and in English were included.

2.1.2. FALSIFIED MEDICINES IN THE PSC AND BLOCKCHAIN TECHNOLOGIES AS A SOLUTION REVIEW METHOD

Similarly to the previous sections, in order to find the relevant literature to understand how can blockchain technologies aid in combating counterfeit medicines in the PSC, a systematic literature review was conducted using the following keywords:

- "Blockchain", "block chain" and "block-chain";
- "Pharmaceutical supply chain", "pharmaceutical supply network", "pharmaceutical distribution" and "pharmaceutical logistics";
- "Counterfeiting", "false", "fake".

And in order to have the full range of derivatives of the words above, the query string input in Scopus in February 2022 was "(TITLE-ABS-KEY ("blockchain" OR "block chain" OR "block-chain") AND TITLE-ABS-KEY ("pharm* supply chain" OR "pharm* supply network" OR "pharm* distribution" OR "pharm* logistics") AND TITLE-ABS-KEY ("counterfei*" OR "fals*" OR "fak*"))".

This search yielded 27 articles which were all in English. From these, 17 were useful for the research. The 10 articles not considered were either impossible to access or were not from relevant sources. It is important to note as well that it was understood that this field is fairly new as the articles retrieved were from between 2017 and 2022.

The found articles can then be divided into the ones that research how the blockchain features can solve counterfeiting but do not propose any concrete solutions on how to actually implement the blockchain in the PSC, and into the ones that propose a concrete implementation architecture of blockchain technologies to combat counterfeiting in the PSC.

2.1.3. OVERVIEW

In the following tables, an overview of all the papers reviewed is presented. It is presented in two tables due to formatting constraints.

Table 2.2: Main takeaways of the Literature Review

Reference	Actors mentioned	Blockchain Initiatives or Pilots Mentioned for drug tracing	Solution/Technology Presented	Blockchain Platform	Identifi-cation Techn
Friend et al.	R&D, API Manufacturers, Secondary Manufacturing and Packaging, Distributors, Wholesalers, Pharmacies, Patient				
Narayana et al.	R&D, Raw material suppliers, Manufacturer, Wholesaler, Distributor, Pharmacies, Retailers, Healthcare Providers, End consumers, Drug Regulatory Agencies, Healthcare Fiscal Intermediaries and Payers				
Franco and Alfonso-Lizarazo	Vendors, Manufacturers (multinational, generic, local, contract, biotech), Distributors, Wholesalers, Providers (hospitals, clinics and pharmacies)				
Da Silva and de Mattos	Vendor, Manufacturers (API, secondary), Distributors (local, main), Wholesalers, Hospitals, Clinics, Pharmacies, Drug Regulatory Agencies				
S. Kumar and Kumar Pundir	Manufacturers, Distributors, Warehouse, Hospitals, Retailer		Blockchain-IoT enabled PSC		
Aich et al.	Raw Material Suppliers, Drug Manufacturers, Third Party Logistics, Wholesalers, Retailers (pharmacies, hospitals), Patient			Blockchain-IoT enabled PSC	GTIN
Chircu et al.	R&D labs, Suppliers (Lab Equipment, Chemicals, Testing, R&D Software), Raw material suppliers, Production equipment suppliers, Wholesalers, Hospitals, Clinics, Pharmacies, Government buyers, Patients, Service intermediaries, Information intermediaries.		RFID		RFID

Table 2.2: Main takeaways of the Literature Review

Reference	Actors mentioned	Blockchain Initiatives or Pilots Mentioned for drug tracing	Solution/Technology Presented	Blockchain Platform	Identifi-cation Techn
Papert et al.	Raw material suppliers, Packaging manufacturers, Pharmaceutical manufacturers, Packaging service providers, LSPs, TSPs, Medical representatives, Direct distributors, Wholesalers (national and international), Pharmaceutical importers, Medical practices, Hospitals, National and International Pharmacies (community and mail-order), Retirement/Care Centers, Patient or Consumer		Auto-ID tech (RFID, wireless sensor networks (WSNs))		Auto-ID tech
Xie and Breen	Pharmaceutical manufacturer, Logistic providers, Wholesalers, General practitioners, Community pharmacy, Customer				
Bhakoo and Chan	Manufacturers, Wholesalers and Distributors, Hospital pharmacies, Third party logistics providers, Patients, Government regulatory agencies, Technology providers				
Pedroso and Nakano	Suppliers (universities, research centers, raw materials), Pharmaceutical companies (manufacturers), Clients and distribution channels (physicians, hospitals, clinics, distributors, drug stores, large drugstore chains, Government, other stakeholders (e.g: regulatory agencies, NGOs, ...), Patients or consumers				
Yousefi and Alibabaei	Internal and external customers, suppliers, distributors, manufacturers, Government agencies.		"Track and Trace" System		

Table 2.3: Main takeaways of the Literature Review (Part 2)

Reference	Actors mentioned	Blockchain Initiatives or Pilots Mentioned for drug tracing	Solution/Technology Presented	Blockchain Platform	Identifi-cation Techn
Mackey and Nayyar		Chronicled, iSolve, BlockVerify, Rubrix by Deloitte.	mobile, radio frequency identification, advanced computational methods, online verification, and blockchain technology		
Badhotiya et al.			Blockchain technology offering a decentralized system, a tampering free environment, and the immutability and pseudonymity of transactions. Paired with RFID and IoT technology.		RFID
Ahmadi et al.	Raw material suppliers, Manufacturers, Distributors, Pharmacies		IoT-based blockchain solution		RFID
Nawale and Konapure	Ingredient supplier, Manufacturer, Distributor, Pharmacy, Patient		IoT-based blockchain solution using a mobile app to check the source		QR code, Temp. sensors
Saindane et al.	Manufacturer, Transporter, Wholesaler, Hospitals, Pharmacists		IoT-based blockchain solution		QR code
Archa et al.		Tracelink. Axway. VerifyBrand. Bosch Packaging Technology. IBM and Maersk	IoT integrated with blockchain		RFID

Table 2.3: Main takeaways of the Literature Review (Part 2)

Reference	Actors mentioned	Blockchain Initiatives or Pilots Mentioned for drug tracing	Solution/Technology Presented	Blockchain Platform	Identifi-cation Techn
Uddin et al.	API supplier, Manufacturer, Distributer (Primary, Secondary), Re-packager, Pharmacy, Patient	- IBM, KPMG, Merck, Walmart - IDLogiq - MediLedger - Amerisource Bergen, McKesson, and Genentech, Pfizer, Gilead - TraceLink - Indiana university health and Wakemed health and hospitals - LedgerDomain - Uni of California Los Angeles health - SAP Multichain - Merck, Amerisource Bergen, GSK, Amgen, Boehringer Ingelheim, McKesson, Novo Nordisk	Blockchain based decentralized private architectures implemented in the PSC	Hyperledger Fabric and Hyperledger Besu	
Pandey and Litoriya	Manufacturers, Logistics, Distributors (regional and local), Hopistals (public and private), Retailers, Consumer/Patient		Electronic health network based on a permissioned blockchain network	Hyperledger Fabric	QR code
Bryatov and Borodinov	Manufacturer, Pharmacy, Doctor, Citizen, and Government		Relational model between the 5 main actors based on smart contracts in a private blockchain network with the Government as the administrator	Hyperledger Fabric	

Table 2.3: Main takeaways of the Literature Review (Part 2)

Reference	Actors mentioned	Blockchain Initiatives or Pilots Mentioned for drug tracing	Solution/Technology Presented	Blockchain Platform	Identification Techn
Raj et al.	Manufacturer, Distributor, Wholesaler, Retailer (Pharmacy), Customer		Permissioned blockchain where only parties verified by the Certificate Authorities (ex: Drug Regulatory Authority) can enter and create the smart contracts in the platform, and only the manufacturer can register the drug.	Hyperledger Fabric	Electronic Product Code (EPC)
A. Kumar et al.	Pharma Department, Extraction Unit, Manufacturer, Distributor, Wholesaler, Patient		Blockchain based drug supply chain that is private and permissioned, and supporting smart contracts. The platform and access to it is fully controlled by the government.	Hyperledger Fabric	QR code
Sylim et al.	Manufacturer, Wholesaler, Retailer, Food and Drug Administration, Consumer.		Distributed Application (DApp) with a back-end Distributed File System (DFS) supporting a private blockchain network utilizing smart contracts	Hyperledger and Ethereum	RFID Tag
Singh et al.	Supplier, Manufacturer, Wholesaler, Distributor, Hospital or Pharmacy, Patient		IoT-based blockchain architecture to monitor the cold chain: application layer (SC), platform softwares (hyperledger), contract layer (smart contract), consensus layer (Raft), data layer (Hash, chain structure, merkie tree, timestamp, encryption, data block), network layer (P2P, BloXroute, cloud)	Hyperledger with bloXroute and Raft	QR code, Temp. sensors

Table 2.3: Main takeaways of the Literature Review (Part 2)

Reference	Actors mentioned	Blockchain Initiatives or Pilots Mentioned for drug tracing	Solution/Technology Presented	Blockchain Platform	Identification Techn
Akhtar and Rizvi	Manufacturer, Distributor, Wholesaler, Retailers or pharmacies, Hospitals, Patients		Recording each transaction of change of ownership of drugs in the SC (starting with the manufacturer) into Hyperledger and Ethereum with use of smart contracts and compare. Hyperledger was the most efficient, and better in scalability, transactions per second, user-friendliness, authentication and accountability.	Hyperledger and Ethereum	QR code
Chiacchio et al.	Pharmaceutical manufacturer, Wholesaler, Pharmacist, Patient		Decentralized Application (DAPP) based on blockchain using smart contracts to ensure ownership, uniqueness, data synchronization, and data retention.	Ethereum	QR code
Musamih et al.	Supplier, Manufacturer, Distributor (primary and secondary), Pharmacy, Patient, Federal Drug Administration	Arsene (IBM, Cisco, Accenture, Intel, Bloomberg and Block stream). MediLedger. Farmatrust based on Quorum blockchain.	Blockchain-based approach using smart contracts and decentralized off-chain storage	Ethereum	QR code

2.2. THE PHARMACEUTICAL SUPPLY CHAIN

2.2.1. ACTORS AND FLOWS IN THE PHARMACEUTICAL SUPPLY CHAIN

It is estimated that medicines consume around 20%-30% of the global health spending, which makes the pharmaceutical industry one of the most important industries in the world (Franco & Alfonso-Lizarazo, 2017). Because of this, the only acceptable service level is of 100%, as it has a direct impact on public health, making a good management of the PSC so crucial.

As mentioned before, the PSC is quite complex as there are many different players involved not only on the passing down and transforming the products through the supply chain, but that also regulate and influence it.

Friend et al. (2020) from PwC considers that the PSC covers everything from research and innovation to create a new product through to delivery to the hospital, retail pharmacy or patient, mentioning that normally pharma companies are not very flexible or cost-efficient. Therefore, the players involved in the PSC are RD, Active Pharmaceutical Ingredient (API) Manufacturers, Secondary Manufacturing and Packaging, Distributors, Wholesalers, Pharmacies, Patient. It is mentioned that pharmaceutical companies have a hard time having a "continuous flow" of production holding large quantities of inventory instead of producing on demand. Friend et al. (2020) consider that there are three different and separately operating supply chains in the pharmaceutical industry: pharmaceuticals, medical devices, and healthcare services. It is expected that these three different streams will merge in the coming years in order to be able to have more visibility and accurately manage the demand and plan accordingly. Furthermore, it is mentioned that contract manufacturing and logistics industries have understood that integrating supply chain services to be able to share resources and take advantage of economies of scale is the best way forward. Therefore, companies in the PSC will have to find ways to interact and work together seamlessly to make this a reality. The management of information will be as important as the management of products.

In their paper, Narayana et al. (2013), conducted a systematic review of research on management in the PSC. It is shown that the PSC considered has different players that are grouped in three different industries: Biotechnology Industry (Research and Design), Pharmaceutical Manufacturing and Distribution Industry (Raw Material Supplier, Manufacturer, Wholesaler, Distributor), and Healthcare Services Industry (pharmacies, Retailers, Healthcare Providers), and End Consumer. It is also included two overarching actors: Drug Regulatory Agencies, and Healthcare Fiscal Intermediaries and Payers. Based on research, three different levels of interest were found that influence the final value delivered to the end consumer which come from the different interactions between the three groups: Interactions between Biotechnology industry – pharmaceuticals manufacturing and distribution industry; Intra-industry interactions in the pharmaceuticals manufacturing and distribution environment; and Interactions between Pharmaceutical manufacturing and distribution industry – healthcare service industry. The papers found focus mainly on efficiency/profitability improvement, process analysis and building technological competence and there is a clear shift of focus to a more network-centric approach facilitated by the healthcare procurement and supply functions. Among the themes mentioned, the improvement of product security with product tracking technology, and the management of information collaboration and business process knowledge management, go in line with the research put forward in this thesis.

Franco and Alfonso-Lizarazo (2017), also conducted a structured review of the PSC but instead they wanted to identify and provide an overview of the quantitative models in this supply chain. Three categories of classification were found: network design, inventory models, and optimization of a PSC. It was understood that the most common source of uncertainty in the PSC is the demand. The activities of a PSC involve the transformation and flow of the medicinal products from raw materials to the end user. In this review, a typical configuration of a PSC is presented which includes vendors, manufacturers, distributors, wholesalers and providers. The manufacturers can be divided into five different categories: multinational companies, generic manufacturers, local companies, contract manufacturers, and biotechnological companies. There is also a group of purchasers, including wholesalers and distributors, and a group of providers which entail hospitals, clinics and pharmacies. It is also mentioned that the flow of supplying the products can be done directly from the warehouse to the hospital or it can be satisfied by the pharmacies. Compared to Franco and Alfonso-Lizarazo (2017), Da Silva and de Mattos (2019) also defends this architecture of the PSC but divides the manufacturers just into two groups: the API manufacturers and the secondary manufacturers responsible for the further production processes. It also divides the distributors into local and main ones, and it distinguishes the organizations into buying and selling capacities: manufacturers are sellers, hospitals are buyers and wholesalers are both. It also adds the importance of governmental agencies that force all these organizations to comply with the regulations set.

In its turn S. Kumar and Kumar Pundir (2020), presents fewer players in the PSC, however it represents better all the different types of distribution and interaction between these players. The fulfillment of the demand of medical essentials is done from manufactures to distributor/warehouse or from distributor/warehouse to hospitals/retail stores. S. Kumar and Kumar Pundir (2020) focused on improving these flows using Blockchain and Internet of Things in order to bring trust among stakeholders in the PSC and reducing the number of interactions between workers amid the COVID-19 outbreak. Likewise, Aich et al. (2019) studied the benefits of IoT integrated Blokchain based SCM implementations, being one of the case studies chosen the PSC in order to bring to it more transparency and visibility. The PSC actors mentioned are the raw material suppliers, drug manufacturers, third party logistics, wholesalers, retailers (pharmacies and hospitals), and finally the patient. These players are shown to be possible to be connected by IoT integrated blockchain by recording the goods movement and transactions using the global trade item number (GTIN).

The following papers analysed, all have a focus on one specific country. Two papers focus on Germany, and the rest on the United Kingdom (UK) and Australia.

Chircu et al. (2014) and Papert et al. (2016) focus their studies on Germany Pharmaceutical Supply Chains in order to bring visibility and improve communication of data and information between the different players. The former offers one of the most complete views of the PSC showed in figure 2.1. It divides the PSC into three different phases: drug discovery and development, drug production, and drug delivery and dispensing. The most important players in the first phase are the R&D labs, laboratory equipment suppliers, suppliers of chemicals and biological specimen for initial testing of molecules, and the suppliers of R&D software. In the production phase the major players are the raw material suppliers and production equipment suppliers for the manufacturing facilities. Finally in the last phase the most important ones are wholesalers, hospitals and clinics, traditional pharmacies, mail order and Internet pharmacies, government buyers, and finally the patients who ultimately consume the pharmaceutical products.

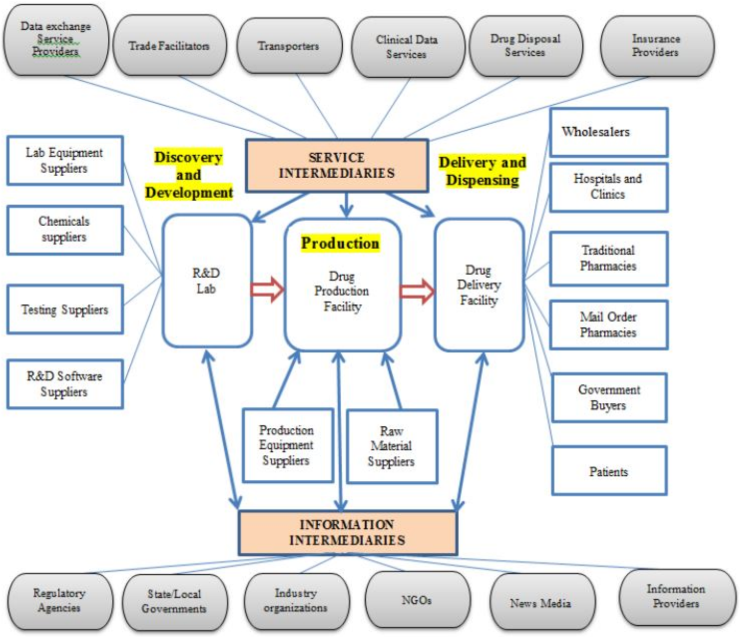

Figure 2.1: Generic Global Pharmaceutical Industry Supply Chain (Chircu et al., 2014)

Adding to these players, there are two types of intermediaries that facilitate the supply chain: service intermediaries and information intermediaries. Information intermediaries exchange data with the different pharmaceutical companies related to R&D, marketing, and regulatory compliance concerning drug counterfeiting and public safety, whereas service intermediaries expedite the supply chain logistics for pharmaceutical companies. Information intermediaries are governments at many levels – including regulatory agencies, non-governmental organizations (NGOs), news media, industry organizations, and information providers. The service intermediaries include value-added network service providers for document interchange, trade facilitators for obtaining customs documents, transporters for shipping and delivering medicines, clinical data services for critical trials, drug disposal services for unused and spent drugs, and insurance providers for reducing the liabilities of the supply chain participants. Based on this supply chain architecture, Chircu et al. (2014) propose a RFID-based solution to reduce counterfeiting and enable drug quality monitoring throughout the PSC.

Papert et al. (2016) proposes a solution for supply chain visibility based on automatic identification (Auto-ID) technologies such as RFID and barcode due to the demand from the good distribution practice guideline created by the European Union of increasing visibility from firms on the distribution of medical products for human use. The actors involved in the PSC are presented and a clear distinction is made between Logistic Service Providers (LSP) and Transportation Service Providers (TSP). The ladder does not provide any value-added services, such as labeling, of package creation, it is just responsible for the transportation of the drugs. Papert et al. (2016) consider that the most common chain in the drug supply is the chain with just TSPs and, therefore, focuses solely on this chain in Germany. However, the complete list of actors presented as part of the PSC network are: raw material suppliers, packaging manufacturers, pharmaceutical manufacturers, packaging service providers, LSPs, TSPs, medical representatives, direct distributors, pharmaceutical wholesalers (national and international), pharmaceutical importers, medical practices, hospitals, national and international pharmacies (community and mail-order), retirement/care centers, and finally the patient or consumer.

The following paper has focused on finding solutions to design a green community PSC in the United Kingdom to prevent pharmaceutical waste and correctly dispose of it. For Xie and Breen (2012), a common community PSC is composed of the pharmaceutical manufacturer, logistic providers and wholesalers, general practitioners, community pharmacy, and finally the customer. It also includes the professional and regulatory bodies, and waste management agencies that produce legislation that impacts all the other actors. It is important to mention that community pharmacies are bound by contractual obligation to offer returns service for medication (Xie & Breen, 2012). The reverse logistics are also mentioned as it is seen as an important step to dispose correctly of the waste. It happens through the relationship built between the consumer and the community pharmacy that receives these products, and that in their turn send it up the supply chain to be disposed by the manufacturer.

The paper from Bhakoo and Chan (2011), gives insights into the implementation of e-business processes in the procurement area of a healthcare supply chain in Australia while more than one stakeholder is involved. It found that the lack of interoperability, consistency and communication of data, and its poor quality between the different stakeholders makes it difficult to implement e-businesses. A single longitudinal case study over three years is the used methodology for the research. The Australian pharmaceutical health-care supply chain is presented as being composed of: manufacturers, wholesalers and distributors, hospital pharmacies, third party logistics providers, the patients. It also mentions the government regulatory agencies, such as the Therapeutic Goods Administration (TGA) and state contracting bodies such as Health Purchasing Victoria (HPV), play significant roles in developing policies, standards, and regulations that affect all entities in the supply chain. As well as external entities such as the technology providers since they play an important part by administering bar-coding standards and providing software infrastructure to other entities in the supply chain.

The following two articles were found in the second research explained in the previous sub-section, that focus more on the type of flows that exist between the different players of the PSC.

The first paper's focal point is the knowledge and information flows in supply chains applied to the PSC. Pedroso and Nakano (2009) used qualitative research to understand, apart from the regular material channel that comprises products and order information flows, how to build a channel for technical or knowledge related information that is also

2

crucial for these companies in the PSC. Since in the PSC consumers or patients do not have the purchasing power, the technical information needs to first be understood by the physician who then creates the demand for the products. Thus, is the technical information that creates order information that then create the goods and services flow. Therefore, Pedroso and Nakano (2009) presents a very complete map, seen in figure 2.2 of the flows between all the PSC actors, including the created knowledge flow that should happen between the physician and the pharmaceutical companies.

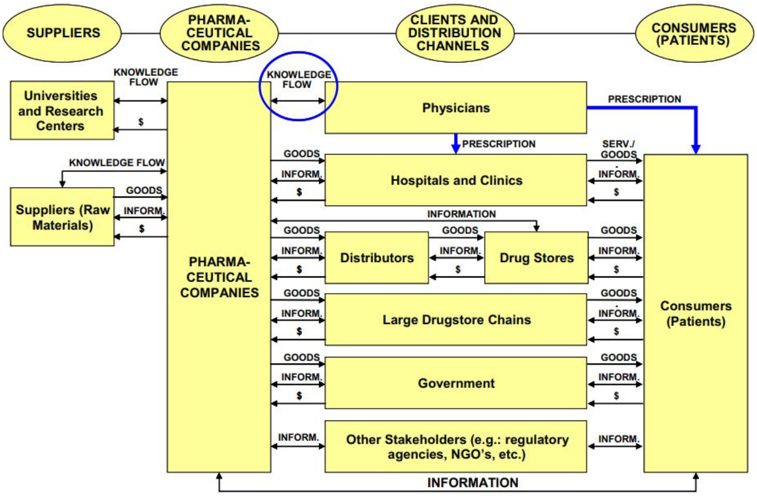

Figure 2.2: Goods, financial, knowledge and information flows in the PSC (Pedroso Nakano, 2009)

As shown, the PSC can be divided into four groups:

- **Suppliers**: universities and research centers, and suppliers of raw materials;
- **Pharmaceutical companies**: manufacturers;
- **Clients and distribution channels**: physicians, hospitals and clinics, distributors, drug stores, large drugstore chains, Government, other stakeholders (e.g: regulatory agencies, NGOs, ...);
- **Consumers or patients.**

The second paper focuses on the Iranian PSC put forward by Yousefi and Alibabaei (2015). It was found that there are four layers in the information systems in a supply chain. Not all levels are necessary to be used, but are highly recommended when it comes to the PSC since it is such a complex environment that has social and political impacts. According to Yousefi and Alibabaei (2015) the levels are:

- **Transaction level**: is the most important one. It initiates and records individual logistics activities data including order entry, inventory assignment, order selection, shipping, pricing, and invoicing and customer inquiry. A transaction processing system's main activities has five categories: order management, order processing, preparations for distribution, transportation and shipping and, procurement. **Most common tools and technologies:** Electronic data interchange (EDI) and Electronic Fund Transfer (EFT), Extensible Markup Language (XML), barcode and Radio frequency identification (RFID), contact wand, contact scanners, active and passive non-contacts scanners, automatic identification and data capturing technologies, Freight Information and Tracking Systems (FITS), graphical information systems (GIS), Mobile satellite services, Radio determination satellite services, Global positioning systems, point of sale (POS) and Electronic Automatic Ordering Systems (EOS).

- **Management control system level:** focus on measuring the performance, reporting, providing feedback and identifying exceptions. A management information system (MIS) helps to identify potential problems such as inventory shortage which is critical for managing a supply chain

- **Decision analysis systems level:** It includes programs that assist managers in identification, evaluation and comparison of different strategies and tactics. Included are decision support systems (DSS), ERP, artificial intelligence application, and simulation/modeling systems.

- **Strategic planning systems level:** focuses on information support systems to develop and refine the strategies used in a supply chain. The executive information system (EIS) is the most common system in this layer. It facilitates and supports senior executive information in a graphical display and easy-to-use user interface.

The PSC uses many different information systems, databases and software (Yousefi & Alibabaei, 2015). These are not integrated which makes the information flow throughout the PSC difficult and unreliable. To improve this situation and also combat counterfeit medicines, bring better management of drug shortage and planning for production, importing and stocking, the food and drug organization of Iran has developed a new system called "track and trace" in the PSC. It aims to streamline online transactions, E-pedigree, the ability to track medicines and E-commerce in a first phase. In the next one it aims to connect e-prescribing and e-health dossiers.

2.2.2. FALSIFIED MEDICINES ENTERING THE LEGAL PSC

Some authors explored the gaps in the PSC that allow for counterfeit products to infiltrate it and reach the end consumer.

For example, both Ahmadi et al. (2020) defends that the gaps can occur at four levels:

- **Level 1:** Raw material delivery. The supplier can deliver already sub-standard quality or fake raw materials from the star of the supply chain.

- **Level 2:** Manufacturer. Most of the counterfeit drugs or ingredients enter into circulation at this level. A counterfeit manufacturer can produce falsified drugs that look like the original and then sell it as such.

- **Level 3:** Distributor. Normally, the manufacturer sells the medicines to the distributor. In order for the falsified medicines to enter the legitimate network highly sophisticated operations can be in place such as using places where security is not as tight or using barcode scams that take advantage of delays in mass scans. However, these operations can also be simple, such as on the level of the shipping of the drugs.

- **Level 4:** Pharmacies. Especially in countries with less regulations and with the increase of online pharmacies, consumers are increasingly vulnerable to purchase falsified medicines. These products are normally cheaper and pharmacies knowingly or not, opt for these options in order to make more profit.

Pandey and Litoriya (2021) also agree with these levels or points of entry of the counterfeit drugs, however, the raw material delivery is not mentioned.

Taking into account the information gathered in sub-sections 2.2.1 and 2.2.2, the most used architecture of a PSC and, therefore, the one that will be taken into consideration for the research, is the following:
Physical and Financial Flow:

- Raw material and packaging suppliers;
- Manufacturers;
- Distributors, including wholesalers and third party logistics providers;
- Retailers, including pharmacies;
- Healthcare providers, including hospitals and clinics;
- Patients or end consumers.

Information Flow:

- All the above;
- Governments and Regulatory Agencies.

Based on this conclusion, a diagram was produced and is presented in figure 7.1.

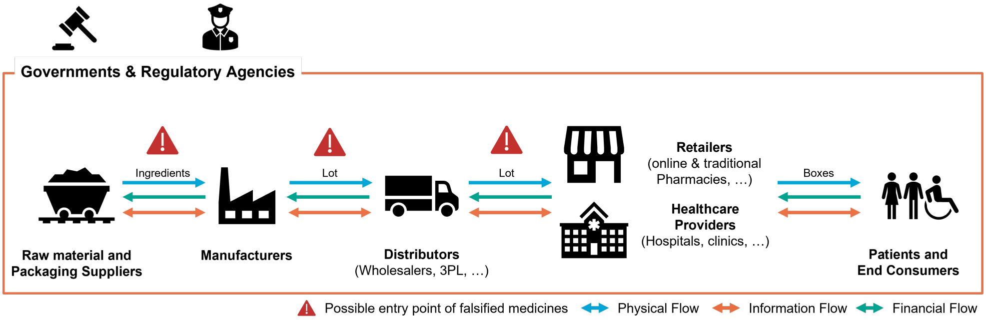

Figure 2.3: Diagram of a normal PSC and potential entry points for falsified medicines.

2.3. Blockchain Technologies as a solution to Falsified Medicines in the Pharmaceutical Supply Chain

2.3.1. Blockchain solutions presented in the literature

As seen in table 2.3, the papers found propose different blockchain-based solutions to combat the distribution of falsified medicines.

Mackey and Nayyar (2017) conducted a multidisciplinary literature review to understand what existing and emerging technological solutions can combat the counterfeiting of medicines in the PSC. They identified five categories of the technology: mobile, radio frequency identification, advanced computational methods, online verification, and blockchain technology. They found that many of these do not operate in isolation due to the underlining technologies they use such as wireless, internet, and radio-enabled capabilities, which facilitates the interaction of these platforms and their design and subsequent utilization from the different supply chain actors. For example, the RFID and mobile technologies that were found to be the most mature, are employed as a digital backbone for the other types of innovation. RFID is, in its core, a technology framework for automatic authentication and transmission of data that can be operated using different forms of technology (including mobile and cloud-based applications), while at the same time has the potential to act as a vehicle for more robust information sharing across different data points in the supply chain. Along these lines, Blockchain, even though being still in its infancy, is seen as having the potential to revolutionize how this information is shared across the stakeholders in the supply chain in a more trustworthy, secured, and accessible distributed and decentralized digital ledger. They also alert for the fact that these emerging technologies can also bring challenges of their own, such as cybersecurity, which technology designers will have to think about as well.

Blockchain is a very versatile technology that has the feature of being able to be paired with other technologies. Therefore, the following papers focused on the use of this technology allied to the use of IoT as well, and how it can be implemented in the PSC.

Both Badhotiya et al. (2021) and S. Kumar and Kumar Pundir (2020) study the use of Blockchain and IoT technologies to improve the PSC. Badhotiya et al. (2021) focuses on what are the challenges that the PSC faces today such as having a large number of vendors, multiple manufacturing facilities, and a complex and unequipped distribution network, and then on the main features of Blockchain technology that can resolve and mitigate these issues, such as being a decentralized system, offering a tampering free environment, and the immutability and pseudonymity of transactions. Similarly, S. Kumar and Kumar Pundir (2020) also focuses on the challenges of the PSC but related to the COVID-19 pandemic, which also saw an increase of falsification of essential products such as protection material, and consequently how the features of Blockchain technology can help solve them. Furthermore, both present a supply chain network model for blockchain applications. Badhotiya et al. (2021) mentions that the key requirements are product identification, tracing and verification, for which it is advised to use RFID technology and IoT to scale the business. Moreover, S. Kumar and Kumar Pundir (2020) alerts for the financial burden of the solution implementation but defends that it would bring an effective long-term return on the investment since it would, among others, help reduce the workforce in the logistics sector that supports the PSC.

Ahmadi et al. (2020) and Nawale and Konapure (2021) also investigated the use of IoT-based blockchain technologies in the PSC. Both found that by using Blockchain and IoT technologies, the PSC would be more connected, transparent and have the ability to trace the products throughout the whole supply chain. Nawale and Konapure (2021) describes the full process from when a manufacturer receives the raw material, creates the medications and encrypts them using a QR (quick response) code with its essential information, until the product is purchased by the patient which can use the QR code and a mobile app to check the drug's source. The process also describes the usefulness of the technologies when tracking the temperature of transportation as it is important in cold chains, for example. This is all made possible because the information on the QR code of the product and the temperatures of the sensors in the trucks are stored in the Blockchain throughout the products' path from manufacturer to patient.

The system proposed by Saindane et al. (2020) to implement blockchain and IoT in order to bring better traceability and trackability to the PSC goes very much in line with how Nawale and Konapure (2021) and Ahmadi et al. (2020) see the solution, and actually with the majority of blockchain solution proposed in the literature. As seen in figure 2.4.

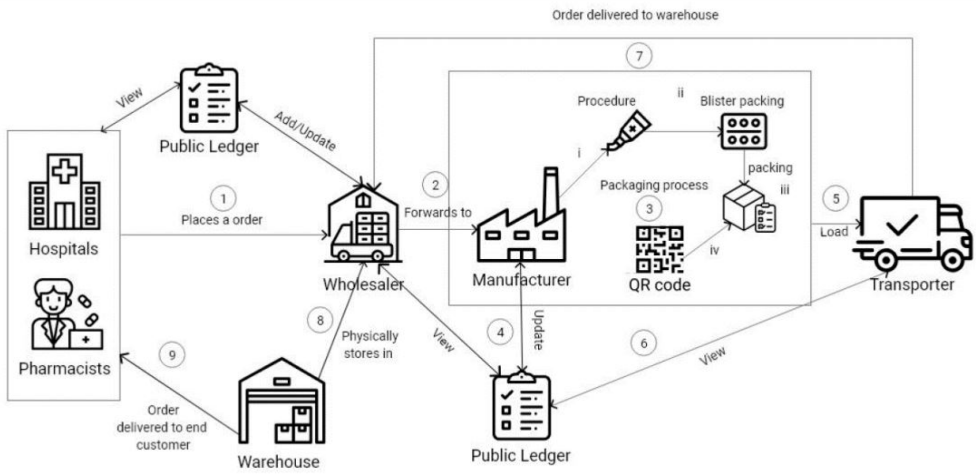

Figure 2.4: Modular diagram of proposed system to have a blockchain and IoT based PSC (Saindane et al., 2020).

1. The hospitals or pharmacists place an order with the wholesaler;
2. The wholesaler forwards the order to the manufacturer;
3. At the manufacturer, the creation of the medicine and its packaging take place and subsequent creation of the QR code, which has the benefits of the one-dimensional barcode but also the advantages of the other 2D barcodes, such as large capacity, high reliability, can encode words and images effectively, strong confidentiality and anti-counterfeiting, etc. An hash is also created with the information of the QR code for authentication purposes;
4. The manufacturer must upload this information, code and hash to the blockchain;
5. Once the product is ready, it is loaded into the trucks of the transporter which can view and verify the information
6. The transporter views and verifies the authenticity of the product;
7. The transporter deliver the product to the warehouse of the wholesaler;
8. The wholesaler physically stores the product in their warehouse;
9. The wholesaler can now view, add or update the information of the path of the product into the public ledger once the authenticity of the product is verified and then it can be delivered to the end customer, who, in their turn, can also view and verify all the information of the product.

The remaining papers analysed showed in table 2.3, focus on the implementation and architecture of the solutions in the PSC based on Blockchain technologies. The majority of the papers found use Hyperledger, but Ethereum is also seen as a viable option.

The majority of the papers also mention or make use of some form of identification technology such as the QR code or RFID tags in order to store the product information that is subsequently recorded in the blockchain platform and is able to be changed, added and verified along the supply chain normally using smart contracts to record these changes of ownership of the product. Smart contracts guarantee data provenance and consequently efficient product traceability, eliminates the need for intermediaries and provides a secure, immutable transaction history to the PSC stakeholders (Musamih et al., 2021; Akhtar & Rizvi, 2021). From the literature it is understood that Hyperledger is the most used blockchain platform since it provides a higher degree of trust, decentralization, transparency, privacy, security and data deployment when comparing to other blockchains platforms such as Ethereum, Quorum, BigChain, and others (Uddin et al., 2021; Akhtar & Rizvi, 2021).

In order to tackle counterfeiting, Pandey and Litoriya (2021) proposes an electronic health network using a hyperledger fabric platform of eleven computer nodes. The system was based on a permissioned blockchain network. The solution records in the blockchain network the logistics information of the medicine from its manufacturing to its delivery to the patient using a QR code. This way, any attempt of entry of falsified medicines into the system will be detected and stopped. Furthermore, the solution was tested at different network configurations and its performance is compared to other existing traditional methods in India using throughput as the metric. Compared to the other two, the proposed one stands out as being solving the others' flaws: geographical limit, not offering an utterly trustless computing environment, and being third party centralized which poses a single point of failure. It was understood that the proposed system is intensive at computational level the more participants it has, however, increasing the nodes also means there would be more nodes available to reach consensus, which is required to make the system as safe as possible.

When it comes to the platforms' governance models, few paper mention this topic as seen in table 2.3. However, when it is mentioned, the authors opt to chose the government or drug regulating authorities as the administrators and the ones that can verify and allow new participants to enter the blockchain network (Bryatov & Borodinov, 2019; Raj et al., 2019; A. Kumar et al., 2019).

2.3.2. BLOCKCHAIN INITIATIVES TO COMBAT THE DISTRIBUTION OF FALSIFIED MEDICINAL PRODUCTS FOR HUMAN USE

Some blockchain initiatives have already been established within the industry or as partnerships between governments and industry and also universities (Mackey & Nayyar, 2017; Archa et al., 2017; Uddin et al., 2021; Musamih et al., 2021). Tracelink, MediLedger, and the partnership between IBM and Merck are the three most mentioned. These initiatives bring traceability and visibility to the network which, even though it might not have been the initial purpose, helps combat the distribution of falsified medicinal products for human use.

TraceLink is a "network creation platform for building integrated business ecossystems with multienterprise applications (...) delivering customer-centric agility and resiliency for end-to-end supply networks" (TraceLink, n.d.). In 2019, the company launched a Pilot Program called Trace Histories built on the company's digital supply network to explore the use of blockchain technologies to track and trace products in the PSC (Lynch, 2019). Only verified partners can enter this network, and the sharing of critical and confidential data is permissioned on a "gather upon request" approach. Participants include manufacturers, wholesale distributors, retail pharmacy chains, diversified healthcare organizations, and third party logistics providers.

The MediLedger Network was established in 2019 administered by Chronicled, a technology company that supports the network and develops solutions to improve it and already counts with partners such as Bayer, Pfizer and McKesson (*The MediLedger Network*, n.d.). The network brings together blockchain technology and advanced cryptography to offer the ultimate privacy-first platform for healthcare trading partner transactions without the need for intermediaries (*The MediLedger Network*, n.d.). This brings a reduction in human processing, revenue leaks, and cash flow inefficiencies that hinder the pharmaceutical industry (Blockchain Healthcare Review, 2022). The network operates Enterprise Ethereum with Proof of Authority consensus on several independent nodes. Moreover Chronicled fulfils the role of Network Manager and the MediLedger Network remains politically impartial and legally centralized through Chronicled. Smart contracts are used in order to transfer custody of a product with its serial number from a wholesaler to a dispenser, for example, and allows the recipient to verify the product's complete chain of custody (Blockchain Healthcare Review, 2022). It is important to mention that this solution is focused in the United States (Ledger Insights, 2021).

Another solution in this country comes as a consequence of the Drug Supply Chain Security Act (DSCSA) stating that by 2023, members of the PSC are required to verify, track and trace prescription drugs as they are distributed in the United States ("Blockchain Interoperability Pilot Project Report", 2020). Various organizations including IBM, Merck, KPMG and Walmart, and government entities, proposed a blockchain solution in order to submit to the Food and Drug Administration (FDA) Pilot program that aims to find solutions to help companies fulfil the requirements of the Act. The Pilot was proven successful in accurately capturing data provenance, maintaining data privacy, increasing patient safety, including reducing the potential dispensing of counterfeit products, and in reporting ("Blockchain Interoperability Pilot Project Report", 2020).

On the European side, there is also a similar initiative called PharmaLedger, created by a consortium of a dozen global pharmaceutical companies in association with numerous technology companies and universities (Ledger Insights, 2021). The initiative started in January 2020, with the pharmaceutical company Novartis as the industry leader, and is a three year project sponsored by the Innovative Medicines Initiative (IMI) and the European Federation of Pharmaceutical Industries and Associations (EFPIA) under the Horizon 2020 program (Morris, 2020). The project is exploring eight use cases, across three domains: supply chain, clinical trials, and health data (PharmaLedger, 2021a). In the supply chain domain, one of the use cases is to address Anti-counterfeiting, which is built on top of another use case of the project that develops an electronic product information (ePI or eLeaflet) using a blockchain based system (Weingold, 2021). PharmaLedger's answer to anti-counterfeiting, as seen in figure 2.5, is a robust solution intended for different types of **users** and stakeholders of the PSC such as hospitals, pharmaceutical dispensaries, distributors, law enforcement and manufacturers (PharmaLedger, 2021a).

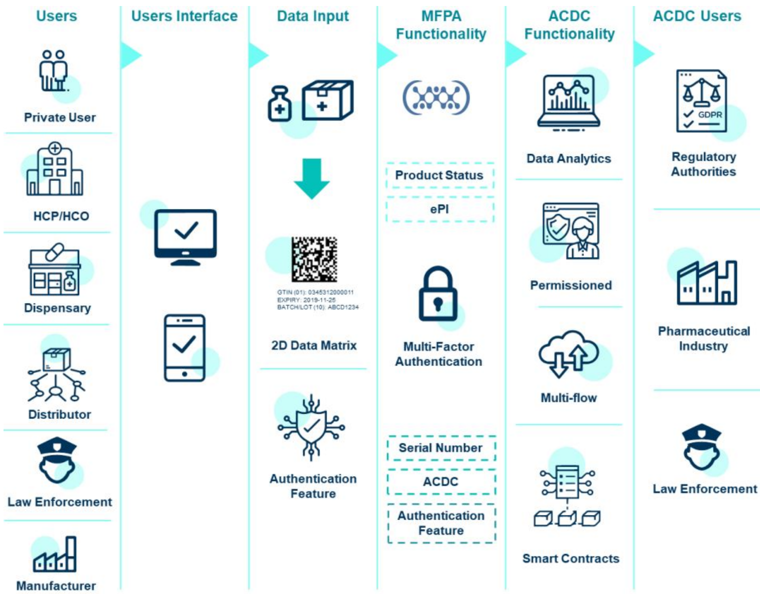

Figure 2.5: PharmaLedger Anti-counterfeiting use case (PharmaLedger, 2021a).

There will be two **user interfaces**: a mobile application that allows the user to access the product information and to perform the authentication of different different pieces of information, and a web application that will be used by institutional users to manage the data. **Data input** comes from individual medicine boxes and batches coming from the manufacturer. In order to understand if the product is counterfeited or not, a number of checks are performed by scanning the 2D data matrix as seen in the **Multi-Factor Product Authentication (MFPA) Functionality** column: the product status check, the ePI check, the serial number check, the Anti-Counterfeiting Data Collaboration (ACDC) check and an authentication feature check (supported by the app using a mobile camera or sensors that collect information). The **ACDC Functionality** is a virtual database which connects on/off chain data and will allow regulatory authorities, the pharmaceutical industry and law enforcement to have deeper insights into the user generated data using a big data approach in order to understand in real time how and where are the counterfeiting issues happening.

As the project approaches its final year in 2022, one of the key objectives for this year is the "Development of system lifecycle documentation and “playbooks” for adoption" (PharmaLedger, 2021b). Both these objectives go in line with what this research proposes to find, as it is to understand what are the barriers and drivers of the stakeholders in the PSC to adopt these types of solutions. This reinforces the importance of this research as we can understand that there are different initiatives but there is little research done on how to increase the adoption of these solutions in the PSC from the stakeholders.

3

Barriers and Drivers influencing blockchain technologies adoption in the pharmaceutical supply chain

In this chapter, the second sub-question "What are the barriers and drivers influencing the adoption of blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use?" will be answered. Firstly, a literature review will be conducted in order to find relevant papers to find the factors that can be classified as barriers and/or drivers. A factor will be considered as a barrier if it deters the PSC players from adopting blockchain technologies to combat the distribution of falsified medicinal products for human use. On the other hand, it will be considered as a driver if it supports this adoption.

3.1. Literature Review

The approach shown in table 3.1 was followed in order to find relevant literature to gather the factors, barriers and drivers influencing the adoption of blockchain technology in the PSC.

This research was done using Scopus as the main repository. Two searches were made because it was noted that the literature about blockchain technologies implementation in the PSC is scarce. Therefore, the first search focused on blockchain technology adoption in the supply chain of any industry. This way, the keywords used were: "factors", "barriers", "drivers", "blockchain adoption", and "supply chain". Their synonyms were included as seen in table 3.1. This yielded 142 articles, from which 45 were found relevant for the research and were reviewed per order of the most cited to the least. After analysing the first 11, 5 more were looked into and it was understood that there were no new factors presented. Therefore, the analysis focused on the first 11, presented in table 3.2.

The second search was focused on the adoption of different technologies, other than blockchain technologies, in the PSC, in order to find factors, barriers and drivers that are more specific to the adoption of novel technologies in this industry. The keywords used were: "factors", "barriers", "drivers", "technology adoption", "pharma", and "supply chain". As it can be seen in table 3.1, the synonyms were included as well. This yielded 24 articles, from which, four were found relevant, and are presented in table 3.2.

It is also important to mention that in both searches only articles that were available in full-text and in English were included.

Table 3.1: Funnel approach to find articles related to barriers, drivers and factors influencing the adoption of: 1. blockchain technology in the supply chain; 2. technology in the PSC.

#	Terms (Query string)	Refined by	Articles
1.1	TITLE-ABS-KEY ("barrier*" OR "driver*" OR "factor*") AND TITLE-ABS-KEY ("blockchain" OR "block chain" OR "distributed ledger" adoption) AND TITLE-ABS-KEY ("supply chain" OR "supply network" OR "supply chain management" OR "logistic*")	Language: English	142
1.2	TITLE-ABS-KEY ("barrier*" OR "driver*" OR "factor*") AND TITLE-ABS-KEY ("blockchain" OR "block chain" OR "distributed ledger" adoption) AND TITLE-ABS-KEY ("supply chain" OR "supply network" OR "supply chain management" OR "logistic*")	Language: English; Relevant title and abstract	45
2.1	TITLE-ABS-KEY ("barrier*" OR "driver*" OR "factor*") AND TITLE-ABS-KEY ("technology" adoption) AND TITLE-ABS-KEY ("pharm*") AND TITLE-ABS-KEY ("supply chai*" OR "supply networ*" OR "logistics networ*")	Language: English	24
2.2	TITLE-ABS-KEY ("pharm*" AND ("supply chai*" OR "supply networ*" OR "logistics networ*")) AND TITLE-ABS-KEY ("inf* flo*" OR "inf* exchange")	Language: English;	4

Table 3.2: Articles analysed to gather the barriers and drivers influencing the adoption of blockchain technology (BT) in the pharmaceutical supply chain (PSC).

#	Year	Author	Focus
1.1	(2018)	Saberi et al.	BT in sustainable SC
1.2	(2019)	Queiroz and Fosso Wamba	BT adoption challenges in India and USA
1.3	(2018)	Wang et al.	Systematic literature review on BT for future SC
1.4	(2021)	Kouhizadeh et al.	BT in sustainable SC
1.5	(2020)	Wong et al.	BT adoption in SC in Malaysian SMEs
1.6	(2020)	Yadav et al.	BT adoption barriers in Indian agricultural SC
1.7	(2021)	Saurabh and Dey	BT adoption in the wine SC
1.8	(2020)	Orji et al.	BT adoption factors in the freight logistics industry
1.9	(2020)	van Hoek	Barriers and drivers of BT adoption in USA SC
1.10	(2020)	Queiroz et al.	BT adoption in Brazil SC
1.11	(2020)	Ghode et al.	Factors influencing BT adoption in SC
2.1	(2014)	Taylor	Barriers and drivers of RFID tech. adoption in the PSC
2.2	(2019)	Da Silva and de Mattos	Factors influencing adoption of a traceability system in the PSC
2.3	(2022)	Papalexi et al.	Barriers and drivers of innovative programmes implementation in the PSC
2.4	(2020)	Alharthi et al.	Factors influencing BT adoption in the PSC in Kingdom of Saudi Arabia

3.2. SELECTING A FRAMEWORK

In order to be able to go through the literature and gather the drivers and barriers in an organized and consistent manner, a framework was selected.

There are several different frameworks existing in the study of ICT adoption. According to Oliveira and Martins (2011), the most used theories are the technology acceptance model (TAM), theory of planned behaviour (TPB), unified theory of acceptance and use of technology (UTAUT), diffusion of innovation (DOI), and the Technology, organization, and environment (TOE) framework.

For this research, the focus is on the acceptance of the technology at the firm level. Therefore, the only two frameworks considered to choose from was the DOI and TOE framework, as the other ones mentioned are at individual level.

DOI theory looks at innovation as being communicated though different channels over time and among a particular social system (Rogers, 1995). It believes that individuals have different degrees of willingness to adopt innovations (innovators, early adopters, early majority, late majority, laggards) following a normal distribution. At firm level, this phenomenon is more complex. To this effect, Rogers (1995) says that innovativeness at organizational level depends on: **Individual characteristics** (leader's attitude towards change), **Internal characteristics of organizational structure** (centralization of power, complexity, formalization of processes, interconnectedness of workers, organizational slack, and size of the organization), and **External characteristics of the organization** (system openness). This model has been employed in different studies such as the adoption of Material requirement planning, Intranet, Web site, Enterprise resource planning, E-procurement, etc (Oliveira & Martins, 2011).

The TOE framework has been found to be consistent and closely related with the DOI theory by researchers (Baker, 2012). The TOE framework was developed by Tornatzky, Fleischer & Chakrabarti in 1990 and defends that there are three aspects that affect the adoption and implementation of innovation, being Technology, Organization, and Environment (Alharthi et al., 2020). The **Technology context** includes all technologies that are relevant to the firm (both already in use, as well as available in the marketplace but not in use) and also the characteristics of the technology innovation (Baker, 2012; Oliveira & Martins, 2011). The **Organization context** describes the attributes, characteristics and resources of the firm that can either facilitate or hinder the adoption of the technology (Baker, 2012; Orji et al., 2020). Finally, the **Environment context** concerns the industry's structure, such as the regulatory and legislative environment and the presence of ICT providers (Baker, 2012). When applying the TOE framework, researchers have used different factors for the three contexts. Some examples can be seen in figure 3.1. Researchers agree that the TOE contexts influence adoption of the technology, but they have assumed that for each specific technology and context that is being studied, there is a distinctive set of factors or measures (Baker, 2012)

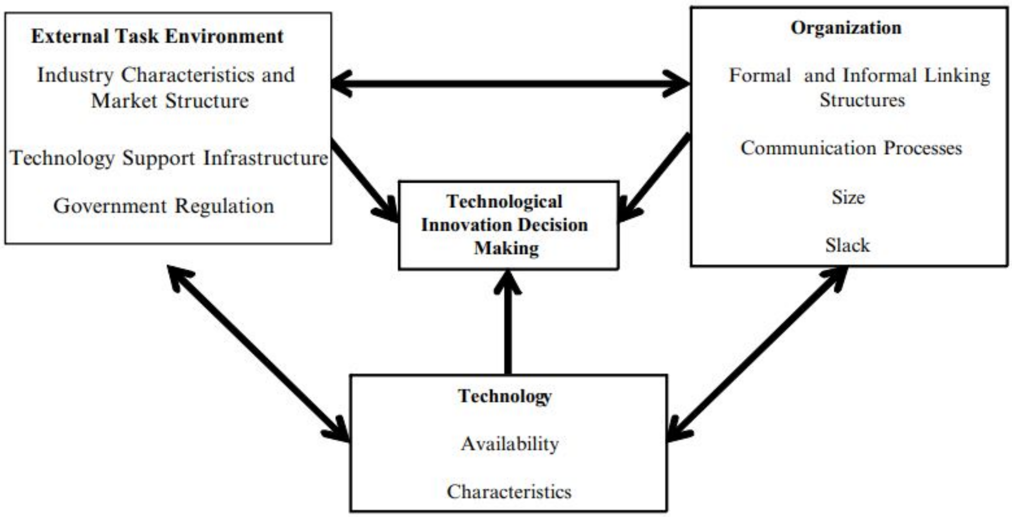

Figure 3.1: The technology-organization-environment framework (Baker, 2012).

The context of technology from TOE is implicitly the same idea as the DOI theory, and DOI's external and internal organizational characteristic are similar as TOE's measures in the organizational context (Oliveira et al., 2014). However, the TOE framework is considered to be more complete as it includes the environment context, which the DOI theory does not provide, hence being better suited to explain intra-firm innovation adoption and to use in this research (Oliveira & Martins, 2011).

3.3. Barriers and Drivers Identification

From the articles analysed, 72 factors were found. The naming of these factors were inconsistent among the authors studied, meaning different words were used for the same definition. Therefore, similar factors were grouped and then classified between barriers, drivers, or both (when they were found in the literature as just an influencing factor). The factors were also classified into one of the three categories according to the TOE framework. Therefore, the list of barriers found is presented in table 3.3 and the list of drivers is presented in table 3.4.

3.3.1. Identified Barriers

Table 3.3: List of barriers found in the literature

Barriers	Sources
Technological Barriers	
Privacy Concerns	(Ghode et al., 2020; Orji et al., 2020; van Hoek, 2020; Wang et al., 2018; Yadav et al., 2020)
Security Concerns	(Da Silva & de Mattos, 2019; Saberi et al., 2018; van Hoek, 2020; Wang et al., 2018)
Data governance	(Da Silva & de Mattos, 2019; Wang et al., 2018)
Immutability	(Ghode et al., 2020; Saberi et al., 2018)
Complexity	(Alharthi et al., 2020; Orji et al., 2020; van Hoek, 2020; Wong et al., 2020; Yadav et al., 2020)
Disintermediation	(Saurabh & Dey, 2021; Wang et al., 2018)
Performance Expectancy	(Queiroz & Fosso Wamba, 2019; Queiroz et al., 2020)
Compatibility/ Interoperability	(Alharthi et al., 2020; Da Silva & de Mattos, 2019; Ghode et al., 2020; Orji et al., 2020; Wang et al., 2018; van Hoek, 2020; Yadav et al., 2020)
Lack of maturity	(Saberi et al., 2018; Orji et al., 2020; Taylor, 2014)
Lack of speed	(van Hoek, 2020; Wang et al., 2018; Yadav et al., 2020)
Lack of scalability	(Saberi et al., 2018; van Hoek, 2020; Yadav et al., 2020)
Organizational Barriers	
Lack of knowledge	(Alharthi et al., 2020; Kouhizadeh et al., 2021; Saberi et al., 2018; van Hoek, 2020; Wang et al., 2018; Yadav et al., 2020)
Lack of Top management support	(Alharthi et al., 2020; Da Silva & de Mattos, 2019; Kouhizadeh et al., 2021; Orji et al., 2020; Saberi et al., 2018; van Hoek, 2020; Wong et al., 2020)
Lack of tools to implement and support the technology	(Alharthi et al., 2020; Da Silva & de Mattos, 2019; Orji et al., 2020; Queiroz & Fosso Wamba, 2019; Queiroz et al., 2020; Saberi et al., 2018; Taylor, 2014; van Hoek, 2020)
Organizational culture	(Orji et al., 2020; Saberi et al., 2018; Wang et al., 2018)
Lack of supplier support	(Da Silva & de Mattos, 2019)
Firm size	(Orji et al., 2020)
Perceived Implementation costs	(Orji et al., 2020; Saurabh & Dey, 2021; Taylor, 2014; van Hoek, 2020; Wang et al., 2018; Wong et al., 2020; Yadav et al., 2020)
Environmental Barriers	
Customer awareness	(Da Silva & de Mattos, 2019; Kouhizadeh et al., 2021; Saberi et al., 2018)

Barriers	Sources
Social influence to not adopt blockchain technologies	(Ghode et al., 2020; Orji et al., 2020)
Stakeholders pressure to not adopt blockchain technologies	(Kouhizadeh et al., 2021; Saberi et al., 2018; Orji et al., 2020)
Competitive pressure to not adopt blockchain technologies	(Saberi et al., 2018; Orji et al., 2020; Wong et al., 2020)
Market dynamics	(Orji et al., 2020; Wong et al., 2020)
Environmental concerns	(Wang et al., 2018)
Lack of collaboration, communication and coordination in the SC	(Da Silva & de Mattos, 2019; Kouhizadeh et al., 2021; Saberi et al., 2018; Saurabh & Dey, 2021; Wang et al., 2018)
Lack of inter-organizational trust	(Ghode et al., 2020; Saurabh & Dey, 2021; Wang et al., 2018; Yadav et al., 2020)
Cultural differences between stakeholders	(Saberi et al., 2018; Kouhizadeh et al., 2021)
Intermediary Resistance	(Wang et al., 2018)
Lack of Government standards/legislation	(Alharthi et al., 2020; Da Silva & de Mattos, 2019; Ghode et al., 2020; Kouhizadeh et al., 2021; Orji et al., 2020; Saberi et al., 2018; Taylor, 2014; van Hoek, 2020; Yadav et al., 2020)
Lack of Government support	(Alharthi et al., 2020; Da Silva & de Mattos, 2019; Orji et al., 2020; Saberi et al., 2018; Saurabh & Dey, 2021; Wong et al., 2020)
Lack of involvement of external stakeholders (NGOs,etc)	(Da Silva & de Mattos, 2019; Kouhizadeh et al., 2021; Saberi et al., 2018; Yadav et al., 2020)

3.3.2. Identified Drivers

Table 3.4: List of drivers found in the literature.

Drivers	Sources
Technological Drivers	
Privacy enhancements	(Ghode et al., 2020; Orji et al., 2020; van Hoek, 2020; Wang et al., 2018; Yadav et al., 2020)
Security enhancements	(Da Silva & de Mattos, 2019; Orji et al., 2020; Wang et al., 2018; Yadav et al., 2020)
Immutability	(Ghode et al., 2020)
Easiness of use	(Alharthi et al., 2020; Orji et al., 2020; Queiroz et al., 2020; Wong et al., 2020; Yadav et al., 2020)
Disintermediation	(Saurabh & Dey, 2021; Wang et al., 2018)
Performance Expectancy	(Queiroz & Fosso Wamba, 2019; Queiroz et al., 2020)

Drivers	**Sources**
Compatibility/ Interoperability	(Alharthi et al., 2020; Da Silva & de Mattos, 2019; Ghode et al., 2020; Orji et al., 2020; Wang et al., 2018)
Traceability	(Saurabh & Dey, 2021; van Hoek, 2020)
Organizational Drivers	
Access to tools to implement and support the technology	(Alharthi et al., 2020; Da Silva & de Mattos, 2019; Orji et al., 2020; Queiroz & Fosso Wamba, 2019; Queiroz et al., 2020; Saberi et al., 2018)
Knowledge of the technology	(Alharthi et al., 2020; Orji et al., 2020; Yadav et al., 2020)
Top management support	(Alharthi et al., 2020; Da Silva & de Mattos, 2019; Orji et al., 2020; Wong et al., 2020)
Organizational culture	(Orji et al., 2020)
Supplier support	(Da Silva & de Mattos, 2019)
Firm size	(Orji et al., 2020)
Perceived Implementation costs	(Saurabh & Dey, 2021; Wong et al., 2020; Yadav et al., 2020)
Reduce operational costs	(Papalexi et al., 2022; Taylor, 2014; van Hoek, 2020)
Brand protection	(Taylor, 2014)
Environmental Drivers	
Customer awareness	(Da Silva & de Mattos, 2019; Kouhizadeh et al., 2021; Wang et al., 2018)
Social influence to adopt blockchain technologies	(Ghode et al., 2020; Orji et al., 2020; Queiroz et al., 2020; van Hoek, 2020)
Stakeholders pressure to adopt blockchain technologies	(Orji et al., 2020)
Competitive pressure to adopt blockchain technologies	(Orji et al., 2020; van Hoek, 2020; Wong et al., 2020)
Market dynamics	(Orji et al., 2020; Wong et al., 2020)
Existing collaboration, communication and coordination in the SC	(Da Silva & de Mattos, 2019; Papalexi et al., 2022; Saberi et al., 2018; Saurabh & Dey, 2021)
Existing inter-organizational trust	(Ghode et al., 2020; Saurabh & Dey, 2021; Queiroz et al., 2020; Wang et al., 2018)
Government standards/ legislation	(Alharthi et al., 2020; Da Silva & de Mattos, 2019; Ghode et al., 2020; Orji et al., 2020)
Government support	(Alharthi et al., 2020; Da Silva & de Mattos, 2019; Orji et al., 2020; Saberi et al., 2018; Saurabh & Dey, 2021; Taylor, 2014; Wong et al., 2020)
Involvement of external stakeholders (NGOs,etc)	(Da Silva & de Mattos, 2019; Kouhizadeh et al., 2021; Saberi et al., 2018; Yadav et al., 2020)
Customer Safety	(Papalexi et al., 2022; Taylor, 2014; van Hoek, 2020; Wang et al., 2018)

3.4. Barriers and Drivers Selected

It was understood that the above lists needed to be reduced in order for the online survey not to be too long and discourage people from answering. To this effect, seven experts with different backgrounds were interviewed and asked to choose which were, for them, the five most important barriers and drivers per category. The interviews consisted of the following experts:

- two experts in blockchain technologies in supply chain,
- three experts in the PSC (one having worked in a manufacturer, another in a distributor, and another being a consultant for the industry),
- one expert in IT project management and SC in the pharmaceutical industry,
- one expert in Law of blockchain technologies applied to falsified products.

Once these semi-structured interviews were finalized, the five most voted barriers and drivers per category were used to build the questionnaire. The complete interview protocol and choices of each expert can be found in appendix B. The final set of barriers and drivers and their definitions is presented in table 3.5 and 3.6.

3.4.1. Selected Barriers

Table 3.5: List of the five most important barriers per category according to the experts interviewed.

Selected Barriers	**Definition**
Technological Barriers	
Complexity	The complexity of technology implementation and the technology itself. Generally, a high degree of complexity confuses technology users and causes them to have difficulty in understanding and using it correctly (Wong et al., 2020).
Compatibility/ Interoperability	The lack of interoperability between blockchains and integration with existing IT systems can be difficult and can constrain a smooth data transfer (Wang et al., 2018).
Privacy Concerns	Depending on the architecture set-up, data might be more or less visible to others. Therefore, people might be concerned with the privacy of their data (Orji et al., 2020).
Security Concerns	Concerns with how safe is the system from facing malicious attacks (Yadav et al., 2020).
Data governance	What data should be stored in blockchains, how such data will be collected and fed into the system and who should be responsible for data input and provision (Wang et al., 2018).

Selected Barriers	Definition
Organizational Barriers	
Perceived Implementation costs	The investment required to acquire the technology and implement it within the organization (Orji et al., 2020).
Lack of knowledge	The degree to which managers know about blockchain technology (Alharthi et al., 2020).
Lack of tools to implement and support the technology	Lack of capabilities from the organization to implement and support the technology such as processes, training capabilities or infrastructure (Orji et al., 2020; Saberi et al., 2018).
Organizational culture	The pattern of people's behaviors and practices within the pharmaceutical industry and within the organization can affect how firms respond to external pressures and makes strategic business decisions (Orji et al., 2020).
Lack of Top management support	When managers do not believe in the technology it can be a true barrier for its implementation (Kouhizadeh et al., 2021).
Environmental Barriers	
Lack of Government standards/legislation	The lack of ability of relevant government agencies to provide aids and enact rules and regulations to encourage blockchain technology adoption (Orji et al., 2020).
Lack of collaboration, communication and coordination in the SC	Lack of collaboration and effective communication among supply chain partners with different and even contradictory operational objectives and priorities (Saberi et al., 2018).
Lack of inter-organizational trust	Unwillingness to share valued information between organizations (Wang et al., 2018).
Cultural differences between stakeholders	Communication and coordination challenges would be worse where supply chain partners are geographically dispersed with different cultures (Kouhizadeh et al., 2021; Saberi et al., 2018) .
Environmental concerns	Blockchain technology requires a high level of energy consumption to maintain the network (Wang et al., 2018).

3.4.2. Selected Drivers

Table 3.6: List of the five most important drivers per category according to the experts interviewed.

Selected Drivers	Definition
Technological Drivers	
Privacy enhancements	Blockchain technology affords pseudonymity, meaning that all transactions are transparent, yet are not explicitly connected to real-world individuals or organisations (Wang et al., 2018).
Security enhancements	Blockchain technology ensures that information shared is essentially secure to avoid manipulation (Orji et al., 2020).
Immutability	Information cannot be changed and removed from the blockchain without consensus (Ghode et al., 2020).
Traceability	Blockchain technology brings more visibility into the supply chain. Traceability is an important quality factor that can be augmented by applying blockchain technology and other existing technologies, such as IoT and RFID. (Saurabh & Dey, 2021).
Compatibility/ Interoperability	When using the same blockchain platform, the technology allows data to be more interoperable. Thus, companies can easily share information with manufacturers, suppliers and vendors (Ghode et al., 2020).
Organizational Drivers	
Reduce operational costs	Blockchain technology can help reduce operational costs by improving asset and inventory management, increase end-to-end visibility in the supply chain, etc. (van Hoek, 2020; Wong et al., 2020).
Knowledge of the technology	Is the degree to which managers know about a technology (Alharthi et al., 2020).
Top management support	When managers believe in the technology it is a driver for its implementation. (Da Silva & de Mattos, 2019).
Firm size	Bigger firms are more inclined to implement blockchain. (Orji et al., 2020).
Brand protection	Blockchain technology brings a tool for organizations to prove that their operations are legal and according to the norms (Taylor, 2014).
Environmental Drivers	
Stakeholders pressure to adopt blockchain technologies	Relates to the external environment that details the high and persistent requirements of various stakeholders or investors in the pharmaceutical industry to adopt or not the technology (Orji et al., 2020)
Competitive pressure to adopt blockchain technologies	The degree to which the competition has adopted the technology (Wong et al., 2020)
Market dynamics	Refer to the continuous changing state of an environment that is highly competitive and complex (Orji et al., 2020).

Selected Drivers	Definition
Government standards/ legislation	The ability of relevant government agencies to provide aids and enact rules and regulations to encourage blockchain technology adoption (Orji et al., 2020).
Customer Safety	Blockchain technology can help patients know if their medicinal products are falsified or not and therefore improve their safety (Wang et al., 2018).

4

OBTAINING THE WEIGHTS OF THE BARRIERS AND DRIVERS SELECTED

In this chapter, it will be described the method used to answer the third sub-question "What is the relative importance attributed to each driver and barrier influencing the adoption of blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use?". It will be explained the need to follow a multi-criteria decision making solving method and why the Bayesian Best-Worst method (BWM) was chosen as the best solution. Following this, the data collection method will be described as well as the target population chosen and tools used to follow the method.

4.1. MULTI-CRITERIA DECISION MAKING PROBLEM

In order to choose the best method to answer the third sub-question, it is important to understand what type of problem the research is tackling. The main objective of this research is to understand how the stakeholders involved in offering blockchain technologies can attract more stakeholders. Therefore, they need to know what are the main barriers and drivers influencing the adoption of blockchain technology so they can design their strategy in a more effective and successful way. This means that a method is needed that allows to rank or arrive to the weights of a set of different criteria (barriers and drivers in this case). This way, the decision-makers can make better informed decisions when building their strategic plans to develop and market the blockchain technology solution.

Therefore, the research deals with a Multi-Attribute Decision Making (MADM) or Multi-Criteria Decision Making (MCDM) problem, as "Attribute" and "Criteria" are often interchangeably used (Triantaphyllou, Shu, Nieto Sanchez, & Ray, 1998).

It is also important to understand that the process of choosing to adopt a new technology involves different people from an organization. Therefore, the MCDM solving method will have to take this specificity into account which is further explained in the next section.

4.2. MULTI-CRITERIA DECISION MAKING METHOD SELECTION

Different methods can be found in the literature to solve a MCDM problem. The two most common ones are the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) which are used to find the weights of decision-criteria based on the preferences of the decision-makers (Saaty, 2004).

More recently, a MCDM method was put forward by Rezaei (2015) called the Best-Worst Method (BWM). This method requires 2n-3 comparisons whereas, in the AHP, n(n-1)/2 comparisons are needed (Rezaei, 2015; Saaty, 2004). This means that, if there are ten criteria (n=10), using the BWM it will be needed 17 comparisons and, with AHP, 45 comparisons. Another advantage of the BWM is that it leads to more consistent comparison data, meaning that it produces more reliable weights. Since the decision-makers select a best and worst attribute before conducting the pairwise comparisons, a more clear understanding regarding the range of evaluation is gained upfront leading to more consistent pairwise comparisons, and more reliable weights (Rezaei, 2020b).

Other advantage of this model is the possibility to mitigate the anchoring bias that can exist during the decision-maker's pairwise comparisons in a single optimization model by using two opposing references, the best and the worst (L. Li, Wang, & Rezaei, 2020). Rezaei (2020a) conducted statistical analysis to find the existence of anchoring bias in SMART and Swing methods. SMART (simple multiattribute rating technique) uses a low anchor and Swing uses a high anchor. It was found that even though these methods use opposite anchors, the obtained weights are affected by anchoring bias in a similar direction. Rezaei, Arab, and Mehregan (2022), besides studying the anchoring bias in SMART and Swing, also analysed the phenomenon in BWM. It was concluded that BWM is less prone to anchoring bias than SMART and Swing.

In their turn, Rezaei, Arab, and Mehregan (2021) studied the existence of equalizing biases, which is one of the primary cognitive biases happening due to the tendency of decision-makers to assign the same weight to different attributes. They researched the methods of AHP, BWM, PA (point allocation), SMART, and Swing. It was concluded that AHP and BWM show less equalizing bias than SMART, Swing, and PA.

Furthermore, BWM balances the data and time efficiency in the structured pairwise comparisons-based method better. It also offers the possibility to check the consistency of the pairwise comparisons. Compared to other methods that use a single vector such as Swing and SMART family, this method tackles this lack of comparison consistency, despite the high data (and time) efficiency of these single vector input-only methods (L. Li et al., 2020).

Due to these advantages, the BWM was chosen to conduct this part of the research.

4.3. BAYESIAN BEST WORST METHOD

In order to solve this MCDM problem, the Bayesian BWM will be used as the preferences of multiple respondents (decision-makers) will be taken into account (Mohammadi & Rezaei, 2020).

With this method, the researcher does not have to obtain the criteria weights of each decision-maker first separately and aggregate the weights afterwards using arithmetic mean, which can be prone to outliers and provides limited information to decision-makers (Mohammadi & Rezaei, 2020). The Bayesian BWM computes the combined distribution and each and every individual preferences at the same time, which results in more reliable criteria weights. Consequently, by using the probabilistic modelling approach, the final optimal group weights for each criterion can be calculated at once (Mohammadi & Rezaei, 2020). The calculated optimal aggregated (group) criterion weight (w^{agg}), indicates the total preference of all decision-makers for a specific criterion.

Another benefit is the credal ranking and the confidence level it provides in the weight directed graph (step 5.3), where each node represents a criterion and each edge represents the obtained confidence (Mohammadi & Rezaei, 2020). The confidence levels obtained indicate the extent to which the group perceives one criterion as more important over another, which can provide decision-makers (the blockchain technology initiatives) with more information on how to proceed (Mohammadi & Rezaei, 2020).

The Bayesian BWM steps can be applied as described by Rezaei (2015) for steps 1 to 4 and following the additional sub-steps for step 5 proposed by Mohammadi and Rezaei (2020):

Step 1. Establishing a set of decision-criteria.

The first step is to identify a set of n decision criteria $C = \{c_1, c_2, c_3, ..., c_n\}$. In the case of this research, the criteria is the lists of barriers and drivers found when answering the second sub-question. Therefore, there are six sets: technological barriers, organisational barriers, environmental barriers, technological drivers, organisational drivers, and environmental drivers.

Step 2. Defining the Best criterion and the Worst criterion.

In this step, the decision-makers choose the best (most important or preferable, c_B) criterion and the worst (least important or least preferable, c_W) criterion from C.

Step 3. Obtaining the Best-to-Others (BO) comparison vector.

In the third step, the decision-makers determine the preference of the best (most important) criterion against all other criteria by using a scale from 1-9. A value of 1 implies that the two criteria are of equal importance, whereas a 9 suggests that the best criterion is absolutely more important than the other one. As a result, a BO vector is obtained:

$A_B = (a_{B1}, a_{B2}, a_{B3}, ..., a_{Bn})$, where a_{Bj} is the preference of the best criterion B over the other criterion j. In addition, it is quite straight forward that the preference of the best perceived criterion B against itself is 1, i.e. $a_{BB} = 1$.

Step 4. Obtaining the Others-to-Worst (OW) comparison vector.

In the fourth step, the decision-makers determine the preference of all other criteria against the worst (least important) criterion by using the same scale from 1-9. A value of 1 implies that the two criteria are of equal importance, whereas a 9 suggests that the other criterion is absolutely more important than the worst one. As a result, an OW vector is obtained:

$A_W = (a_{1W}, a_{2W}, a_{3W}, ..., a_{nW})^T$, where a_{jW} is the preference of the other criterion j over the worst criterion W. In addition, it is quite straight forward that the preference of the worst criterion against itself is 1, i.e. $a_{WW} = 1$.

Step 5. Establishing optimal group weights of criteria.

Step 5.1. Constructing the probability distribution

Assume that there are k decision-makers ($k = 1, 2, ..., K$) there are j evaluation criteria ($c_1, c_2, c_3, ..., c_n$), then ${A_B}^k$ represents the Best-to-Others (BO) vector of one decision-maker and ${A_W}^k$ the Others-to-Worst (OW) vector of once decision-makers. If the optimal weights of one decision-maker is w^k, the optimal group weight after aggregation is w^{agg} . The vector, $A_B^{1:K}$ represents the BO vector of all decision-makers and $A_W^{1:K}$ indicates the OW vector of all decision-makers. Based on this, the equation for the joint probability distribution of the group decision for the Bayesian BWM is formulated as:

$$P\left(w^{agg}, w^{1:K} \mid A_B^{1:K}, A_W^{1:K}\right)$$

If the probability in the aforementioned equation is calculated, the following probability rule can be used to compute the probability of each individual variable:

$$P(x) = \sum_y P(x, y)$$

with x and y representing arbitrary random variables.

Step 5.2. Calculating the optimal group weight

The aggregated weight w^{agg} is dependent on the optimal weight of every individual decision-maker w^k, which is calculated by the input BO and OW vectors (A_B and A_W). Each time new input data (pairwise comparison data) is inserted, w^{agg} is updated. As a result of the previous concepts, conditional independence is present between variables. Taking this independence into consideration, the equation for the joint probability of the Bayesian BWM can be presented as:

$$P\left(w^{agg}, w^{1:K} \mid A_B^{1:K}, A_W^{1:K}\right) \propto P\left(A_B^{1:K}, A_W^{1:K} \mid w^{agg}, w^{1:K}\right) P\left(w^{agg}, w^{1:K}\right)$$

The above equation, can further be presented as:

$$P\left(A_B^{1:K}, A_W^{1:K} \mid w^{agg}, w^{1:K}\right) P\left(w^{agg}, w^{1:K}\right) = P\left(w^{agg}\right) \prod_{k=1}^{K} P\left(A_w^k \mid w^k\right) P\left(A_B^k \mid w^k\right) P\left(w^k \mid w^{agg}\right)$$

Based on the above equation, the corresponding probability can be found by specifying the distribution of each element. As a result, $A_B^k \mid w^k$ and $A_W^k \mid w^k$ can be defined as follows:

$$A_B^k \mid w^k \sim multinomial\left(\frac{1}{w^k}\right), \forall_k = 1, 2, ..., K; A_W^k \mid w^k \sim multinomial(w^k),$$
$$\forall_k = 1, 2, ..., K$$

Furthermore, w^k under w^{agg} conditioned can be composed as underlying Dirichlet distribution:

$$w^k \mid w^{agg} \sim Dir(\gamma \times w^{agg}), \forall_k = 1, 2, ..., K$$

with w^{agg} being the averaged value of the distribution and γ is a non-negative parameter.

Since γ is a non-negative parameter, it needs to obey the underling gamma distribution where a and b represents the shape and the scale parameters of the gamma distribution.

$$\gamma \sim gamma(a, b)$$

Ultimately, the aggregated or group optimal weight w^{agg} abides to the Dirichlet distribution, with the parameter α being set to 1.

$$w^{agg} \sim Dir(\propto)$$

Once the probability distribution of all parameters is finalized, the posterior distribution is calculated by using the Markov-chain Monte Carlo (MCMC) technique.

Step 5.3. Credal ranking and Confidence level The Bayesian BWM provides a credal ordering of each and every pair of criteria (c_i, c_j) for all $(c_i, c_j \in C)$ with C being the set of criteria. In order to understand whether the rankings of the criteria (based on their group weights) are consistent with the evaluation of all experts, the confidence level (CL) is computed in the weight directed graph. The CL indicates the probability or confidence (P) that c_i is better that c_j and is computed as follows:

$$P\left(c_i > c_j\right) = \int I\left(w_i^{agg} > w_j^{agg}\right) P\left(w^{agg}\right)$$

In the above equation, I represents a conditional parameter which can only be computed if $(w_i^{agg} > w_j^{agg})$ is detained, or else it is 0. Evidently, the CL is obtained by the number of samples Q acquired by the Markov-chain Monte Carlo technique (MCMC).

$$P\left(c_i > c_j\right) = \frac{1}{Q} \sum_{q=1}^{Q} I\left(w_i^{agg_q} > w_j^{agg_q}\right); P\left(c_j > c_i\right) \frac{1}{Q} \sum_{q=1}^{Q} I\left(w_j^{agg_q} > w_i^{agg_q}\right)$$

In the above equation, w^{agg_q} is the q^{th} sample of w^{agg} from the MCMC samples. If $P(c_i > c_j) > 0.5$, then the criterion i is more important than criterion j. The total probability is equal to 1, $P(c_i > c_j) + P(c_j > c_i) = 1$.

Computing the criteria weights using the Bayesian BWM

To acquire the groups' optimal weights and the assigned CLs with this method, the Bayesian BWM solver needs to be used which is operationalized in MATLAB with the need to install "just another Gibbs sampler" (JAGS) (Mohammadi & Rezaei, 2020). Both can be found and downloaded from the website http://bestworstmethod.com/home/software/

4.4. Data collection method

4.4.1. Method selection

As mentioned in sub-section 4.3, the Bayesian BWM requires, as input, a set of k vectors A_B and A_W. In order to find these vectors, different decision-makers need to be approached to be asked for their preferences regarding the criteria. This can be done by conducting interviews or questionnaires.

Interviews can offer some advantages such as more flexibility in the sense that questions asked can be progressively adjusted as the interview develops. On the other hand, questionnaires provide a superior solution, since it has less costs, and energy and time expenditure (Sekaran & Bougie, 2016). Moreover, a questionnaire is more appropriate when the researcher knows the exact variables needed from the respondent, which is the case in this research.

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Therefore, taken into account the constrains and requirements of this research such as the short time frame, the limited resources, and the fact that the researcher knows the exact data needed, an online questionnaire will be used as the data method collection.

4.4.2. Questionnaire design

The questionnaire for this research was designed with Qualtrics Survey Software with the license provided by the TU Delft. The complete questionnaire can be consulted in appendix C.

Throughout the construction of the questionnaire, it was important to keep in mind the three key areas to focus according to Sekaran and Bougie (2016): the wording of the questions, the planning of issues regarding how the variables will be categorized, scaled and coded, and the general appearance of the questionnaire.

The questions were worded in the simplest way possible as to not create confusion to the respondent. It was also attempted to prevent bias that can come from double-barreled, ambiguous, leading, and socially desirable questions (Sekaran & Bougie, 2016). The questions were closed as the data required to build the input vectors for the Bayesian BWM was known.

Personal information questions were also closed and were decided to be included at the start of the questionnaire because the researcher agrees with the authors defending that this way respondents are more inclined to finish the questionnaire once they have shared some personal information (Sekaran & Bougie, 2016). However, there is another school of thought in this subject saying that respondents are more inclined to share personal information once they have filled the questionnaire because they have been convinced of the legitimacy of the questionnaire by then (Sekaran & Bougie, 2016). The questionnaire aimed to be completely anonymous, therefore only questions related to the respondents' job position, scope, duration, and company's role in the Supply Chain, location, and size, were asked. This data was not considered threatening for the privacy of the respondents, and it will only be shown in aggregated form to describe the sample's characteristics.

To start the questionnaire, an opening statement was presented to the respondent in order to clearly state the purpose of the exercise, disclose the identity of the researcher, assure the data would be treated anonymously and in accordance with the TU Delft

Ethics Committee, and to also ask for consent to gather the data. This statement is shown in the appendix section C.2.

Following this, a question asking the participant if they were familiar or working in the pharmaceutical industry was presented. If the respondent answered that they were not familiar or working in the industry the questionnaire would automatically end. This way only the target group would be able to answer the questionnaire. After this, the ones that were allowed to continue, were asked the personal questions mentioned before.

Next, a brief introductory video to blockchain technology for SCM (courtesy of Blockchain Council) was presented. This way, the participants could understand better the concept and what it means for SCM and the pharmaceutical industry.

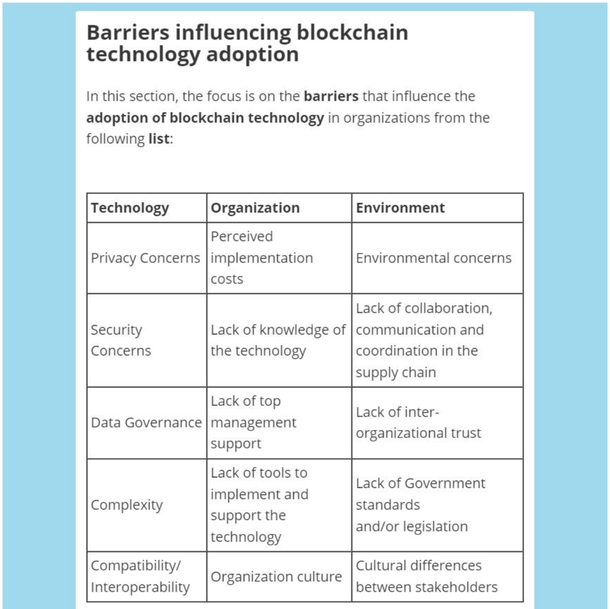
In the next section of the questionnaire, an explanation of the BWM is presented. This was added after the questionnaire was first built and reviewed by the supervision team and other contacts of the researcher in order to proof read and raise any problems related to the wording used, structure, length, or other. Apart from the problem regarding the understanding of the BWM, other problems arose concerning the length, and the explanation of the drivers and barriers which the solution will be shown later in this section. Unfortunately, nothing was possible to be done concerning the length of the exercise.

The questions that follow were designed according to the guidelines provided by Rezaei (2015) and also based on the work previously done by Lanzini (2020), that used the BWM to find the key influencing factors to adopt blockchain technologies in small and medium enterprises and used an online survey in Qualtrics to gather the data. Therefore, his insights were quite useful for this research.

The questions are divided into eight sections: Barrier Categories, Technological Barriers, Organisational Barriers, Environmental Barriers, Driver Categories, Technological Drivers, Organisational Drivers, and Environmental Drivers. At the beginning of each section, the respondents of the questionnaire are presented with the correspondent set of factors to the section that they are responding to. For example, in the first section, the respondent is asked to express their preferences for the categories of barriers (Technology, Organization, and Environment). Therefore, a table with the list of all barriers categorised according to the TWO framework already presented in table 3.5, are shown to the respondent as seen in figure 4.1.

During the phase of questionnaire revision before publishing, the respondents mentioned that it would be helpful to have an explanation of the factors concerned. On that account, a "Read more" section was added, where respondents could click to see the definitions if needed, as presented in tables 3.5 and 3.6, depending on the section.

After this, the respondents are asked to choose their most and least important category of barriers or drivers, or just barrier or driver depending on the section. This is illustrated by figure 4.2.

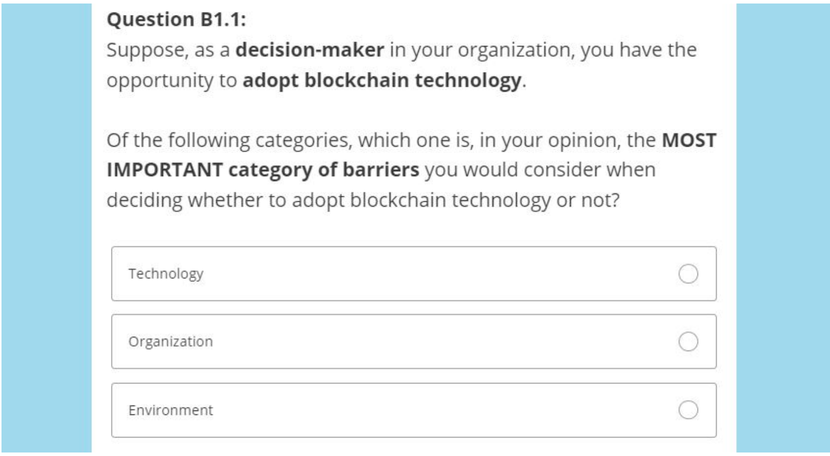


Barriers influencing blockchain technology adoption

In this section, the focus is on the **barriers** that influence the **adoption of blockchain technology** in organizations from the following **list**:

Technology	Organization	Environment
Privacy Concerns	Perceived implementation costs	Environmental concerns
Security Concerns	Lack of knowledge of the technology	Lack of collaboration, communication and coordination in the supply chain
Data Governance	Lack of top management support	Lack of inter-organizational trust
Complexity	Lack of tools to implement and support the technology	Lack of Government standards and/or legislation
Compatibility/ Interoperability	Organization culture	Cultural differences between stakeholders

Figure 4.1: Presenting the barriers per category



Question B1.1:
Suppose, as a **decision-maker** in your organization, you have the opportunity to **adopt blockchain technology**.

Of the following categories, which one is, in your opinion, the **MOST IMPORTANT category of barriers** you would consider when deciding whether to adopt blockchain technology or not?

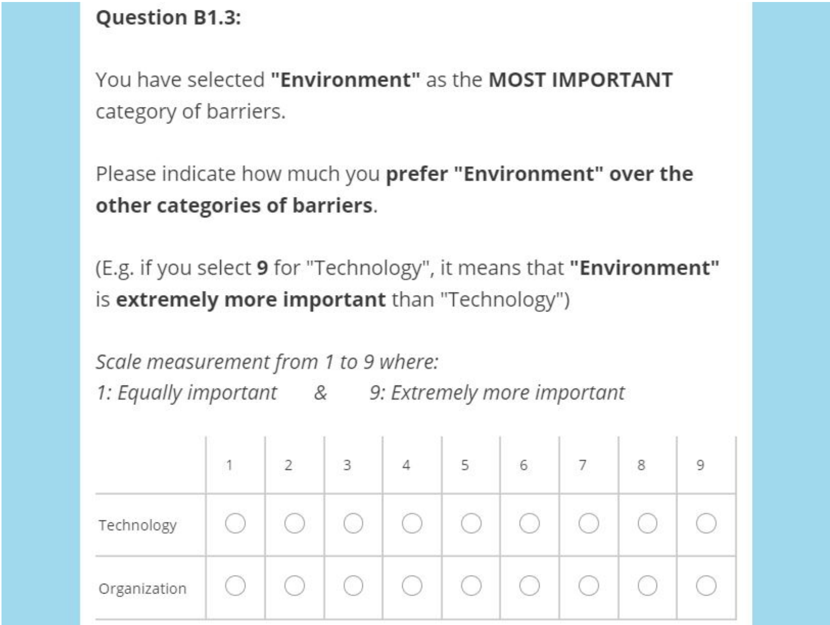
Technology

Organization

Environment

Figure 4.2: Question on the preference of the most important category of barriers.

Subsequently, the respondents are asked to compare the most important category, barrier or driver chosen to the others, and then, all the others to the least important category, barrier or driver chosen. This is done, by asking the respondents to use a scale between 1 and 9 as suggested by Rezaei (2015). Only the extreme values (1 and 9) were explained, with the definition of 9 being "much more important" and 1 as "Equally important". The exact manner that the question is posed is shown in figure 4.3.



Question B1.3:

You have selected **"Environment"** as the **MOST IMPORTANT** category of barriers.

Please indicate how much you **prefer "Environment" over the other categories of barriers**.

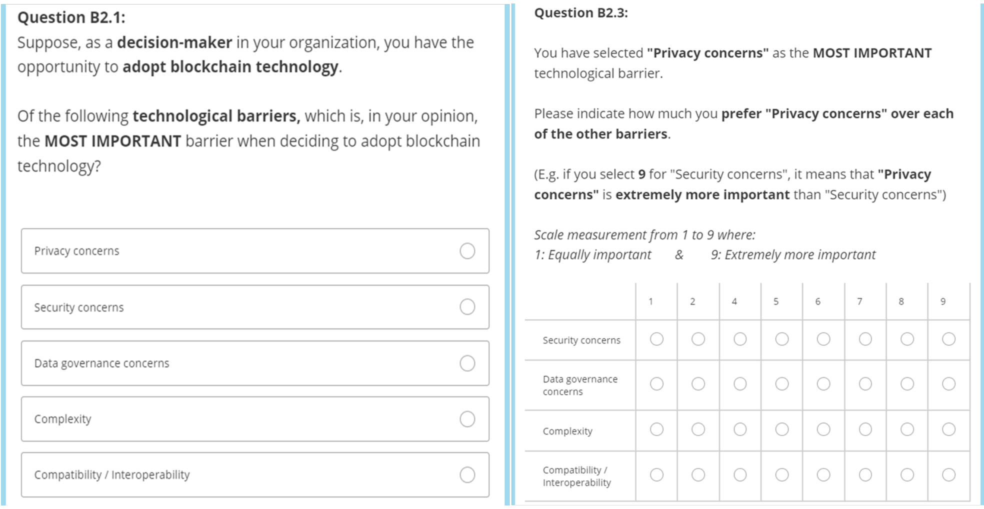
(E.g. if you select **9** for "Technology", it means that **"Environment"** is **extremely more important** than "Technology")

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
Technology	○	○	○	○	○	○	○	○	○
Organization	○	○	○	○	○	○	○	○	○

Figure 4.3: Question asking to compare the most important category of barriers to the others.

Then, in order to gather the preference within each category of barriers and drivers the same structure is followed and an example is shown in figure 4.4.



Question B2.1:
Suppose, as a **decision-maker** in your organization, you have the opportunity to **adopt blockchain technology**.

Of the following **technological barriers,** which is, in your opinion, the **MOST IMPORTANT** barrier when deciding to adopt blockchain technology?

- Privacy concerns ○
- Security concerns ○
- Data governance concerns ○
- Complexity ○
- Compatibility / Interoperability ○

Question B2.3:

You have selected **"Privacy concerns"** as the **MOST IMPORTANT** technological barrier.

Please indicate how much you **prefer "Privacy concerns" over each of the other barriers**.

(E.g. if you select **9** for "Security concerns", it means that **"Privacy concerns"** is **extremely more important** than "Security concerns")

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	4	5	6	7	8	9
Security concerns	○	○	○	○	○	○	○	○
Data governance concerns	○	○	○	○	○	○	○	○
Complexity	○	○	○	○	○	○	○	○
Compatibility / Interoperability	○	○	○	○	○	○	○	○

Figure 4.4: Questions gathering the preference of the technological barriers.

After the respondents complete all sections, a "thank you" message is shown with the email of the researcher so it can be used for questions or more information requests.

4.4.3. SAMPLING

To start sampling, a target population needs to be defined, which derives naturally from the research objective and scope of the study (Sekaran & Bougie, 2016). According to the research objective presented in section 1.3, the scope is the pharmaceutical industry, more specifically the PSC. While answering the first sub-question it was understood that there are many different players in this supply chain, and therefore, anyone part of these entities would be eligible to answer. It was also understood, while answering the first sub-questions, that the blockchain technology initiatives are being developed around the world, especially in Europe and United States of America, and that pharmaceutical companies that would be profiting from these solutions are also global companies. This means that there is no reason to define a specific geographical constraint to the sample. This is beneficial, since the survey is complex and it was found that the survey takes around 25 minutes to be completed during the revision phase, which is more than an ideal survey duration (10 minutes) (Sekaran & Bougie, 2016). Taking all these factors into consideration, a low response rate was expected.

The next step is to determine the sample design (Sekaran & Bougie, 2016). There are two types of sampling: probability and nonprobability. Since time constraints and resources are a critical factor in this research, nonprobability sampling is the most appropriate one. This means that the elements of the population do not have any probabilities attached to their being chosen as sample objects, and therefore, the findings will not be able to be confidently generalized to the population (Sekaran & Bougie, 2016). The most suitable type of nonprobability sampling is *judgement sampling* as this study has a narrow focus and tight time constraints. This type of sampling requires the choice of subjects who are in the best position to provide the information required (Sekaran & Bougie, 2016). In this research, people who have the knowledge on how the pharmaceutical industry works and how technology is adopted are the better equiped to answer this survey. To make sure the right people answer the survey, question Q0 in section A.2 General Questions as shown in section C.2, was put in place. This way, respondents that answer they are not familiar with the pharmaceutical industry are automatically prevented to continue the questionnaire.

The online questionnaire will be distributed through different channels and made available from the 20^{th} of June 2022. First, the survey will be shared with the interviewees approached during the interviewing phase which emailed the link to their network as well. Secondly, the researcher reached out to employees in the fields of supply chain, logistics operations, and ICT of major pharmaceutical companies through Linkedin, as well as through personal contacts of friends and family that would be familiar with the pharmaceutical industry.

The minimum sample size is set at 20 respondents, and the survey will be closed on 23^{th} of July 2022. Even though it is a small sample size, the research is not meant to find generalizable findings. It is rather to shed some light on how to attract players in the PSC for companies which are building blockchain technologies know how to better develop their product and strategy.

5

Data Analysis

In this chapter, the third sub-question "What is the relative importance attributed to each driver and barrier influencing the adoption of blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use?" will be answered. The results from the online questionnaire described in section 4, will be presented,as well as an overview of the sample's characteristics.

5.1. Respondents Overview

The questionnaire was distributed mostly through the personal network of the researcher, as mentioned in section 4.4.3. It is difficult to say the true reach of the questionnaire since it might have been forward and reforwarded by the immediate connections of the researcher. Nevertheless, it is possible to see in Qualtrics how many people opened the survey, even if they did not finish.

In total 68 people opened the survey, from these, only 34 actually completed the survey. From the 34 answers, one had to be excluded because the person chose the same category as the most and least important category of barriers, and then did the same for the category of drivers. Therefore, in total there were 33 valid answers. However, these still include people that said they were not familiar with the pharmaceutical industry as seen in figure 5.1. Hence, only 21 answers were useful to this research.

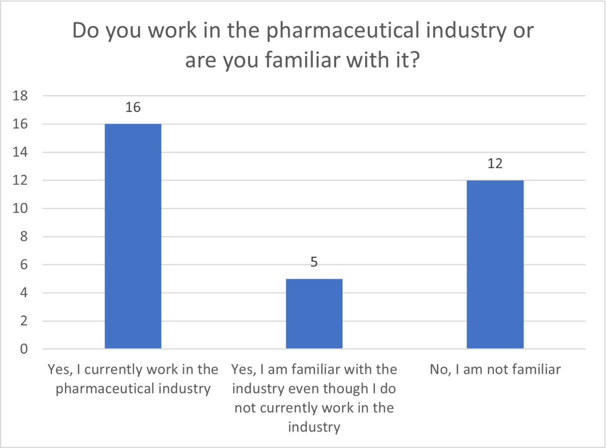


Figure 5.1: Respondents' knowledge of the pharmaceutical industry.

5.1.1. PERSONAL EXPERIENCE

In order to minimize the risk of breaking the participants' anonymity no personal information such as name, address, email, gender or nationality was asked. It was only requested data regarding their job position in the pharmaceutical industry to be able to better understand the pool of respondents gathered in terms of experience in the field.

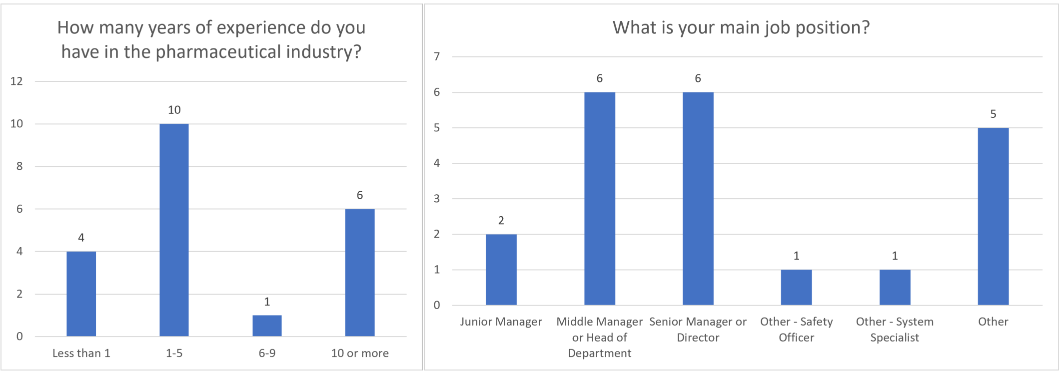


Figure 5.2: Number of years of experience and job position of the respondents in the pharmaceutical industry.

As depicted in figure 5.2, the majority of the respondents have less than six years of experience in the field, 35% have 10 or more, while just one has between six and nine years. It can also be seen that 12 out of the 21 participants are either Middle Manager, Head of Department, Senior Manager or Director, and five people did not specify their position.

Figure 5.3 shows that the majority of the respondents works in either Operations (Supply Chain/Logistics, Procurement/Purchasing, Production/Manufacturing), Technology and Pharmacovigilance. From which, Supply Chain/Logistics is the one with the most respondents (seven). This means that the majority of the respondents' work would be impacted by the adoption of blockchain technologies as a way to combat the distribution of falsified products, hence it is expected they would have the most insightful opinions when understanding the barriers and drivers of adopting this technology in the industry.

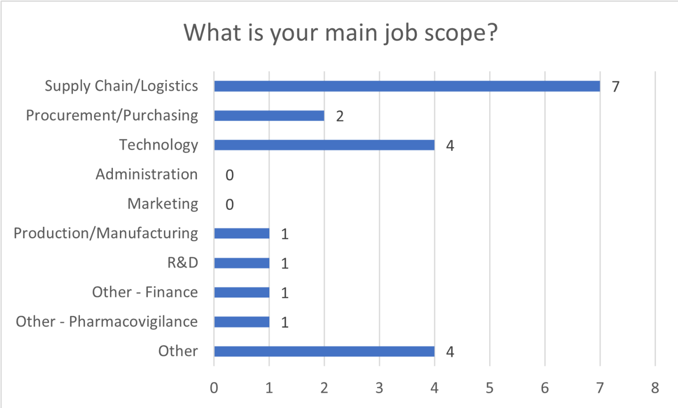


Figure 5.3: Job scope of the respondents in the pharmaceutical industry.

5.1.2. COMPANY INFORMATION

Following the questions related to their position, the respondents were asked three questions about their companies.

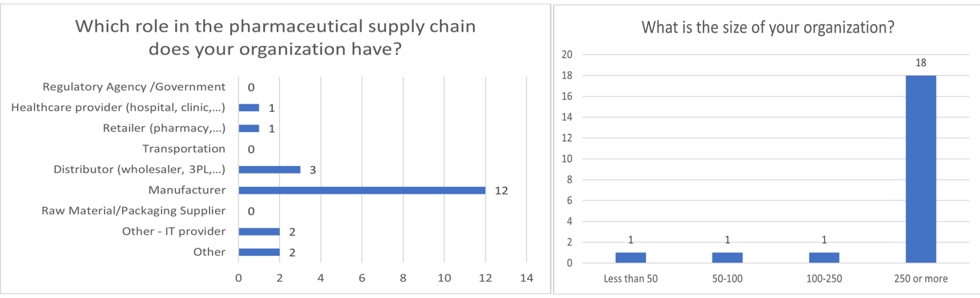


Figure 5.4: Organizations' role in the pharmaceutical supply chain and size.

As seen in figure 5.4, 12 out of the 21 respondents' companies are manufacturers. The other companies are Distributors, IT providers, Retailer, Healthcare provider or others, with 3, 2, 1, 1, and 2 respondents respectively. This was expected as one of the contacts approached while distributing the survey had a strong network of contacts working in manufacturers. Furthermore, manufacturer companies tend to be very well known to the general public, such as Bayer or Pfizer, whereas Distributors or Raw Material or Packaging Suppliers are harder to be recognized without some research or knowledge of the industry. Figure 5.4 also depicts the size of the organization. It can be seen that the vast majority has 250 employees or more, with 18 respondents. This was also to be expected since manufacturers tend to be big multinational companies.

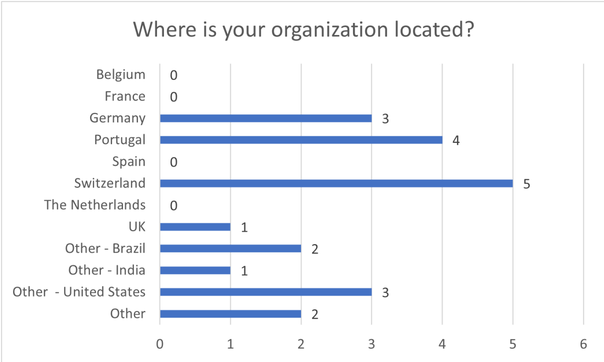


Figure 5.5: Organizations' geographical location.

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Regarding the location of the organizations, figure 5.5 shows that the sample is quite geographical diverse. The respondents' companies are divided into (at least) four continents: North America, South America, Europe and Asia. The majority coming from Europe, encompassing Switzerland with five respondents, Portugal with four, Germany with three, and United Kingdom (UK) with one. The remaining eight respondents are divided into three people from the United States, two from Brazil, one from India, and two that did not mention their country.

5.2. BWM Results: Barriers

In this section, the results for the BWM regarding the barriers are presented. Firstly, the weights of the categories of barriers (Technology, Organization, and Environment) are computed. Secondly, the weights of the barriers inside of each category will be weighted among themselves ("local weights"). Finally, the global weights of the barriers will be calculated by multiplying the "local weights" by the weight of the respective category.

5.2.1. Barrier Category Weights

The selection of the most and least important category of barriers by the respondents, and their respective weights computed with the Bayesian BWM's MATLAB implementation is presented in table 5.1. It was found important to show the frequency of the most and least important categories chosen by the respondents since this way it can be understood if there was a consensus of the choices and attempt to derive conclusions from it.

It can be seen that Technology was chosen as the most important category of barriers by 11 respondents, and Organization by nine. Whereas Environment was only chosen one time as the most important. On the other hand, Technology and Organization are equally divided as the second least important category of barriers, being chosen 5 times each, while Environment was the clear least important category for the participants.

The column "Weights", shows Technology and Organization as clearly more important than Environment, with weights of 0.3711 and 0.3645 respectively, while Environment has a weight of 0.2644.

Table 5.1: Selection of the most and least important categories of barriers by the respondents and weights generated with the Bayesian BWM.

Category of Barriers	Most Important	Least Important	Weights
Technology	11	5	0.3711
Organization	9	5	0.3645
Environment	1	11	0.2644

This ordering can also been seen with the Credal Ranking which is presented in figure 5.6. As explained before, in section 4.3, the Credal Ranking provides more information on the confidence of the relation between each pair of criteria. Each arrow has a direction (> or <) that identifies the relation between each pair, and the numbers that appear on top of the lines represent the confidence (0-1) of the relation.

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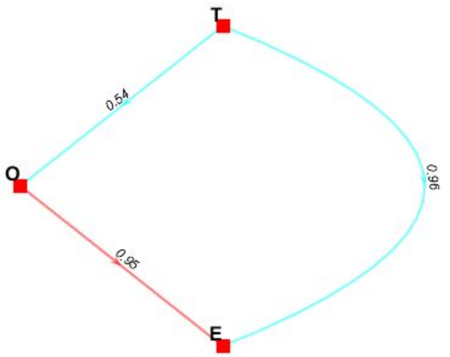

Figure 5.6: Categories of Barriers' Credal Ranking (Technology (T), Organization (O), Environment (E)).

It can be seen that Technology is the most important category of barriers. However, the confidence that Technology is superior over Organization is just of 54% whereas it has 95% over Environment. This means that Technology's superiority over Organization is not very high from the respondents' point of view. However, it can be said with 95% confidence that Organization is superior to Environment.

5.2.2. TECHNOLOGICAL BARRIERS: LOCAL WEIGHTS

When asking the respondents about the different Technological Barriers, the results presented in figure 5.2, show that Complexity is the barrier selected the most times as being the most important one, with 10 respondents. The other barriers were chosen by almost the same number of people: Security concerns four times, Data governance concerns three times, and in last place, Privacy concerns, and Compatibility/Interoperability with two times each. Additionally, it demonstrates that Data governance concerns was considered the least important barrier by the most respondents (seven times). Followed by the remaining barriers: Complexity (five), Privacy concerns (four), Compatibility/Interoperability (three), and Security concerns (two). It is interesting to note that even though Complexity was chosen the most times as the most important barrier, it was found to be voted as the least important barrier in second place behind Data governance concerns.

Table 5.2: Selection of the most and least important Technological barriers by the respondents and weights generated with the Bayesian BWM.

Technological Barriers	Most Important	Least Important	Weights
Privacy concerns	2	4	0.1734
Security concerns	4	2	0.2240
Data governance concerns	3	7	0.1818
Complexity	10	5	0.2282
Compatibility/Interoperability	2	3	0.1925

5

Furthermore, table 5.2 shows the weights of each barrier obtained with the Bayesian BWM. Complexity and Security concerns are closely placed first and second with 0.2282 and 0.2240 respectively. Followed by the remaining three barriers also with similar weights, in order of importance: Compatibility/Interoperability (0.1925), Data governance concerns (0.1818), and Privacy concerns (0.1734). It is important to notice that, contrary to the expectations of the researcher, Privacy concerns and Security concerns are not closely ranked. Contrary to some authors that analyse the factors as one, it was clearly important to separate the two (Orji et al., 2020; Yadav et al., 2020). This means that respondents are more concerned with the risk of hacking than with the privacy of their data and if it is visible to others or not.

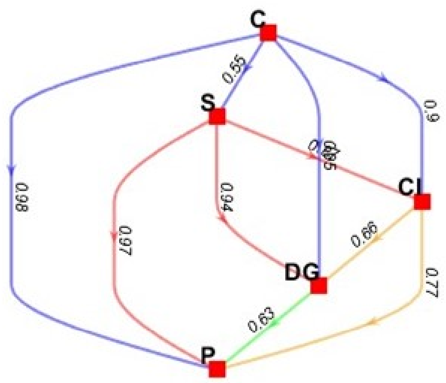

Figure 5.7: Technological Barriers' Credal Ranking (Privacy concerns (P), Security concerns (S), Data governance concerns (DG), Complexity (C), and Compatibility / Interoperability (CI)).
(For clarity purposes: Credal Ranking C>DG=0.95, and S>CL=0.87)

With the Credal Ranking, seen in figure 5.7, it is confirmed that there is not a high confidence that C is superior to S, since it has a confidence of only 55%. The same happens for CI to DG and to P with just 66% of confidence and 77% respectively, and DG to

P with 63%. Therefore, it can be said with high confidence that Complexity and Security concerns are superior to the remaining barriers.

5.2.3. ORGANIZATIONAL BARRIERS: LOCAL WEIGHTS

In this sub-section, the results from the relative importances attributed by the respondents to each organizational barrier are exposed.

Table 5.3: Selection of the most and least important Organizational barriers by the respondents and weights generated with the Bayesian BWM.

Organizational Barriers	Most Important	Least Important	Weights
Perceived implementation costs	6	2	0.2092
Lack of knowledge of the technology	5	4	0.1806
Lack of top management support	5	1	0.2358
Lack of tools to implement and support the technology	2	3	0.1946
Organization culture	3	11	0.1798

There is no clear favorite to the respondents as the most important barrier compared to the others. As depicted in table 5.3, from the most times chosen to the least, the barriers are: Perceived implementation costs (six), Lack of knowledge of the technology (five), Lack of top management support (five), Organization culture (three), and finally, Lack of tools to implement and support the technology (two). This can mean that respondents equally value these options as important ones, and therefore had difficulty in choosing their most important one.

Regarding the least important Organizational barrier compared to the others, the respondents chose Organization culture the largest number of times, 11. Followed by Lack of knowledge of the technology (four), Lack of tools to implement and support the technology (three), and finally Perceived implementation costs (two). In this case, it is clear that the respondents are in agreement that Organization culture is the least important Organizational barrier.

With the Bayesian BWM, the weights computed of the Organizational barriers can also be seen in table 5.2. Even though the respondents selected Perceived implementation costs as the most important barrier more times, the weights show that Lack of top management support is ranked first over the other barriers with 0.2358. Perceived implementation costs is the second in the ranking with 0.2092, followed by Lack of tools to implement and support the technology with 0.1946, Lack of knowledge of the technology with 0.1806, and finally, in line with the barrier selected the most times as the least important one, Organization culture with 0.1798.

Once again, the confidence of these results can be ascertained with the Credal Ranking shown in figure 5.8. The ranking shown with the weights are confirmed with high confidence by the Credal Ranking, with the exception of the superiority of LK over OC, since there is a confidence of just 52%.

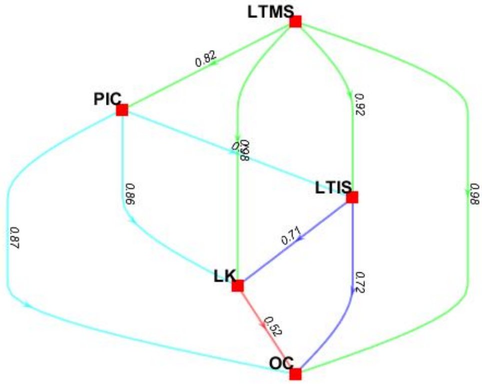

Figure 5.8: Organizational Barriers' Credal Ranking (Perceived implementation costs (PIC), Lack of knowledge of the technology (LK), Lack of top management support (LTMS), Lack of tools to implement and support the technology (LTIS), and Organization culture (OC)).
(For clarity purposes: Credal Ranking LTMS>LK=0.98, and PIC>LTIS=0.7)

5

5.2.4. ENVIRONMENTAL BARRIERS: LOCAL WEIGHTS

For the category of barriers that came last in the ranking, seen previously in sub-section 5.2.1, the results from the respondents are displayed in table 5.4.

Table 5.4: Selection of the most and least important Environmental barriers by the respondents and weights generated with the Bayesian BWM.

Environmental Barriers	Most Important	Least Important	Weights
Environment concerns	1	7	0.1649
Lack of Government standards and/or legislation	5	2	0.2148
Lack of collaboration, communication and coordination in the SC	7	1	0.2264
Lack of inter-organizational trust	4	4	0.2098
Cultural differences between stakeholders	4	7	0.1841

In this case, Lack of collaboration, communication and coordination in the SC, was the barrier that was selected more times (seven) as the most important barrier and was also the one with the least votes (one) as the least important barrier. The contrary is also observed, with the barrier selected more times as the least important (seven) being Environment concerns, was also the one least voted (one) as the most important barrier. This result goes in line with the weights attributed to these barriers, since the former is ranked first (0.2264), and the latter is ranked last (0.1649), according to the Bayesian BWM. The second most voted as the most important barrier (five), Lack of Government standards and/or legislation, was also the second least voted as the least important barrier (two). This means that there was a clear alignment from the respondents on the two most important barriers being Lack of Government standards and/or legislation and Lack of collaboration, communication and coordination in the SC.

When analysing the weights of the remaining barriers and looking at the Credal Ranking in figure 5.9, it can be seen that there is a high confidence of the resulting ranking with all confidences above 72%. However, there are two exceptions with LCCC over LGSL, and LGSL over LIOT having, respectively, 65% and 57%. This means that, although the weights show that LCCC is first, LGSL is ranked second (0.2148) and LIOT third (0.2098), the Credal Ranking reveals that there is not a high confidence in this placing. Nevertheless it is clear that these three barriers are the most important over CD and E.

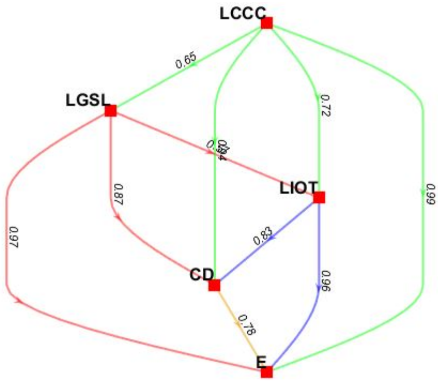

Figure 5.9: Environmental Barriers' Credal Ranking (Environmental Concerns (E), Lack of government standards and/or legislation (LGSL), Lack of collaboration, communication and coordination in the supply chain (LCCC), Lack of inter-organizational trust (LIOT), and Cultural differences between stakeholders (CD)).
(For clarity purposes: Credal Ranking LCCC>CD=0.94 , and LGSLC>LIOT=0.57)

5.2.5. BARRIERS' GLOBAL WEIGHTS

In this sub-section, the local weights of the different barriers are computed and presented in table 5.5. This process was done by multiplying the weight of the respective category of the barrier by the local weight of the barrier in question. Based on the results of this calculation, a column with the overall ranking of the barriers is displayed.

The table confirms what was expected given the analysis conducted in the previous subsections. Considering that Technology and Organization were closely ranked as first and second most important categories of barriers, the top ten barriers are spread between these two categories, with the bottom five ranked barriers being Environmental ones.

Hence, the top ranked barrier is Lack of top management support (Organizational), the second is the Complexity of the technology (Technological), followed by Security concerns (Technological), Perceived implementation costs (Organizational), and the fifth most important barrier is Compatibility/Interoperability of the technology with other systems and technologies (Technological).

On the other hand, as said before, the Environmental barriers are the ones with the lowest weights. Thus, Cultural differences between stakeholders and Environmental concerns are, respectively, the second to last and last barriers ranked.

Table 5.5: Global weights of all barriers and ranking.

Barriers	Categ	Categ Weight	Local Weight	Global Weight	#
Privacy concerns	TECH	0.3711	0.1734	0.0643	10
Security concerns			0.2240	0.0831	3
Data governance concerns			0.1818	0.0675	7
Complexity			0.2282	0.0847	2
Compatibility/Interoperability			0.1925	0.0714	5
Perceived implementation costs	ORG	0.3645	0.2092	0.0763	4
Lack of knowledge of the technology			0.1806	0.0658	8
Lack of top management support			0.2358	0.0859	1
Lack of tools to implement and support the technology			0.1946	0.0709	6
Organization culture			0.1798	0.0655	9
Environment concerns	ENV	0.2644	0.1649	0.0436	15
Lack of Government standards and/or legislation			0.2148	0.0568	12
Lack of collaboration, communication and coordination in the Supply Chain			0.2264	0.0599	11
Lack of inter-organizational trust			0.2098	0.0555	13
Cultural differences between stakeholders			0.1841	0.0487	14

5.3. BWM RESULTS: DRIVERS

In this section, similarly to section 5.2, the results for the Bayesian BWM regarding the drivers are exposed and analysed. The weights of the categories (Technology, Organization, and Environment) are presented first. Then, the local weights of the barriers in each category are exposed. Ultimately, the global weights of the barriers are calculated and presented as well as the final ranking of the drivers.

5.3.1. DRIVER CATEGORY WEIGHTS

In table 5.10, the selection of the most and least important category of drivers and their weights resulted from the Bayesian BWM are presented.

Table 5.6: Selection of the most and least important categories of drivers by the respondents and weights generated with the Bayesian BWM.

Category of Drivers	Most Important	Least Important	Weights
Technology	10	6	0.3656
Organization	8	6	0.3420
Environment	3	9	0.2924

Technology was the category most selected as the most important driver by the respondents, followed by Organization and Environment, being respectively selected ten, eight and three times. In relation to the respondents' selection of the the least important categories, Environment is the unequivocal preferred category with nine votes. Whereas the remaining votes were equally spread between Technology and Organization with 6 votes each. This means that respondents had a harder time choosing between Technology and Organization as their overall most important driver, whereas Environment was clearly the least favourite.

From the weights computed by the Bayesian BWM's MATLAB implementation, it is confirmed that Technology is the most important category of drivers (0.3656) and the least important is Environment (0.2924). Organization, therefore, occupies the second place with a weight of 0.3420.

With the Credal Ranking presented in figure 5.10, it is confirmed that this raking has a high confidence. However, it is understood that the superiority of Technology over Organization does not have a high confidence with just 65%.

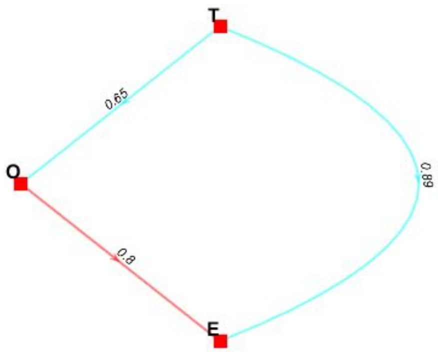

Figure 5.10: Categories of Drivers' Credal Ranking (Technology (T), Organization (O), Environment (E)).

5.3.2. TECHNOLOGICAL DRIVERS: LOCAL WEIGHTS

Almost half of the respondents (nine) chose Traceability as the most important driver, as seen in table 5.7. The remaining respondents chose as the most important driver, per order: Security enhancements (six respondents), Immutability (three), Compatibility/Interoperability (two), and finally, Privacy enhancements (one). On the other hand, concerning the least important driver chosen by the respondents, Immutability was the one with the most votes, eight. Followed by Privacy enhancements, with six people selecting the option. The least selected as the least important driver is Traceability, with just one vote, which goes in line with it being chosen the highest number times as the most important driver. This way it is understood that the respondents clearly favoured Traceability and Security enhancements as the two most important drivers, having more difficulty in distinguishing the importance of the other drivers.

Table 5.7: Selection of the most and least important Technological drivers by the respondents and weights generated with the Bayesian BWM.

Technological Drivers	Most Important	Least Important	Weights
Privacy enhancements	1	6	0.1560
Security enhancements	6	2	0.2274
Immutability	3	8	0.1863
Traceability	9	1	0.2389
Compatibility/Interoperability	2	4	0.1913

The table also displays the weights of the Technological drivers computed by the Bayesian BWM's MATLAB implementation. In this column it is clear that the number one Technological driver is Traceability with a weight of 0.2389, closely followed by Security enhancements with 0.2274. Concerning these two drivers, the Credal Rankings presented in figure 5.11, show the lack of confidence in the superiority of T over SE with just 65% confidence.

In third place is Compatibility/Interoperability with 0.1913. To note that, as seen in sub-sections 3.4.1 and 3.4.2, this driver is different from the one analysed in the previous sub-section (5.2.2). In this case, the driver discussed is about the compatibility and interoperability that blockchain technologies bring by offering a platform where companies can share information smoothly when using the same blockchain. On the other hand, the barrier discussed before is about the disadvantages of having different blockchain platforms that do not allow for information sharing.

The last two ranked drivers are Immutability with 0.1863, and Privacy enhancements with 0.1560. It is important to notice that CI's superiority to I has a lower confidence of 58%. It is interesting to notice that, similarly to what was seen in the Technological barriers' ranking, Privacy enhancements was not closely ranked with Security enhancements. Once again, for the respondents, a more important driver is the fact that blockchain technologies can bring more security for their data, and are less concerned with the improved privacy options that the technology can bring.

Hence, it is understood from the analysis that the most important drivers are Traceability and Security enhancements, followed by Compatibility/Interoperability and Immutability, and as the last ranked is Privacy enhancements.

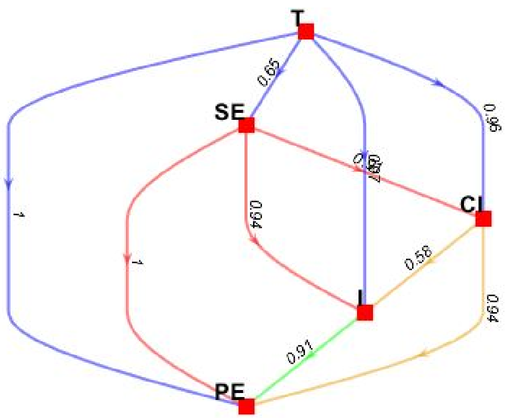

Figure 5.11: Technological Drivers' Credal Ranking (Privacy enhancements (PE), Security enhancements (SE), Immutability (I), Traceability (T), and Compatibility / Interoperability (CI)).
(For clarity purposes: Credal Ranking T>I=0.97, and SE>CI=0.91)

5.3.3. ORGANIZATIONAL DRIVERS: LOCAL WEIGHTS

In order to analyse the Organizational drivers, the selection made by the respondents when asked what, in their opinion, the most important and the least important Organizational driver, is shown in table 5.8, as well as the weights from the MATLAB implementation.

Table 5.8: Selection of the most and least important Organizational drivers by the respondents and weights generated with the Bayesian BWM.

Organizational Drivers	Most Important	Least Important	Weights
Reduce operational costs	10	1	0.2416
Knowledge of the technology	3	3	0.2030
Top management support	5	2	0.2165
Firm size	1	12	0.1436
Brand protection	2	3	0.1953

Reduce operational costs was the driver chosen the most times (ten) as the most important Organizational driver. There is also a clear favorite for the least important driver with more than half the votes (12) from the respondents, it being Firm size. Both these drivers had just one vote in their respective opposite questions. The second most chosen as the most important driver was Top management support with five votes, followed by Knowledge of the technology (three), Brand protection (two), and finally, Firm size with one vote. On the other side, the least important drivers chosen by the respondents are, in order, Knowledge of the technology (three) tied with Brand protection (three), and lastly, Top management (two). This can mean that respondents had no difficulty choosing the most and least important drivers, respectively, Reduce operational costs and Firm size. However, the remaining drivers were more challenging to distinguish.

Thus, it is no surprise that Reduce operational costs is the first ranked driver, and Firm size is in last place, with their respective weights being 0.2416 and 0.1436. Top management support takes the second place with a weight of 0.2165, followed by Knowledge of the technology with 0.2030 closely ahead of Brand Protection in fourth place with 0.1953.

With the Credal Ranking shown in figure 5.12, this ranking can be taken with high confidence with the exception of the superiority of K over BP, with just 60% confidence.

It is interesting to compare this ranking with the one shown in section 5.2.3 on the local weights of the Organizational barriers. For the respondents, the Lack of top management support is the utmost important barrier, and at the same time they believe that having this support is an important driver placing it only below the reduction of operational costs. Furthermore, the other repeated barrier and driver is Knowledge of the technology. The respondents are once again consistent, considering that having or not having knowledge about the technology is not the most important driver. They place the lack of knowledge as a less important barrier in fourth place and having knowledge about the technology in third place of Organizational drivers.

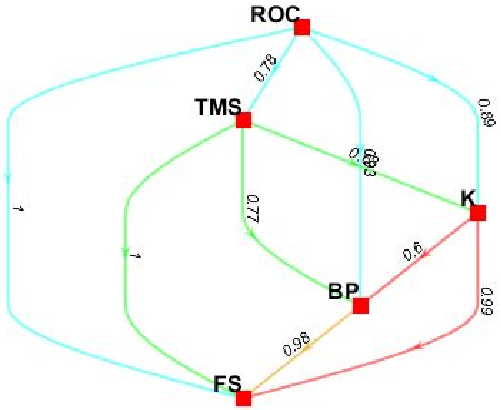

Figure 5.12: Organizational Drivers' Credal Ranking (Reduce operational costs (ROC), Knowledge of the technology (K), Top management support (TMS), Firm size (FS), and Brand protection (BP)).
(For clarity purposes: Credal Ranking ROC>BP=0.93, and TMS>K=0.68)

5

5.3.4. ENVIRONMENTAL DRIVERS: LOCAL WEIGHTS

In this section, the results of the selection of the most and least important drivers and weights of the Environmental drivers are displayed in table 5.9 and the Credal Rankings in figure 5.13.

For the respondents, Customer safety was selected as the most important driver compared to the other options, with nine votes. Competitive pressure to adopt the technology was the second most selected one with five answers, with Market dynamics and Government standards and/or legislation tied with three votes, and lastly, Stakeholder pressure to adopt blockchain technologies with one vote. On the least important column, Market dynamics is displayed as being considered the most times (ten) as the least important Environmental driver. Followed by Stakeholder pressure to adopt BT (five), Competitive pressure to adopt BT (three), Government standards and/or legislation (two), and lastly, with just one vote is Customer Safety. This means that it is consensual that Customer safety the most important Environmental driver. However, it can be argued that the respondents had difficulty distinguishing the levels of importance of the remaining drivers.

Table 5.9: Selection of the most and least important Environmental drivers by the respondents and weights generated with the Bayesian BWM.

Environmental Drivers	Most Important	Least Important	Weights
Stakeholder pressure to adopt BT	1	5	0.1697
Competitive pressure to adopt BT	5	3	0.1893
Market dynamics	3	10	0.1587
Government standards and/or legislation	3	2	0.2079
Customer safety	9	1	0.2744

Hence, the resulting ranking based on the respondents' answers and the weights computed with the Bayesian BWM's implementation is led by Customer safety with 0.2744 with a fair advantage over the second driver, Government standards and/or legislation with a weight of 0.2079. In third place comes Competitive pressure to adopt the technology with 0.1893, followed by Stakeholder pressure with 0.1697 and, finally, Market dynamics as the least important Environmental driver with 0.1587. This ranking can be considered with high confidence as it is shown with the Credal Rankings in figure 5.13.

The fact that Customer safety is the most important Environmental driver is not surprising. It is known that the well-being of the patient or the consumer of the products passed down the supply chain is the number one priority for all the players in the pharmaceutical industry. Therefore, any solution that can improve this factor is a key driver and selling point for companies to adopt it. Furthermore, Government standards and/or legislation was also expected to be placed high in the ranking. As mentioned before, and also gathered from the interviews, the pharmaceutical industry is highly regulated since it can have deadly consequences when procedures are not followed. Therefore, if any solution goes against regulations or there is no legislation that incentives the solution, companies will not implement it.

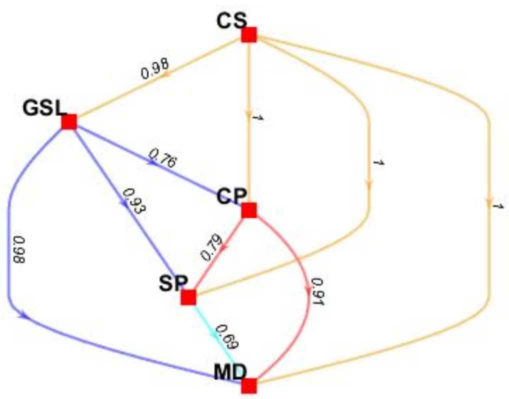

Figure 5.13: Environmental Drivers' Credal Ranking (Stakeholder pressure to adopt blockchain technology (SP), Competitive pressure to adopt blockchain technology (CP), Market dynamics (MD), Government standards and/or legislation (GSL), and Customer safety (CS)).

5.3.5. DRIVERS' GLOBAL WEIGHTS

In this sub-section, the local weights of the different drivers are computed and presented in table 5.10. The process to arrive to the global weights was the same as followed for the barriers in sub-section 5.2.5. The weight of the respective category of the driver was multiplied by the local weight of the driver. Consequently, a column with the overall ranking based on the global weights of the drivers was included in the table.

Even though respondents found that Technological drivers were overall more important than Organizational drivers, and then followed by Environmental drivers, the top five most important overall drivers based on the global weights are distributed throughout the three categories.

The first two most important drivers are Traceability and Security enhancements, both Technological drivers. It is clear that the pharmaceutical industry finds the manipulation of data important and, therefore, any means that help bring more security and visibility into the supply chain are seen as advantageous. The third driver, with a global weight of 0.0826, is the Reduction of operational costs. It is known that one of the most relevant key performance indicators of a company is its Gross profit (Revenue - Cost of sold goods). If a solution potentially reduces the operational costs, it means it reduces the costs of sold goods, hence it increases the Gross profit. This way, Reducing operational costs is an important driver for companies in the PSC to adopt blockchain technologies. The fourth driver, is Customer Safety. This Environmental driver actually has the highest local weight. However, since respondents found the category of Environmental drivers overall less important than the other two, this factor was placed fourth in the ranking. The fifth most important driver for the pharmaceutical industry is having Top management support. As noted before, this is an important factor both as a barrier and as a driver.

Looking into the bottom five drivers, the majority of them belong to the Environment category. Market dynamics is ranked last place with a weight of 0.0464. In 12^{th} and 13^{th} place, there is Competitive pressure and Stakeholder pressure to adopt blockchain technologies. In 11^{th} place comes Privacy enhancements, a Technological driver, with a weight of 0.0570, which was the found the least important Technological driver by the respondents. In second to last place, it is found the Organizational driver Firm size which, as raised before, was distinctly the least important Organizational driver with a local weight of just 0.1436.

Table 5.10: Global weights of all drivers and ranking.

Drivers	**Categ**	**Categ Weight**	**Local Weight**	**Global Weight**	**#**
Privacy enhancements	TECH	0.3656	0.1560	0.0570	11
Security enhancements			0.2274	0.0831	2
Immutability			0.1863	0.0681	8
Traceability			0.2389	0.0873	1
Compatibility/Interoperability			0.1913	0.0699	6
Reduce operational costs	ORG	0.3420	0.2416	0.0826	3
Knowledge of the technology			0.2030	0.0694	7
Top management support			0.2165	0.0740	5
Firm size			0.1436	0.0491	14
Brand protection			0.1953	0.0668	9
Stakeholder pressure to adopt BT	ENV	0.2924	0.1697	0.0496	13
Competitive pressure to adopt BT			0.1893	0.0554	12
Market dynamics			0.1587	0.0464	15
Government standards and/or legislation			0.2079	0.0608	10
Customer safety			0.2744	0.0802	4

5.4. CONCLUSION

In this chapter, the outputs of the questionnaire and subsequent BWM results were analyzed. In each subsection, the local weights of each category of barriers, and then of the drivers, were discussed based on the importance attributed by the respondents. Furthermore, the credal ranking showing the confidence of each category's ranking was presented and discussed. After the analyses of each category's local weights, an overview of the global weights of the overall barriers and drivers was presented and discussed. These overviews can be seen in tables 5.5 and 5.10.

It was understood that in both barriers and drivers, the category of Technology was the favorite, followed by Organization, and lastly Environment.

Concerning the barriers, the top 10 ones are divided between Technology and Organization. The most important ones, in order, are Lack of top management support (Organization), Complexity (Technology), Security concerns (Technology), Perceived implementation costs (Organization), Compatibility/Interoperability (Technology), Lack of tools to implement and support the technology (Organization), Data governance concerns (Technology), Lack of knowledge of the technology (Organization), Organization culture (Organization), and finally Privacy concerns (Technology). The least important barriers are the Environmental ones. These are, per order, Lack of collaboration, communication and coordination in the Supply Chain, Lack of Government standards and/or legislation, Lack of inter-organizational trust, Cultural differences between stakeholders, and finally Environment concerns.

Regarding the drivers, most of the top 10 ones are divided into Technological and Organizational drivers apart from two Environmental ones. These are Customer safety in fourth place, and Government standards and/or legislation in tenth. This finding made it clear that the pharmaceutical industry will more easily adopt solutions that improve patient well-being and that are within approved protocols, as it a highly regulated industry. The remaining top 12 most important drivers are, in order of importance, Traceability (Technology), Security enhancements (Technology), Reduce operational costs (Organization), Top management support (Organization), Compatibility/Interoperability (Technology), Knowledge of the technology (Organization), Immutability (Technology), and finally, Brand protection (Organization). The last five most important drivers are mainly Environmental, with one from Organization and another from Technology. These are, in order, Privacy enhancements (Technology), Competitive pressure to adopt BT (Environment), Stakeholder pressure to adopt BT (Environment), Firm size (Organization), and finally, Market dynamics (Environment).

5

6

Recommendations for Blockchain Initiatives

In this section, the fourth sub-question "How can blockchain technology initiatives overcome the most important barriers to adopt blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use, while leveraging the most important drivers, to stimulate adoption?" will be answered based on the results gathered throughout this research.

The objective is to provide meaningful insights to the players developing and offering blockchain technologies as a solution to the PSC to help combat the distribution of falsified products, so they can attract more actors in the supply chain. This will be done by discussing the most important barriers and drivers to adopt this technology for the actors in the PSC gathered through the online questionnaire and analysed in chapter 5. Furthermore, the researcher will also make use of insights from academic literature or business reports from the industry, as well as the knowledge gathered through the interviews in order to provide the most holistic recommendations.

The insights will follow the TOE framework in order to be coherent with the work done until this point. As explained in section 3.2, this framework is one of the most used when studying the acceptance of technology at the firm level. Hence, the insights will be based on the comparison of the local rankings of the barriers and drivers of each category, as discussed in chapter 5.

6.1. Technological Recommendations

Out of the three categories (Technology, Organization, and Environment), it is clear that blockchain initiatives need to focus primarily on the first one, as it was considered by the respondents as the most important category of barriers and drivers. This means that they need to understand what are the stakeholders concerns and priorities in regards to the technology in order to develop the solution in a way that will attract the companies.

Table 6.1: Ranking of Technological Barriers and Drivers based on the local weights.

Technological Barriers	**Local Weight**	**Technological Drivers**	**Local Weight**
Complexity	0.2282	Traceability	0.2389
Security concerns	0.2240	Security enhancements	0.2274
Compatibility/Interoperability	0.1925	Compatibility/Interoperability	0.1913
Data governance concerns	0.1818	Immutability	0.1863
Privacy concerns	0.1734	Privacy enhancements	0.1560

Table 6.1 shows Blockchain offering companies what are the most important barriers and drivers of blockchain adoption by the pharmaceutical industry. Beginning with the most important driver, it is clear that the most important benefit that blockchain technologies bring to the table is their capacity for Traceability. As mentioned before, blockchain technologies are also known as distributed ledger technologies that can be used to record data using crypto-analytic hash function consisting of nodes that are secure and immutable (Wang et al., 2019). It is important to mention that the benefit of traceability is a natural consequence of the immutability feature the principle of blockchain offers (Wang et al., 2019; Ghode et al., 2020). According to the respondents, this feature is not as important as Traceability, hence, blockchain companies should focus on advertising and making Traceability the selling point of the solution instead of Immutability. Thus, by using solutions that are based on the blockchain principle, it can bring more visibility to the supply chain as transactions that occur throughout the chain are recorded and can be consulted to check the path of the products (van Hoek, 2020). By being able to verify the course that the product followed, all actors in the supply chain, including the final consumer, can feel safe that it is a legitimate product. Saurabh and Dey (2021) also mention the potential that blockchain technologies have to be paired with other technologies, such as RFID. By pairing these solutions, it ultimately increases the traceability power of the technology, especially when in can be combined with the ones already in use by the pharmaceutical companies.

The second driver and barrier of adopting blockchain technologies in the PSC are about Security. The fact that the technology ensures that data is not manipulated, gives users a better sense of trust and confidence on the transactions in the supply chain (Wang et al., 2018). At the same time, respondents show that it is important for them that the solution is safe against hacking or other malicious attacks. Hence, it is clear that actors in the pharmaceutical industry are in need of a solution that can act as a single source of truth and that is secure.

Both the third driver and barrier are about Compatibility and Interoperability of the technology. This means that another core capability that needs to be built as part of the architecture of the solution is the ability to integrate other technologies and transfer data in a smooth and effortless manner. As mentioned in section 1.1.2, one of the issues in the supply chain across industries, is the lack of interoperability of systems used by the different actors involved (Queiroz et al., 2019; Wang et al., 2019). These issues can lead to mismatches between data, overall inefficiencies in the processes and ultimately increase the operating costs (Orji et al., 2020). Fortunately, Blockchain technologies are known to make data more interoperable (Ghode et al., 2020). This way, as mentioned by Wang et al. (2018), in order to attract more participants, blockchain offering companies need to make sure they provide interoperability with core enterprise IT systems.

Thus, companies developing blockchain technologies for the PSC, need to primarily focus on developing and advertising the traceability, security and interoperability features of the technology. This way companies will understand that the solution tackles their needs for visibility, trust and smooth transfer of data across the industry's supply chain.

Furthermore, they also need to keep in mind that Complexity of the technology is actually the number one barrier to adopt blockchain technologies according to this research's respondents. As explained by Wong et al. (2020) and Wang et al. (2018), the complexity of blockchain poses a significant challenge for individuals to understand, accept and be confident in participating in the technology. Consequently, apart from focusing on building the before mentioned capabilities, it is important that these features are built in a comprehensible and user-friendly manner. Literature shows that when the solution is set-up in a straightforward manner, there is less resistance from top management to adopt the solution (Wang et al., 2018; Wong et al., 2020).

6.2. ORGANIZATIONAL RECOMMENDATIONS

The second most important category of drivers and barriers found is Organization. These factors are related to the capacity of the firms to adopt the technology. In order to attract more players, companies that are developing blockchain technologies need to understand what are the needs of the pharmaceutical industry to better adapt their strategy.

Table 6.2 depicts the ranking of the most important Organizational barriers and drivers influencing the adoption of blockchain technology in the PSC, according to the respondents of the online survey.

Table 6.2: Ranking of Organizational Barriers and Drivers based on the local weights.

Organizational Barriers	**Local Weight**	**Organizational Drivers**	**Local Weight**
Lack of top management support	0.2358	Reduce operational costs	0.2416
Perceived implementation costs	0.2092	Top management support	0.2165
Lack of tools to implement and support the technology	0.1946	Knowledge of the technology	0.2030
Lack of knowledge of the technology	0.1806	Brand protection	0.1953
Organization culture	0.1798	Firm size	0.1436

When looking at the two top barriers and drivers, it is inarguable that top management support and costs are the principal priorities for pharmaceutical companies.

Lack of top management support is the most important barrier, while having Top management support is the second most important driver. As explained by Orji et al. (2020), managers are the ones who are able to provide direction, resources, tools and necessities before, during and after implementation of a technology. This means that managers and decision-makers need to be convinced of the benefits of the technology in order to facilitate its implementation. It is also important that the technology is overall aligned with the strategic goals of the enterprise (Wong et al., 2020). Furthermore, according to some authors, the more familiar and knowledgeable upper management is on the technology, the more likely it is to support its adoption (Kouhizadeh et al., 2021; Wong et al., 2020). This appears to go in line with this study's findings. Even though, Lack of knowledge of the technology was not in the top chosen barriers from the respondents, having Knowledge of the technology was closely ranked to Top management support as drivers.

Regarding the financial dimension of the solution, firms are compelled by the potential operational savings that blockchain technologies bring, while still being concerned about the implementation costs. Also during the interviews, all experts mentioned costs as the most important driver influencing the decision to adopt a technological solution, highlighting the need to have a strong business case to sway upper management. Blockchain technologies applied to SCM have been shown to help reduce inventory, improve asset management, and reduce intermediaries costs, while improving the quality of the service, flexibility, speed and sustainability (Kouhizadeh et al., 2021; Papalexi et al., 2022; Wong et al., 2020). However, adopting a new technology in an organization requires a high budget, especially since blockchain technologies need hardware and software investments. Besides supporting the technology, it is also expensive to support the people and process infrastructure around it (Kouhizadeh et al., 2021). Even though Firm size was found as the least important driver, one can associate the ability to fund these requirements with bigger firms. This may be the reason why the development of these blockchain initiatives are often done in partnership with multinational firms that can make the needed investments.

Hence, blockchain initiatives need to make sure that upper management is aware of the blockchain technologies' benefits, especially the technological ones mentioned in the previous section. Furthermore, it needs to be clear how these advantages impact the overall financial statements of the company and its strategic goals. A strong business case where the savings outweigh the costs is crucial to attract more pharmaceutical actors. It can also be mentioned that the solution brings benefits to Brand protection but, as deduced from the research, this is not a main driver for the firms. Furthermore, blockchain offering companies could take into account the Organization culture of the clients. Although it was seen as the least important barrier, a company that is more open to innovation would be easier to persuade to adopt and implement blockchain technologies.

6.3. Environmental Recommendations

For the final set of recommendations, table 6.3 will be analysed. As mentioned before, the category of Environmental factors was deemed the least important in both drivers and barriers. According to the TOE framework, the Environment context has to do with the industry's characteristics and Market structure (Baker, 2012). Hence, the suggestions made in this section regard these elements, including regulatory and legislative entities.

Table 6.3: Ranking of Environmental Barriers and Drivers based on the local weights.

Environmental Barriers	**Local Weight**	**Environmental Drivers**	**Local Weight**
Lack of collaboration, communication and coordination in the Supply Chain	0.2264	Customer safety	0.2744
Lack of Government standards and/or legislation	0.2148	Government standards and/or legislation	0.2079
Lack of inter-organizational trust	0.2098	Competitive pressure to adopt BT	0.1893
Cultural differences between stakeholders	0.1841	Stakeholder pressure to adopt BT	0.1697
Environment concerns	0.1649	Market dynamics	0.1587

The main barrier to the adoption of blockchain technologies is the Lack of collaboration, communication and coordination in the Supply Chain. This is an important barrier to overcome as, in order to have true end-to-end visibility and traceability (main technological driver) of the products in the PSC, all players (raw material suppliers, manufacturers, distributors, retailers, and healthcare providers) need to be using the technology (Banerjee, 2018a). Furthermore, respondents also believe that the Lack of inter-organizational trust needs to be solved. Some authors and one expert interviewed, actually defend that blockchain technologies will be able to help build trust among the organizations in the supply chain (Ghode et al., 2020; Yadav et al., 2020). As the use of blockchain technologies becomes more widespread, companies will understand the value and advantages of the solution such as immutability, traceability and security of the transactions, contributing to wider adoption.

The second important dimension regarding the Environmental drivers and barriers is legislation. Respondents say that not having Government issued standards or legislation hinders the adoption of blockchain technologies, while stating that the opposite would be the second most important driver. Moreover, during the interviews and literature review, this point was repeatedly highlighted as one of the most important factors in all industries, but especially in the pharmaceutical one. Since this industry is highly regulated, companies will be less inclined to adopt novel technologies that have not been approved by the regulatory entities. At the same time, as mentioned by Taylor (2014), legislative incentives put in place to improve the patient and consumer's safety are a catalyst to the development and adoption of new technologies. For example, in the USA, the Drug Supply Chain Security Act mentioned in section 2.3.2, that requires the members of the PSC to verify, track and trace prescription drugs, motivated the creation of a blockchain solution by different big players of the industry. Ultimately, this all contributes to Customer safety, which is the utmost driver for blockchain adoption in the pharmaceutical industry according to the 21 respondents.

Therefore, blockchain initiatives should aim to involve the different actors across the PSC including Governmental entities. Some of the initiatives mentioned in section 2.3.2 are a good example of this approach. Pharmaledger was able to build a consortium of 29 members distributed across large manufacturers,distributors, patient organizations, hospitals, as well as government authorities, research centers, and universities

(PharmaLedger, 2021b). This strategy also goes in line with the third most important driver: Competitive pressure to adopt blockchain technologies. Once companies see that some players are already using the technology, the remaining ones will feel pushed to implement it in order to keep up with the demanding competition. Blockchain technology providers also need to pay attention to the legislation of the respective countries. As discussed, when a country has standing laws that motivate the adoption of the technology, companies will be more easily persuaded to embrace it. If the country does not have this type of legislation, companies could try to work with the Government to show the benefits that it could bring to the industry and patients, and design policies together that facilitate the technology's adoption (Alharthi et al., 2020).

6.4. CONCLUSION

In this chapter, the local weights of each category of the barriers and drivers were compared and analyzed to provide meaningful recommendations to providers of blockchain technologies in the PSC to gather more clients.

It was suggested that the providers need to focus on developing and advertising the novel and advantageous features that blockchain technologies can bring to the industry's supply chain. Especially traceability, security and interoperability, keeping the solution overall simple and easy to use. These features need to be presented to upper management of the target customers, alongside a strong business case that can persuade them into providing the needed resources to implement the technology. The developers of blockchain technology need to also keep in mind the existing environment where this technology will be introduced in. The main topics to keep in mind is to make sure that the solution improves patient safety and that is compliant with the current legislation. Therefore, involving the regulatory entities and governments is crucial to build policies that incentive the technology's adoption.

7

Conclusions and Discussion

In this final chapter, the research will be summarized with the key findings of each sub-question that contributed to answer the main research question. Following this, the limitations of the study and suggestions for future research will be discussed. Lastly, the connection of the research with the Management of Technology (MoT) Master is presented.

7.1. Summary and Key Findings

With the increase in globalization, supply chains are becoming more complex and companies are starting to feel competitive pressures, such as costs, demand for shorter times to the market, and volatile demand patterns. It has also made organizations realize that solving their supply chain challenges will contribute to their overall competitive advantage. Therefore, companies have turned to new technologies and solutions to try to solve their supply chain challenges and stay ahead of the curve.

One industry's supply chain that could immensely benefit from technology is the pharmaceutical one. According to the WHO, trading falsified medicinal products is worth billions of dollars and is responsible for thousands of deaths every year. Furthermore, this problem is thought to be increasing at an alarming rate driven by the growth of online pharmacies and market places. This is possible because the PSC has many different players through which the drugs pass by until reaching the final consumer. Nowadays, the traceability and verification of the origin and path of the products is almost impossible. This means that falsified products can easily enter the supply chain.

Different technological solutions have been implemented in attempt to combat this issue such as RFID, IoT, machine learning algorithms, and blockchain technologies. Blockchain technologies are thought to have the biggest potential to mitigate the issues found in the PSC. Due to their features of immutability, decentralization, cryptographic security, privacy, interoperability, and smart contracts; blockchain technologies provide the right platform for traceability, interoperability, data sharing, and transparency in the PSC. However, this technology has not been widely deployed in the industry.

It was understood that there was a knowledge gap on how to further deploy blockchain technologies in the PSC to combat the distribution of falsified medicinal products for human use.

Consequently, to bridge this gap, the main research question of this thesis was:

MRQ: "How can blockchain technology initiatives in the pharmaceutical supply chain stimulate blockchain technologies' adoption to combat the distribution of falsified medicinal products for human use?"

To answer the main research question, several sub-questions were formulated.

SQ1: "How can blockchain technologies combat the distribution of falsified medicinal products for human use?"

With this sub-question, two objectives were achieved. The first objective was to understand the main actors in the PSC, their connections in the three flows: information, physical and financial, and where are the weaknesses in the supply chain that allow the entry of falsified products. The second objective was to understand how blockchain technologies can prevent this problem.

To achieve these two objectives, two different systematic literature reviews were conducted. The first one was conducted in two stages using a funnel approach. The first stage focused on finding papers related to the PSC stakeholders, whereas the second one aimed to find papers related to the flows, especially the information one. The second literature review had the goal of finding papers on blockchain technologies and their utility in preventing counterfeiting in the PSC.

Regarding the first objective, diagram 7.1 was produced showing the main actors in the PSC, the flows between them and where counterfeited ingredients or products can enter.

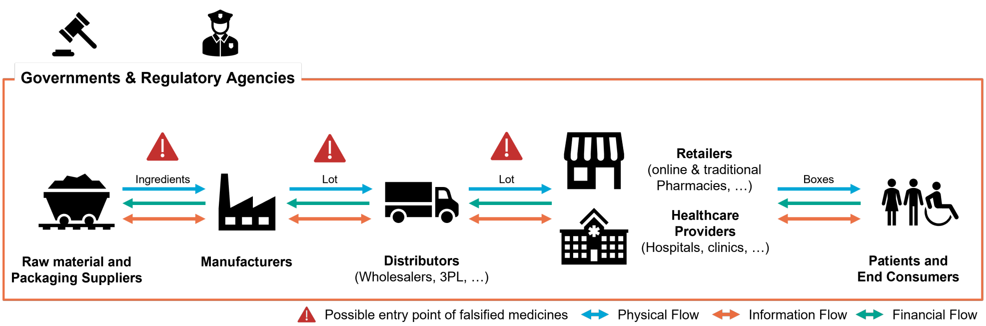

Figure 7.1: Diagram of a normal PSC and potential entry points for falsified medicines.

While reviewing the literature on how blockchain technologies can help prevent the distribution of falsified medicinal products for human use, it was understood that the set up was fairly common among the solutions presented. The main elements found are: a platform based on blockchain technology with user interfaces, a form of identification technology that can hold the information of the product from a verified manufacturer to be uploaded to the blockchain platform such as a QR code or RFID tag, and the use of smart contracts to record the changes in ownership along side the supply chain where the trustworthiness of the players can be verified if needed. The majority of the papers also seemed to use Hyperledger since it provides a higher degree of trust, decentralization, transparency, privacy, security and data deployment when compared to others such as Ethereum or Quorum. With this set-up, it was understood that the origin of the products and their tracking throughout the supply chain is made simple and trustworthy. Consequently, it was concluded that blockchain technologies could help prevent the distribution of falsified medicinal products for human use in the PSC.

However, it was also found that, although there are some initiatives of companies offering the solution such as MediLedger and PharmaLedger, the technology is not widely adopted yet. Which brought the second sub-question.

SQ2: "What are the barriers and drivers influencing the adoption of blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use?"

This question was answered in chapter 3 by conducting a literature review to find relevant papers to acquire the barriers and drivers that influence the adoption of blockchain technology. The literature review was performed in two stages as well. The first stage yielded results related to the adoption of blockchain technologies in SCM in any industry since literature related specifically to the PSC was scarce. Therefore, a second search was made to find barriers and drivers of adopting technologies in general to this specific industry.

Also in this chapter, a framework to classify and analyse the barriers and drivers was chosen. The TOE framework was chosen due to its widely use in studying firm level acceptance of technology adoption, and it is considered to be the more complete framework compared to the others (Oliveira et al., 2014). It defends that there are three different contexts that influence the adoption of a technology: Technology, Organization, and Environment. Accordingly, the barriers and drivers found in the literature were grouped into the three different contexts, resulting in six lists of factors which are presented in tables 3.3 and 3.4.

These lists were too extensive to build a survey that respondents would be able to answer in acceptable time. Hence, seven experts in blockchain technology, PSC, and in law, were interviewed to narrow down the lists to the most chosen as their most important five barriers and five drivers of each category (table 7.1).

Table 7.1: List of the most important barriers and drivers chosen per category by the experts.

Categ	Barriers	Drivers
TECH	Privacy concerns	Privacy enhancements
	Security concerns	Security enhancements
	Data governance concerns	Immutability
	Complexity	Traceability
	Compatibility/Interoperability	Compatibility/Interoperability
ORG	Perceived implementation costs	Reduce operational costs
	Lack of knowledge of the technology	Knowledge of the technology
	Lack of top management support	Top management support
	Lack of tools to implement and support the technology	Firm size
	Organization culture	Brand protection
ENV	Environment concerns	Stakeholder pressure to adopt BT
	Lack of Government standards and/or legislation	Competitive pressure to adopt BT
	Lack of collaboration, communication and coordination in the Supply Chain	Market dynamics
	Lack of inter-organizational trust	Government standards and/or legislation
	Cultural differences between stakeholders	Customer safety

SQ3: "What is the relative importance attributed to each driver and barrier influencing the adoption of blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use?"

The ranking of these barriers and drivers based on their importance are found in chapter 5 but, before that, the methods used to find them are explained in chapter 4.

The Bayesian Best-Worst Method was chosen as the most suitable method due to its many advantages compared to other Multi-Criteria Decision Making problem solving methods. This method is less data-intensive, more user-friendly, and mitigates anchoring bias (L. Li et al., 2020). It allows to compute the weights of a set of criteria (in this case, six sets) based on the preferences of one or more decision-maker(s) (Mohammadi & Rezaei, 2020).

In order to collect these preferences, an online questionnaire was designed and shared through different channels such as the personal connections of the researcher and through LinkedIn. The target population was anyone with knowledge on the pharmaceutical industry.

The analysis of the output of the online questionnaire was presented in chapter 5, as mentioned before. The answers to the questionnaire were the input for the Bayesian BWM's MATLAB implementation which produced the local and global weights of all the barriers and drivers per category that can be seen in tables 5.5 and 5.10. Technology was the winning category in both drivers and barriers, closely followed by Organization. Which left Environment as the least favorite category in both types of factors. Therefore, globally, the ten most important barriers were split between the categories of Technology and Organization. Concerning the drivers, the situation is similar with the difference that, Customer safety, an Environmental driver, is placed fourth overall showing the importance of this factor for the pharmaceutical industry.

Overall, it was found that globally, respondents believe that Lack of top management support was the most important barrier hindering the adoption of blockchain technologies in the PSC with a global weight of 0.0859. Following that, their biggest concerns were the Complexity of the technology with 0.0847, and Security issues with 0.0831. The fourth most important barrier found was the Perceived implementation costs with a global weight of 0.0763. And, finally, the top fifth barrier overall was the Compatibility/Interoperability that can occur from not having smooth transmission of information between blockchain solutions.

Concerning the global ranking of the drivers, the first two most important ones were Traceability and Security enhancements with the global weight of 0.0873 and 0.0831, respectively. Making it clear that the PSC is truly in need of a solution that brings visibility, transparency and trust to the trade. Thirdly, with a global weight of 0.0826, was Reduce operational costs. As mentioned before, Gross profits are a key performance indicator for companies in general. Therefore, a solution that improves this measure will be better received. In fourth place, was the before mentioned Customer Safety with a global weight of 0.0802, which actually had the highest local weight of 0.2744. This goes to show that patient and consumer safety is truly at the heart of the industry. The fifth most important driver was Top management support with a global weight of 0.0740. Since it was found that lack of upper management support was actually the most important barrier, it was concluded that top management support is really an important factor that influences the adoption of the technology.

SQ4: "How can blockchain technology initiatives overcome the most important barriers to adopt blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use, while leveraging the most important drivers, to stimulate adoption?"

This question was answered in chapter 6 by using the information gathered until that point. Recommendations were put together to providers of blockchain technologies in the PSC in order to attract more customers. The insights were done by comparing the local weights of the barriers and drivers per category of the TOE framework. This way, it is more clear for blockchain initiatives on how to proceed with their strategy concerning the three different contexts.

Regarding the Technological context, it was suggested that blockchain technologies' developing companies need to primarily focus on developing and advertising the technology's advantageous features of traceability, security and interoperability. While at the same time, keeping in mind to build a solution that is not too complex since that was found to be the key barrier for its adoption. Thus, actors in the PSC would understand that this solution tackles their needs for increased visibility, trust and smooth data transfer across the industry's supply chain in a user-friendly manner.

Additionally, the learnings from the Organizational context, indicated that blockchain initiatives need to ensure that upper management is convinced and positive about the technology. In order to do this it is important to not only share the benefits of the technology mentioned above and how the technology works, but also present the financial impact that this solution will bring. A strong and favourable business case is the most crucial driver to stimulate blockchain technologies' adoption. Once top management endorses the implementation the technology it will much easier to find resources to carry the endeavour.

Finally, the main insights regarding the Environmental barriers and drivers covered different topics. As mentioned before, the main driver was the customer and patient safety, therefore blockchain technologies providers have to ensure that this will not be affected. Furthermore, a key point found was the importance of involving the different actors of the supply chain, including Governmental entities. Having their involvement is crucial, especially of regulatory entities since the pharmaceutical industry is highly regulated. It was also understood that the more players are involved the better since competitive pressures in the pharmaceutical industry were established as an important driver.

In conclusion, the four above sub-questions have allowed the researcher to answer the main research question "How can blockchain technology initiatives in the pharmaceutical supply chain stimulate blockchain technologies' adoption to combat the distribution of falsified medicinal products for human use?". This has resulted in the identification of the actors in the PSC and where are the weaknesses allowing the distribution of counterfeited products. Furthermore, a ranking of the most important barriers and drivers per category of the TOE framework that influence the adoption of blockchain technologies in the pharmaceutical industry was found. Furthermore, meaningful recommendations were provided to developers of blockchain technologies that aim to attract more actors in the PSC to further deploy its adoption.

7.2. Scientific Relevance

The study has resulted in the selection of 31 barriers and 28 drivers that influence the implementation of blockchain technologies in the PSC and categorized according to the TOE framework. Based on this selection, experts were interviewed to narrow down the options to the most important five drivers and barriers per category. Following this, the ultimate most important barriers and drivers per category were found and ranked by employing the Bayesian BWM. These were then analysed and compared to give concrete recommendations to providers of blockchain technologies to in the PSC.

Furthermore, when conducting the literature review to find the drivers and barriers, it was understood that no paper studied the drivers and barriers at the same time. This is another advantage of the present study, as drivers and barriers were identified and analysed together, resulting in more holistic and meaningful insights and recommendations to the providers of blockchain technologies.

Another scientific contribution of this study concerns the TOE framework. By using this framework for the first time in the context of the adoption of blockchain technologies in the PSC, it brings further empirical validity to the framework. Finally, the present research contributes as well to the validity of the Bayesian Best-Worst-Method.

7.3. LIMITATIONS

While conducting this master thesis, some challenges were encountered during the process. In this section, these limitations are addressed by explaining them and giving suggestions on how to solve them in future research.

7.3.1. EXPERT AND SURVEY RESPONDENT SAMPLES

In order to narrow down the list of barriers and drivers found in the literature, seven experts were interviewed. It was rather difficult to find experts with knowledge on blockchain technology implementation in the PSC as it is such a novel subject. Therefore, the ones approached and available to conduct the interview were well-versed in either the pharmaceutical industry, IT, blockchain technology, or law. Even tough the answers converged in the same direction, it would be advised to continue the research with more experts. Especially ones that are more familiar with the PSC as well as blockchain technologies. It would also be beneficial to interview professionals from the companies that are developing and providing this type of solution for the pharmaceutical industry. Since these professionals have first-hand experience presenting the solution to potential customers in the PSC, their knowledge on the barriers and drivers felt by these customers would be helpful to conduct the research.

Some limitations were also found concerning the population reached with the online survey to participate in the BWM. The first limitation was the extraordinarily difficulty to have respondents finish the questionnaire. From the 68 people that opened the survey, only 34 actually completed the survey, that accounts for just 50%. From the 34, only 21 respondents were familiar with the pharmaceutical industry and, therefore, were allowed to participate in the BWM. This could be due to the length of the exercise, which was already a concern demonstrated during the testing phase of the questionnaire. Nevertheless, despite the small sample size of just 21 respondents, it can be seen in chapter 5, that in the majority of the cases there was a tendency to pick the same barriers and drivers as the most important ones and least important ones. Also, there seems to be a consistency between the chosen barriers and drivers as the most important ones per category. Moreover, even though most of the credal orderings appear to be well consolidated (over 70%), there was still some around 50%. This indicates that some of the rankings could be changed if more responses are gathered.

Another limitation found was that, from the 21 people that gave useful answers, only seven had more than six years of experience. Furthermore, the respondents' company role in the PSC was mainly manufacturing and with more that 250 employees. This makes the generalizing of the findings to the entire PSC less plausible.

Future research should aim at having a larger and more varied sample of respondents. This could be done through separating the questionnaire into one with just the barriers, and the other with the drivers. This way the respondents would be less inclined to give up during the questionnaire and would lead to more responses. It would be interesting to have a sample diverse enough to conclude on the preferences per type of role that the pharmaceutical company occupies in the supply chain, and also on the differences per country or region. This suggestion actually came from different experts during the interviews, since it was mentioned that manufacturers and distributors may have different drivers while operating the supply chain. Moreover, the degree of knowledge that the respondents possessed on blockchain technologies was not inquired. It would be interesting to understand if the answers would change dependently of this aspect.

7.3.2. Barrier and driver finding

In order to group and classify the drivers and barriers identified, the TOE framework was chosen. This was due to its robustness and proven validity in studying the adoption of technologies at firm level (Oliveira et al., 2014). When applying the method, researchers use different factors as it is assumed that for each specific technology and context that is being studied, there are distinctive factors or measures (Baker, 2012). For this particular research it was not possible to find relevant literature on the barriers and drivers influencing the adoption of blockchain technologies in the PSC. Hence, these factors were gathered through literature that covered the adoption of blockchain technologies in supply chains of different industries, and then on literature of the adoption of technologies in general in the PSC specifically. Furthermore, the comprehensiveness of the developed framework in this research is determined by the quality of the consulted research which means that it can not be ensured that all the relevant barriers and drivers were included. Additionally, during the literature review conducted to find the factors related to the adoption of blockchain technologies in the different industries, 142 papers were found, from which 45 were found relevant. These were then ranked by number of citations and after analysing the first 11 papers, five more were looked into and it was assumed that no new factors would be found. However, if the researcher did not have time constrains, in order to be be able to conclude this statement with absolute certainty, the full 45 papers should have been analysed. However, when asked during the interviews if any factors were missing, both in the barriers and drivers, the experts said that to the best of their knowledge the list seemed complete.

Nevertheless, it is advised to future researchers to search for the specific factors influencing blockchain adoption in the PSC, as it is expected that the literature will evolve and become available.

Another suggestion of future research is to explore the interrelationships among the identified barriers and drivers. This knowledge could shed new light on the strategy providing companies with better understanding on how to position themselves. Lastly, the designed conceptual model could be used to analyse the barriers and drivers in other industries. According to the experts, the set of barriers and drivers put together was quite complete and, provided it is adapted to the new context, it could easily be applied and derive meaningful conclusions.

7.4. Connection with the MoT Master

The research conducted was set to find the most important barriers and drivers that influence the adoption of blockchain technologies in the PSC to combat the distributions of falsified medicinal products for human use. The ultimate objective was to provide recommendations to blockchain technology initiatives, such as IT developing and provider companies or consortiums, to be able to overcome the barriers and leverage the drivers to attract the greatest number of actors in the PSC. Contributing, overall, to better public safety and also improving the efficiencies in the industry's supply chain.

To successfully carry this study, the knowledge gathered during the completion of the MoT courses was crucial.

In order to learn about how to overall conduct and design a scientific research project, the courses "Research Methods" and "Preparation for the Master Thesis" were really important. "Research Methods" provided the guidance on the notions needed to follow through the steps of the study in a coherent and scientific manner. Furthermore, "Preparation for the Master Thesis" allowed the researcher to become familiar with the process of finding a research problem and conducting a literature review, even though it ended up being on a different topic.

The courses of "Leadership and technology management", "Technology, strategy and entrepreneurship" and "High-tech marketing" were important to understand the different elements of putting together a corporate strategy and marketing it in a sustainable and suitable way to the company's and markets' reality. They taught as well that the technical superiority of a product is not enough and that the right holistic market strategy adapted to the consumers in the right organizational and environmental contexts is crucial for success.

Furthermore, “Inter and intra-organizational decision making” taught me that me that decision making is an intricate and convoluted endeavour that normally needs the participation of different individuals. It takes a great deal of effort, compromises, and understanding from all parties to achieve the better outcome. Some methods for solving Multi-Criteria Decision Making problems were explained such as the Best-Worst-Method, which was finally selected for this work as well.

During the course of "Sustainable innovation and transitions", the influence that society and technology have on each other became clear. Therefore, it is important to understand the broader system of stakeholders that the technology will be inserted, and it is crucial that they are involved in the development and implementation of new solutions. Only proceeding this way will allow a smooth transition to new solutions and yield the most benefits.

Finally, the courses related to supply chain were very important to understand more about this topic which proved very useful to this research. The two most relevant ones were "Design Innovation 4.0 in Supply Networks" and "Logistics and supply chain innovation". In the latter, the theoretical and practical issues concerning supply chain analysis, engineering and management were explored. State of the art practices in logistics and supply chain as well as new technologies used in this realm were discussed. Here happened the first understanding of the use of blockchain technologies in SCM and their benefits in it. In "Design Innovation 4.0 in Supply Networks", the focus was on the application of fundamental concepts, models and instruments in the design and innovation of Industry Networks, as well as understanding the basics of design from the perspective of buyer/supplier relationships. Moreover, it allowed the researcher to understand the dynamics of a demand/supply context and the interdependence of the involved firms in a network while performing different roles. This interdependence creates tensions but also opportunities to innovate, collaborate and adopt new solutions together which was also confirmed in this research.

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A

Barriers and Drivers Identified

In this appendix, the definitions of all the barriers and drivers found in the literature will be presented. These were the factors presented to the experts during the interviews, with the respective definitions.

A.1. Identified Barriers and Definitions

Table A.1: List of barriers and their definitions found in the literature

Barriers	Definition
Technological Barriers	
Privacy Concerns	Depending on the architecture set-up, data might be more or less visible to others. Therefore, people might be concerned with the privacy of their data (Orji et al., 2020).
Security Concerns	Concerns with how safe is the system from facing malicious attacks (Yadav et al., 2020).
Data governance	What data should be stored in blockchains, how such data will be collected and fed into the system and who should be responsible for data input and provision (Wang et al., 2018).
Immutability	Information cannot be changed and removed from the blockchain without consensus (Ghode et al., 2020).

A

Barriers	Definition
Complexity	The complexity of technology implementation and the technology itself. Generally, a high degree of complexity confuses technology users and causes them to have difficulty in understanding and using it correctly (Wong et al., 2020).
Disintermediation	Functional attribute of blockchain and its affiliated technology named smart contract that operates on a peer-to-peer network to remove the intermediaries (Saurabh & Dey, 2021).
Performance Expectancy	The degree to which an individual believes that using the system will help him or her to attain gains in job performance (Queiroz et al., 2020)
Compatibility/ Interoperability	The lack of interoperability between blockchains and integration with existing IT systems can be difficult and can constrain a smooth data transfer (Wang et al., 2018).
Lack of maturity	Blockchain technology is in its early development stages and considered an immature technology (Saberi et al., 2018)
Lack of speed	Long time pass for each verified block of transactions to be added to the ledger (Wang et al., 2018)
Lack of scalability	Blockchain technology has problems in terms of scalability and handling a large number of transactions (Saberi et al., 2018)
Organizational Barriers	
Lack of knowledge	The degree to which managers know about blockchain technology (Alharthi et al., 2020).
Lack of Top management support	When managers do not believe in the technology it can be a true barrier for its implementation (Kouhizadeh et al., 2021).
Lack of tools to implement and support the technology	Lack of capabilities from the organization to implement and support the technology such as processes, training capabilities or infrastructure (Orji et al., 2020; Saberi et al., 2018).
Organizational culture	The pattern of people's behaviors and practices within the pharmaceutical industry and within the organization can affect how firms respond to external pressures and makes strategic business decisions (Orji et al., 2020).
Lack of supplier support	The degree to which the suppliers support the adoption of the technology and are willing to adopt it. (Da Silva & de Mattos, 2019)
Firm size	Bigger firms are less inclined to implement blockchain. (Orji et al., 2020)
Perceived Implementation costs	The investment required to acquire the technology and implement it within the organization (Orji et al., 2020).
Environmental Barriers	

Barriers	Definition
Customer awareness	The degree to which the customer is aware of the technology. (Kouhizadeh et al., 2021).
Social influence to not adopt blockchain technologies	Issues that are associated with the possible influence exerted by co-workers, family, and so forth, to make them adopt or not blockchain. (Ghode et al., 2020)
Stakeholders pressure to not adopt blockchain technologies	Relates to the external environment that details the high and persistent requirements of various stakeholders or investors in the pharmaceutical industry to adopt or not the technology (Orji et al., 2020)
Competitive pressure to not adopt blockchain technologies	The degree to which the competition has adopted the technology (Wong et al., 2020)
Market dynamics	Refer to the continuous changing state of an environment that is highly competitive and complex (Orji et al., 2020).
Environmental concerns	Blockchain technology requires a high level of energy consumption to maintain the network (Wang et al., 2018).
Lack of collaboration, communication and coordination in the SC	Lack of collaboration and effective communication among supply chain partners with different and even contradictory operational objectives and priorities (Saberi et al., 2018).
Lack of inter-organizational trust	Unwillingness to share valued information between organizations (Wang et al., 2018).
Cultural differences between stakeholders	Communication and coordination challenges would be worse where supply chain partners are geographically dispersed with different cultures (Kouhizadeh et al., 2021; Saberi et al., 2018) .
Intermediary Resistance	Since blockchain allows for disintermediation, intermediary entities could put pressure to not adopt the technology (Wang et al., 2018).
Lack of Government standards/legislation	The lack of ability of relevant government agencies to provide aids and enact rules and regulations to encourage blockchain technology adoption (Orji et al., 2020).
Lack of Government support	The degree to which the Government supports or not the adoption of the technology, including rewards or incentives in general, and compliance incentives specifically (Orji et al., 2020)
Lack of involvement of external stakeholders (NGOs,etc)	The degree to which external stakeholders such as NGOs and universities, are involved in promoting and adopting blockchain technology (Saberi et al., 2018).

A.2. IDENTIFIED DRIVERS AND DEFINITIONS

A

Table A.2: List of drivers and their definitions found in the literature.

Drivers	Definitions
Technological Drivers	
Privacy enhancements	Blockchain technology affords pseudonymity, meaning that all transactions are transparent, yet are not explicitly connected to real-world individuals or organisations (Wang et al., 2018).
Security enhancements	Blockchain technology ensures that information shared is essentially secure to avoid manipulation (Orji et al., 2020).
Immutability	Information cannot be changed and removed from the blockchain without consensus (Ghode et al., 2020).
Easiness of use	The degree of ease associated with the use of the system (Queiroz et al., 2020)
disintermediation	Functional attribute of blockchain and its affiliated technology named smart contract that operates on a peer-to-peer network to remove the intermediaries (Saurabh & Dey, 2021).
Performance Expectancy	The degree to which an individual believes that using the system will help him or her to attain gains in job performance (Queiroz et al., 2020)
Compatibility/ Interoperability	The lack of interoperability between blockchains and integration with existing IT systems can be difficult and can constrain a smooth data transfer (Wang et al., 2018).
Traceability	Blockchain technology brings more visibility into the supply chain. Traceability is an important quality factor that can be augmented by applying blockchain technology and other existing technologies, such as IoT and RFID. (Saurabh & Dey, 2021).
Organizational Drivers	
Access to tools to implement and support the technology	Availability of capabilities from the organization to implement and support the technology such as processes, training capabilities or infrastructure (Orji et al., 2020; Saberi et al., 2018).
Knowledge of the technology	The degree to which managers know about blockchain technology (Alharthi et al., 2020).
Top management support	When managers believe in the technology it is a driver for its implementation. (Da Silva & de Mattos, 2019).
Organizational culture	The pattern of people's behaviors and practices within the pharmaceutical industry and within the organization can affect how firms respond to external pressures and makes strategic business decisions (Orji et al., 2020).
Supplier support	The degree to which the suppliers support the adoption of the technology and are willing to adopt it. (Da Silva & de Mattos, 2019)

Drivers	Definitions
Firm size	Bigger firms are more inclined to implement blockchain. (Orji et al., 2020).
Perceived Implementation costs	The investment required to acquire the technology and implement it within the organization (Orji et al., 2020).
Reduce operational costs	Blockchain technology can help reduce operational costs by improving asset and inventory management, increase end-to-end visibility in the supply chain, etc. (van Hoek, 2020; Wong et al., 2020).
Brand protection	Blockchain technology brings a tool for organizations to prove that their operations are legal and according to the norms (Taylor, 2014).
Environmental Drivers	
Customer awareness	The degree to which the customer is aware of the technology. (Kouhizadeh et al., 2021).
Social influence to adopt blockchain technologies	Issues that are associated with the possible influence exerted by co-workers, family, and so forth, to make them adopt or not blockchain. (Ghode et al., 2020).
Stakeholders pressure to adopt blockchain technologies	Relates to the external environment that details the high and persistent requirements of various stakeholders or investors in the pharmaceutical industry to adopt or not the technology (Orji et al., 2020)
Competitive pressure to adopt blockchain technologies	The degree to which the competition has adopted the technology (Orji et al., 2020).
Market dynamics	Refer to the continuous changing state of an environment that is highly competitive and complex (Orji et al., 2020).
Existing collaboration, communication and coordination in the SC	Existing collaboration and effective communication among supply chain partners with different and even contradictory operational objectives and priorities (Saberi et al., 2018)
Existing inter-organizational trust	Willingness to share valued information between organizations (Wang et al., 2018).
Government standards/ legislation	The ability of relevant government agencies to provide aids and enact rules and regulations to encourage blockchain technology adoption (Orji et al., 2020)
Government support	The degree to which the Government supports or not the adoption of the technology, including rewards or incentives in general, and compliance incentives specifically (Orji et al., 2020).
Involvement of external stakeholders (NGOs,etc)	The degree to which external stakeholders such as NGOs and universities, are involved in promoting and adopting blockchain technology (Saberi et al., 2018).
Customer Safety	Blockchain technology can help patients know if their medicinal products are falsified or not and therefore improve their safety (Wang et al., 2018).

B

Interview Protocol and Findings

In this section, the interview protocol will be explained as well as the results. The experts were approached through personal connections of the researcher and through the social network LinkedIn. They were firstly sent a consent form and then the interview was scheduled. The interviews were conducted through Microsoft Teams, where automatic transcripts were produced, and took approximately 45 minutes.

B.1. Consent form

Consent Form for the "Adoption of blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use" Master Thesis Interview

For the Master Thesis about blockchain adoption in the pharmaceutical supply chain

I, [name of expert], hereby freely and voluntarily give my consent to participate in the interview on "Adoption of blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use" organized by The Delft University of Technology as part of Master Thesis of Management of Technology Program, supervised by Dr J. Ubacht.

The objective of this Master Thesis research is to identify the barriers and drivers of blockchain adoption in the pharmaceutical supply chain.

I understand that my participation in this study is entirely voluntary and I can withdraw my participation from the study at any time. I understand I can choose the online platform of my preference to participate in the interviews. To withdraw, I must inform Mariana Lopes Vieira at any time before the completion of the study (expected 25/08/2022) without any penalty.

I understand that the interview will be recorded with both audio and video if I give permission to do so. The recording of the meeting will be treated as confidential by the research team and will only be accessed by the supervisor and the student (Dr J. Ubacht., and Mariana Lopes Vieira). The recording will be stored in the TU Delft Safe Drive until October 2022, after which will be permanently deleted.

I understand that an anonymized summary of the interview will be produced, whether voice/ video recording was allowed or not.

I understand that the anonymize summaries will remain available to Dr J. Ubacht and Mariana Lopes Vieira during the project and then will be made publicly available at TU Delft Repository as part of the Master Thesis report.

I understand that I have the right to refrain from answering any questions I judge inappropriate for my professional image or the company I work for. I also have the right to request adjustments to the anonymised summary, if I understand the questions I have answered impose any professional risk, or request the interview summary to be deleted after the current study.

I understand that I have the right to consult, rectify, and request the deletion of any and all personal data about my participation. I can consult with Mariana Lopes Vieira at any moment should I have any further questions about the handling of personal data during this project. All personal data gathered will be deleted at the end of the project (latest October 2022).

Date: XX /05/2022, Participant's signature:

B.2. INTERVIEW PROTOCOL & RESULTS

The interviews were individual and semi-structured. A small introduction was given on the research and any questions that were posed were answered. Then, the researcher asked the researchers to read the set of Technological barriers and definitions as seen in table A.2 presented in appendix A. Then the experts were asked to choose the five most important Technological barriers from the ones read. After this, the same process was applied in the following order: Technological drivers, Organizational barriers, Organizational drivers, Environmental barriers, and finally, Environmental drivers. When the interviewees had any questions during this process, the researcher answered to the best of their abilities while trying not to influence the expert in their thinking and, consequently, the answers given.

In sub-section B.2.1, the expertise and years of experience of the interviewees are shown. Then, in the following sections, the results of the selections made during the interviews are presented. It is important to note that expert number seven did not comply with the request of choosing the top five most important factors, and the selection is presented accordingly.

B.2.1. EXPERTS

The main focus of the jobs and years of experience of the experts are depicted in table B.1. These experts were found and approached through the personal network of the researcher and LinkedIn.

Table B.1: Expertise and years of experience of the seven experts interviewed.

Expert	Expertise	Years of experience
E1	Technology implementation expert in the pharmaceutical industry	10+
E2	Zone purchasing director of a multinational pharmaceutical manufacturer	10+
E3	Blockchain technology design and implementation in food supply chain	1-5
E4	Business analyst in pharmaceutical consulting firm focusing on commercial and supply chain effectiveness projects	1-5
E5	Supply chain and business consultant in a pharmaceutical distributor	1-5
E6	Lawyer specialized in Web3, Blockchain and Cryptoassets	1-5
E7	IT strategy and project management, supply chain performance in a multinational pharmaceutical manufacturer	10+

B

B.2.2. INTERVIEW RESULTS: TECHNOLOGY

Table B.2: Interview results on the Technological barriers and drivers

	E1	E2	E3	E4	E5	E6	E7	Total
BARRIERS								
Privacy concerns	x		x	x	x		x	**5**
Data governance concerns	x	x	x				x	**4**
Security concerns	x	x		x		x		**4**
Immutability	x		x	x				3
Complexity	x	x	x	x		x	x	**6**
Disintermediation						x		1
Performance Expectancy		x			x		x	3
Compatibility/Interoperability	x		x	x	x	x		**5**
Lack of maturity		x			x		x	3
Lack of speed					x			1
Lack of Scalability						x		1
DRIVERS								
Privacy enhancements	x		x	x		x		**4**
Security enhancements		x	x		x	x		**4**
Immutability		x		x	x	x	x	**5**
Easiness of use	x		x		x			3
Desintermediation		x		x			x	3
Performance Expectancy	x					x		2
Compatibility/Interoperability	x	x	x	x	x			**5**
Traceability	x	x	x	x	x	x	x	**7**

B.2.3. INTERVIEW RESULTS: ORGANIZATION

Table B.3: Interview results on the Organizational barriers and drivers

	E1	E2	E3	E4	E5	E6	E7	Total
BARRIERS								
Lack of Access to tools to implement and support the technology	x	x	x	x	x			**5**
Lack of Knowledge of the technology	x	x	x	x	x	x	x	**7**
Lack of Top Management Support	x		x	x		x		**4**
Organization Culture	x	x	x		x			**4**
Lack of Supplier Support		x				x		2
Firm size						x		1
Perceived implementation costs	x	x	x	x	x	x		**6**
DRIVERS								
Access to tools to implement and support the technology				x	x			2
Knowledge of the technology	x	x	x	x	x			**5**
Top Management Support	x	x			x	x	x	**5**

Organizational Culture			x				x	2
Supplier Support			x			x		2
Firm Size	x	x		x		x		**4**
Perceived implementation costs							x	1
Reduce operational costs	x	x	x	x	x	x	x	**7**
Brand Protection	x	x	x	x	x	x	x	**7**

B.2.4. INTERVIEW RESULTS: ENVIRONMENT

Table B.4: Interview results on the Environmental barriers and drivers

	E1	E2	E3	E4	E5	E6	E7	Total
BARRIERS								
Customer awareness								0
Social influence to not adopt blockchain					x		x	2
Stakeholders pressure to not adopt blockchain				x			x	2
Competitive pressure to not adopt blockchain					x	x		2
Market dynamics		x	x		x		x	**4**
Environmental concerns			x		x	x		3
Lack of Collaboration, communication and coordination in the SC	x	x	x	x		x	x	**6**
Lack of Inter-organizational trust	x			x	x	x	x	**5**
Cultural differences between stakeholders	x	x	x				x	**4**
Intermediary resistance	x	x		x				3
Lack of Government Standards/Legislation	x	x	x	x		x	x	**6**
Lack of Government Support								0
Lack of Involvement of external stakeholders (universities, NGOs, etc)								0
DRIVERS								
Customer awareness					x			1
Social influence to adopt blockchain							x	1
Stakeholder pressure to adopt blockchain	x	x	x	x		x	x	**6**

Competitive pressure to adopt blockchain	x		x	x		x	x	**5**
Market dynamics	x	x	x	x		x	x	**6**
Existing Collaboration, communication and coordination in the SC	x						x	2
Existing Inter-organizational trust			x		x			2
Existing Government Standards/Legislation		x	x	x	x			**4**
Existing Government Support	x		x					2
Involvement of external stakeholders (universities, NGOs, etc)		x				x		2
Customer Safety		x		x	x	x	x	**5**

C

Questionnaire Building

In this section, the questionnaire format, flow and questions will be presented. It is important to mention that the survey was based on the one put forward previously by Lanzini (2020) since the BWM was also used by the author and yielded good results.

C.1. Qualtrics functions

Since the options that appeared in some questions depended on the answers given previously to other questions, specific functions from Qualtrics had to be used to interconnect the questions and answers.

${B1.1/ChoiceGroup/SelectedChoices}

This function is included within the "Piped Text" tool from Qualtrics. It allows the survey to pull information from different sources such as previous questions and enables the editor to "pipe" it later in the survey (Qualtrics, n.d.-c). It is also important to enable the "variable naming" in the questions from which the survey will pull the information. If this is not done, instead of displaying the name of the option selected, such as "Technology", it will display the number of the option, such as "1". This was therefore enabled in questions: B1.1, B1.2, B2.1, B2.2, B3.1, B3.2, B4.1, B4.2, D1.1, D1.2, D2.1, D2.2, D3.1, D3.2, D4.1, and D4.2.

${e://Field/Unselected1}

This function is also part of the Piped Text tool. Firstly, the "Embedded Data" called "Unselected1" needs to be created in the survey flow. Embedded Data consists of a field (which is the name of the variable, e.g. Unselected1) and a value, which is assigned to the field (Qualtrics, n.d.-b). A custom Javascript (JS) (shown below), based on the work done by Lanzini (2020), was created in order to assign the value of one of the unselected choices to the variable "Unselected1". In total 16 "Unselected" variables were created and the JS was added to all the questions where the respondents needed to choose the most and least important barrier/driver. These questions are: B1.1, B1.2, B2.1, B2.2, B3.1, B3.2, B4.1, B4.2, D1.1, D1.2, D2.1, D2.2, D3.1, D3.2, D4.1, and D4.2.

```
1  var selected_name;
2
3  Qualtrics.SurveyEngine.addOnPageSubmit(function()
4  {
5      var temp= this.getChoiceAnswerValue();
6      selected_name=this.getChoiceVariableName(temp);
7      var all_codes=this.getChoices();
8      var all_names=[];
9
10     for(let i=0; i<3; i++) {
11         all_names.push(this.getChoiceVariableName(all_codes[i]));
12     }
13
14     var unselected_names=all_names.filter(name => name!=
           selected_name);
15
16     Qualtrics.SurveyEngine.setEmbeddedData('Unselected1',
           unselected_names[0]);
17 });
18
19 Qualtrics.SurveyEngine.addOnReady(function()
20 {
21     /*Place your JavaScript here to run when the page is fully
           displayed*/
22
23 });
24
25 Qualtrics.SurveyEngine.addOnUnload(function()
26 {
27     /*Place your JavaScript here to run when the page is unloaded*/
28
29 });
```

In line 10, the "i" will have to be changed accordingly to the number of answer options of the question.

${B1.1/ChoiceDescription/1}

This Piped Text is the output of the Carry Forward Logic of Qualtrics. This allows the editor to carry forward the choices done before in a question and bring them into a future question in the survey (Qualtrics, n.d.-a). In this case, the editor has employed the function to carry forward the available choices from B1.1, B1.2, B2.1, B2.2, B3.1, B3.2, B4.1, B4.2, D1.1, D1.2, D2.1, D2.2, D3.1, D3.2, D4.1, and D4.2 (when the respondent chooses the most and least important driver/barrier). Then, by applying Display Logic, which is another built-in tool from Qualtrics, the editor was able to hide the selected choice in the questions: B1.3, B1.4, B2.3, B2.4, B3.3, B3.4, B4.3, B4.4, D1.3, D1.4, D2.3, D2.4, D3.3, D3.4, D4.3, and D4.4. These questions asked the respondents to compare the other barriers/drivers to the most important or least important barrier/driver previously chosen. With this function, the previous choices did not appear in the answer options of these questions.

C.2. QUESTIONNAIRE

A.1 OPENING STATEMENT

Dear Sir/Madam,

You are cordially invited to participate in a research study titled **“Adoption of blockchain technologies in the pharmaceutical supply chain to combat the distribution of falsified medicinal products for human use”**.

According to the World Health Organization, the distribution of falsified medicinal products is **increasing** at an alarming rate, and is responsible for **tens of thousands of deaths** every year. Applying blockchain technology to the pharmaceutical supply chain could **help combat** this issue due the technology’s features.

The purpose of this research study is to understand the **barriers** and **drivers** influencing the **adoption of blockchain technologies in the pharmaceutical supply chain** and **provide recommendations** on the topic for **blockchain technology developers** and/or **providers**.

This survey is part of the master thesis of Mariana Lopes Vieira from Delft University of Technology (TU Delft), The Netherlands, supervised by Dr J. Ubacht from TU Delft.

It will take you approximately **15-25 minutes to complete**. We hope you are willing to share your assessment, which is paramount to our study.

The survey follows the **Best-Worst Method** and consists of **2 steps**.
First, you will be asked to choose (from a provided list) the most and the **least important barrier** and **driver** per **category** (Technology, Organizational and Environment). These categories are described at during the survey.
Second, you will be asked to **rank the remaining barriers and drivers** from the list, **compared** to the **most and least important barrier and driver** chosen in the first step.
This allows the researcher to have a ranking of the barriers and drivers which will allow her to retrieve **meaningful insights** on how to overcome the barriers while leveraging the drivers of blockchain technology adoption.

As with any online activity the risk of a breach is always possible. To the best of our ability and knowledge your **answers** in this study will **remain anonymous**. We will minimize any risks by **not asking any personal data** such as name, address, email or nationality, and by presenting the data in aggregate form only, in Mariana’s Master Thesis report and any potential publications that might arise from it.

You are free to stop the survey at any time. However, **once submitted**, the answers are **cannot be deleted** as the survey is anonymous.

If you are interested in receiving more information about this research, you can contact m.lopesvieira@student.tudelft.nl at any time.

By clicking **"Next"** to continue this online survey, **you agree to this opening statement**.

Thank you in advance for your participation.

Kind regards,

Mariana Vieira

A.2 General Questions

Thank you again for your participation.

Even though this questionnaire is anonymous, we would like to ask you a **few general questions** about yourself and work experience to conduct a better statistical analysis.

This information will **not be individually shared**.

C

Q0 Do you work in the pharmaceutical industry or are you familiar with it?

- Yes, I currently work in the pharmaceutical industry
- Yes, I am familiar with the industry even though I do not currently work in the industry
- No, I am not familiar

Q1 What is your main **job position**?

- Junior Manager
- Middle Manager or Head of Department
- Senior Manager or Director
- Other:

Q2 What is your main **job scope**?

- R&D
- Production/Manufacturing
- Marketing
- Admnistration
- Technology
- Procurement/Purchasing
- Supply Chain/Logistics
- Other:

Q3 How many **years** of experience do you have in the pharmaceutical industry?

- Less than 1
- 1-5
- 6-9

- 10 or more

Q4 Which **role in the pharmaceutical supply chain** does your organization have?

- Raw Material / Packaging supplier
- Manufacturer
- Distributor (wholesaler, 3PL,...)
- Transportation
- Retailer (pharmacy, ...)
- Healthcare provider (hospital, clinic, ...)
- Regulatory Agency / Government
- Other :

Q5 Where is your organization **located**?

- Belgium
- France
- Germany
- Portugal
- Spain
- Switzerland
- The Netherlands
- UK
- Other:

Q6 What is the **size** of your organization?

- Less than 50
- 50-100
- 100-250
- 250 or more

C

A.3 WHAT IS BLOCKCHAIN TECHNOLOGY?

This video (courtesy of Blockchain Council) provides a brief introduction on **how can blockchain technology be employed and benefit supply chain management.**

According to the World Health Organization, the distribution of falsified medicinal products is increasing at an alarming rate, and is responsible for tens of thousands of deaths every year. Applying blockchain technology to the **pharmaceutical supply chain** can help combat this issue due the technology's features.

If you are already familiar with the concept of blockchain technology, feel free to continue without watching the video.

A.4 WHAT IS THE BEST-WORST METHOD?

In this questionnaire, we will follow the **Best-Worst Method**.
This is a **multi-criteria decision making** method, that allows to **rank the barriers and drivers** that will be presented to you.
A **barrier** is a condition that **influences** decision makers **not to adopt** blockchain technology in their organization.
A **driver** is a condition that **influences** decision makers **to adopt** blockchain technology in their organization.
The **barriers and drivers** have been divided into **three categories**: Technology, Organization and Environment.

The Method

In each category of barriers and drivers you will:

- **Be presented** with a **list of barriers/drivers** for the adoption of blockchain technology in the pharmaceutical supply chain found in the literature and validated by experts in the industry.

- **Choose** the most important barrier/driver when considering adopting blockchain technology in your organization

- **Choose** the least important barrier/driver when considering adopting blockchain technology in your organization

- **Indicate**, from **1-9** how much more you **prefer the most important barrier/driver chosen** compared to the **other barriers/drivers**.

- **Indicate**, from **1-9** how much more you **prefer the other barriers/drivers** compared to the **least important barrier/driver chosen**.

You will be guided along the way, with all the explanations and definitions to make it as comprehensible as possible.

B1 - BARRIERS INFLUENCING BLOCKCHAIN TECHNOLOGY ADOPTION

In this section, the focus is on the **barriers** that influence the **adoption of blockchain technology** in organizations from the following **list**:

Technology	Organization	Environment
Privacy Concerns	Perceived implementation costs	Environmental concerns
Security Concerns	Lack of knowledge of the technology	Lack of collaboration, communication and coordination in the supply chain
Data Governance	Lack of top management support	Lack of inter-organizational trust
Complexity	Lack of tools to implement and support the technology	Lack of Government standards and/or legislation
Compatibility/ Interoperability	Organization culture	Cultural differences between stakeholders

Click on "Read more" to see the **definitions**

- Read More

B1.1:
Suppose, as a **decision-maker** in your organization, you have the opportunity to **adopt blockchain technology**.

Of the following categories, which one is, in your opinion, the **MOST IMPORTANT category of barriers** you would consider when deciding whether to adopt blockchain technology or not?

- Technology
- Organization
- Environment

B1.2:
Of the following categories, which one is, in your opinion, the **LEAST IMPORTANT category of barriers** you would consider when deciding whether to adopt blockchain technology or not?

- Technology
- Organization
- Environment

B1.3:

You have selected **"${q://B1.1/ChoiceGroup/SelectedChoices}"** as the **MOST IMPORTANT** category of barriers.

Please indicate how much you **prefer "${q://B1.1/ChoiceGroup/SelectedChoices}" over the other categories of barriers.**

(E.g. if you select **9** for "${e://Field/Unselected1}", it means that **"${q://B1.1/ChoiceGroup/SelectedChoices}"** is **extremely more important** than "${e://Field/Unselected1}")

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${B1.1/ChoiceDescription/1}									
${B1.1/ChoiceDescription/2}									
${B1.1/ChoiceDescription/3}									

B1.4:

You have selected **"${q://B1.2/ChoiceGroup/SelectedChoices}"** as the **LEAST IMPORTANT** category of barriers.

Please indicate how much you **prefer each of the other categories of barriers over "${q://B1.2/ChoiceGroup/SelectedChoices}" .**

(E.g. if you select **1** for "${e://Field/Unselected2}", it means that "${e://Field/Unselected2}" is **equally important** as **"${q://B1.2/ChoiceGroup/SelectedChoices}"**)

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${B1.2/ChoiceDescription/1}									
${B1.2/ChoiceDescription/2}									
${B1.2/ChoiceDescription/3}									

B2 - TECHNOLOGICAL BARRIERS INFLUENCING BLOCKCHAIN TECHNOLOGY ADOPTION

In this section, the focus is on comparing the **Technological Barriers** that influence the **adoption of blockchain technology** in organizations.

The **barriers** and its **definitions** are the following:

- **Privacy concerns** - Depending on the architecture set-up, data might be more or less visible to others. Therefore, people might be concerned with the privacy of their data.
- **Security concerns** - Concerns with how safe is the system from facing malicious attacks.
- **Data governance concerns** - What data should be stored in blockchains, how such data will be collected and fed into the system and who should be responsible for data input and provision.

- **Complexity** - The complexity of technology implementation and the technology itself. Generally, a high degree of complexity confuses technology users and causes them to have difficulty in understanding and using it correctly.
- **Compatibility / Interoperability** - The lack of interoperability between blockchains and integration with existing IT systems can be difficult and can constrain a smooth data transfer.

B2.1:
Suppose, as a **decision-maker** in your organization, you have the opportunity to **adopt blockchain technology**.

Of the following **technological barriers**, which one is, in your opinion, the **MOST IMPORTANT** barrier when deciding whether to adopt blockchain technology or not?

- Privacy concerns
- Security concerns
- Data governance concerns
- Complexity
- Compatibility / Interoperability

B2.2:
Of the following categories, which one is, in your opinion, the **LEAST IMPORTANT** barrier when deciding whether to adopt blockchain technology or not?

- Privacy concerns
- Security concerns
- Data governance concerns
- Complexity
- Compatibility / Interoperability

B1.3:
You have selected **"${q://B2.1/ChoiceGroup/SelectedChoices}"** as the **MOST IMPORTANT** technological barrier.
Please indicate how much you **prefer "${q://B2.1/ChoiceGroup/SelectedChoices}" over the other barriers.**
(E.g. if you select **9** for "${e://Field/Unselected3}", it means that **"${q://B2.1/ChoiceGroup/SelectedChoices}"** is **extremely more important** than "${e://Field/Unselected3}")
Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${B2.1/ChoiceDescription/1}									
${B2.1/ChoiceDescription/2}									
${B2.1/ChoiceDescription/3}									
${B2.1/ChoiceDescription/4}									
${B2.1/ChoiceDescription/5}									

C

B2.4:

You have selected **"${q://B2.2/ChoiceGroup/SelectedChoices}"** as the **LEAST IMPORTANT** technological barrier.

Please indicate how much you **prefer each of the other barriers over "${q://B2.2/ChoiceGroup/SelectedChoices}" .**

(E.g. if you select **1** for "${e://Field/Unselected4}", it means that "${e://Field/Unselected4}" is **equally important** as **"${q://B2.2/ChoiceGroup/SelectedChoices}"**)

Scale measurement from 1 to 9 where:

1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${B2.2/ChoiceDescription/1}									
${B2.2/ChoiceDescription/2}									
${B2.2/ChoiceDescription/3}									
${B2.2/ChoiceDescription/4}									
${B2.2/ChoiceDescription/5}									

B3 - Organizational Barriers Influencing blockchain technology adoption

In this section, the focus is on comparing the **Organizational Barriers** that influence the **adoption of blockchain technology** in organizations.

The **barriers** and its **definitions** are the following:

- **Perceived implementation costs** - The investment required to acquire the technology and implement it within the organization.
- **Lack of knowledge of the technology** - The degree to which managers know about blockchain technology
- **Lack of top management support** - When managers do not believe in the technology it can be a true barrier for its implementation.
- **Lack of tools to implement and support the technology** - Lack of capabilities from the organization to implement and support the technology such as processes, training capabilities or infrastructure.
- **Organization culture** - The pattern of people's behaviors and practices within the pharmaceutical industry and within the organization can affect how firms respond to external pressures and makes strategic business decisions.

B3.1:

Suppose, as a **decision-maker** in your organization, you have the opportunity to **adopt blockchain technology**.

Of the following **organizational barriers**, which one is, in your opinion, the **MOST IMPORTANT** barrier when deciding whether to adopt blockchain technology or not?

- Perceived implementation costs
- Lack of knowledge of the technology
- Lack of top management support
- Lack of tools to implement and support the technology
- Organization culture

B3.2:

Of the following categories, which one is, in your opinion, the **LEAST IMPORTANT** barrier when deciding whether to adopt blockchain technology or not?

- Perceived implementation costs
- Lack of knowledge of the technology
- Lack of top management support
- Lack of tools to implement and support the technology
- Organization culture

B3.3:

You have selected **"${q://B3.1/ChoiceGroup/SelectedChoices}"** as the **MOST IMPORTANT** organizational barrier.

Please indicate how much you **prefer "${q://B3.1/ChoiceGroup/SelectedChoices}" over the other barriers.**

(E.g. if you select **9** for "${e://Field/Unselected5}", it means that **"${q://B3.1/ChoiceGroup/SelectedChoices}"** is **extremely more important** than "${e://Field/Unselected5}")

Scale measurement from 1 to 9 where:

1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${B3.1/ChoiceDescription/1}									
${B3.1/ChoiceDescription/2}									
${B3.1/ChoiceDescription/3}									
${B3.1/ChoiceDescription/4}									
${B3.1/ChoiceDescription/5}									

B3.4:

You have selected **"${q://B3.2/ChoiceGroup/SelectedChoices}"** as the **LEAST IMPORTANT** organizational barrier.

Please indicate how much you **prefer each of the other barriers over "${q://B3.2/ChoiceGroup/SelectedChoices}" .**

(E.g. if you select **1** for "${e://Field/Unselected6}", it means that "${e://Field/Unselected6}" is **equally important** as **"${q://B3.2/ChoiceGroup/SelectedChoices}"**)

Scale measurement from 1 to 9 where:

1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${B3.2/ChoiceDescription/1}									
${B3.2/ChoiceDescription/2}									
${B3.2/ChoiceDescription/3}									
${B3.2/ChoiceDescription/4}									
${B3.2/ChoiceDescription/5}									

B4 - ENVIRONMENTAL BARRIERS INFLUENCING BLOCKCHAIN TECHNOLOGY ADOPTION

In this section, the focus is on comparing the **Environmental Barriers** that influence the **adoption of blockchain technology** in organizations.

The **barriers** and its **definitions** are the following:

- **Environment concerns** - Blockchain technology requires a high level of energy consumption to maintain the network
- **Lack of government standards and/or legislation** - The lack of ability of relevant government agencies to provide aids and enact rules and regulations to encourage blockchain technology adoption
- **Lack of collaboration, communication and coordination in the supply chain** - Lack of collaboration and effective communication among supply chain partners with different and even contradictory operational objectives and priorities.
- **Lack of inter-organizational trust** - Unwillingness to share valued information between organizations
- **Cultural differences between stakeholders** - Communication and coordination challenges would be worse where supply chain partners are geographically dispersed with different cultures

B4.1:

Suppose, as a **decision-maker** in your organization, you have the opportunity to **adopt blockchain technology**.

Of the following **organizational barriers**, which one is, in your opinion, the **MOST IMPORTANT** barrier when deciding whether to adopt blockchain technology or not?

- Environment concerns
- Lack of government standards and/or legislation
- Lack of collaboration, communication and coordination in the supply chain
- Lack of inter-organizational trust
- Cultural differences between stakeholders

B4.2:

Of the following categories, which one is, in your opinion, the **LEAST IMPORTANT** barrier when deciding whether to adopt blockchain technology or not?

- Environment concerns
- Lack of government standards and/or legislation
- Lack of collaboration, communication and coordination in the supply chain
- Lack of inter-organizational trust
- Cultural differences between stakeholders

B4.3:

You have selected **"${q://B4.1/ChoiceGroup/SelectedChoices}"** as the **MOST IMPORTANT** environmental barrier.

Please indicate how much you **prefer "${q://B4.1/ChoiceGroup/SelectedChoices}" over the other barriers.**

(E.g. if you select **9** for "${e://Field/Unselected7}", it means that **"${q://B4.1/ChoiceGroup/SelectedChoices}"** is **extremely more important** than "${e://Field/Unselected7}")

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${B4.1/ChoiceDescription/1}									
${B4.1/ChoiceDescription/2}									
${B4.1/ChoiceDescription/3}									
${B4.1/ChoiceDescription/4}									
${B4.1/ChoiceDescription/5}									

B4.4:

You have selected **"${q://B4.2/ChoiceGroup/SelectedChoices}"** as the **LEAST IMPORTANT** environmental barrier.

Please indicate how much you **prefer each of the other barriers over "${q://B4.2/ChoiceGroup/SelectedChoices}" .**

(E.g. if you select **1** for "${e://Field/Unselected8}", it means that "${e://Field/Unselected8}" is **equally important** as **"${q://B4.2/ChoiceGroup/SelectedChoices}"**)

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${B4.2/ChoiceDescription/1}									
${B4.2/ChoiceDescription/2}									
${B4.2/ChoiceDescription/3}									
${B4.2/ChoiceDescription/4}									
${B4.2/ChoiceDescription/5}									

C

D1 - DRIVERS INFLUENCING BLOCKCHAIN TECHNOLOGY ADOPTION

In this section, the focus is on the **drivers** that influence the **adoption of blockchain technology** in organizations from the following **list**:

Technology	Organization	Environment
Privacy enhancements	Reduce operational costs	Stakeholder pressure to adopt blockchain technology
Security enhancements	Knowledge of the technology	Competitive pressure to adopt blockchain technology
Immutability	Top management support	Market dynamics
Traceability	Firm size	Government standards and/or legislation
Compatibility/ Interoperability	Brand protection	Customer Safety

Click on "Read more" to see the **definitions**

- Read More

D1.1:
Suppose, as a **decision-maker** in your organization, you have the opportunity to **adopt blockchain technology**.

Of the following categories, which one is, in your opinion, the **MOST IMPORTANT category of drivers** you would consider when deciding whether to adopt blockchain technology or not?

- Technology
- Organization
- Environment

D1.2:
Of the following categories, which one is, in your opinion, the **LEAST IMPORTANT category of drivers** you would consider when deciding whether to adopt blockchain technology or not?

- Technology
- Organization
- Environment

D1.3:

You have selected **"${q://D1.1/ChoiceGroup/SelectedChoices}"** as the **MOST IMPORTANT** category of drivers.

Please indicate how much you **prefer "${q://D1.1/ChoiceGroup/SelectedChoices}" over the other categories of drivers.**

(E.g. if you select **9** for "${e://Field/Unselected9}", it means that **"${q://D1.1/ChoiceGroup/SelectedChoices}"** is **extremely more important** than "${e://Field/Unselected9}")

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${D1.1/ChoiceDescription/1}									
${D1.1/ChoiceDescription/2}									
${D1.1/ChoiceDescription/3}									

D1.4:

You have selected **"${q://D1.2/ChoiceGroup/SelectedChoices}"** as the **LEAST IMPORTANT** category of drivers.

Please indicate how much you **prefer each of the other categories of drivers over "${q://D1.2/ChoiceGroup/SelectedChoices}" .**

(E.g. if you select **1** for "${e://Field/Unselected10}", it means that "${e://Field/Unselected10}" is **equally important** as **"${q://D1.2/ChoiceGroup/SelectedChoices}"**)

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${D1.2/ChoiceDescription/1}									
${D1.2/ChoiceDescription/2}									
${D1.2/ChoiceDescription/3}									

D2 - TECHNOLOGICAL DRIVERS INFLUENCING BLOCKCHAIN TECHNOLOGY ADOPTION

In this section, the focus is on comparing the **Technological drivers** that influence the **adoption of blockchain technology** in organizations.

The **drivers** and its **definitions** are the following:

- **Privacy enhancements** - Blockchain technology affords pseudonymity, meaning that all transactions are transparent, yet are not explicitly connected to real-world individuals or organisations

- **Security enhancements** - Blockchain technology ensures that information shared is essentially secure to avoid manipulation.
- **Immutability** - Information cannot be changed and removed from the blockchain without consensus.
- **Traceability** - Blockchain technology brings more visibility into the supply chain. Traceability is an important quality factor that can be augmented by applying blockchain technology and other existing technologies, such as IoT and RFID.
- **Compatibility / Interoperability** - When using the same blockchain platform, the technology allows data to be more interoperable. Thus, companies can easily share information with manufacturers, suppliers and vendors.

D2.1:
Suppose, as a **decision-maker** in your organization, you have the opportunity to **adopt blockchain technology**.

Of the following **technological drivers**, which one is, in your opinion, the **MOST IMPORTANT** driver when deciding whether to adopt blockchain technology or not?

- Privacy enhancements
- Security enhancements
- Immutability
- Traceability
- Compatibility / Interoperability

D2.2:
Of the following categories, which one is, in your opinion, the **LEAST IMPORTANT** driver when deciding whether to adopt blockchain technology or not?

- Privacy enhancements
- Security enhancements
- Immutability
- Traceability
- Compatibility / Interoperability

D2.3:
You have selected **"${q://D2.1/ChoiceGroup/SelectedChoices}"** as the **MOST IMPORTANT** technological driver.
Please indicate how much you **prefer "${q://D2.1/ChoiceGroup/SelectedChoices}" over the other drivers.**

(E.g. if you select **9** for "${e://Field/Unselected11}", it means that **"${q://D2.1/ChoiceGroup/SelectedChoices}"** is **extremely more important** than "${e://Field/Unselected11}")

Scale measurement from 1 to 9 where:

1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${D2.1/ChoiceDescription/1}									
${D2.1/ChoiceDescription/2}									
${D2.1/ChoiceDescription/3}									
${D2.1/ChoiceDescription/4}									
${D2.1/ChoiceDescription/5}									

D2.4:

You have selected **"${q://B2.2/ChoiceGroup/SelectedChoices}"** as the **LEAST IMPORTANT** technological driver.

Please indicate how much you **prefer each of the other drivers over "${q://B2.2/ChoiceGroup/SelectedChoices}" .**

(E.g. if you select **1** for "${e://Field/Unselected12}", it means that "${e://Field/Unselected12}" is **equally important** as **"${q://B2.2/ChoiceGroup/SelectedChoices}"**)

Scale measurement from 1 to 9 where:

1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${D2.2/ChoiceDescription/1}									
${D2.2/ChoiceDescription/2}									
${D2.2/ChoiceDescription/3}									
${D2.2/ChoiceDescription/4}									
${D2.2/ChoiceDescription/5}									

D3 - Organizational drivers Influencing blockchain technology adoption

In this section, the focus is on comparing the **Organizational drivers** that influence the **adoption of blockchain technology** in organizations.

The **drivers** and its **definitions** are the following:

- **Reduce operational costs** - Blockchain technology can help reduce operational costs by improving asset and inventory management, increase end-to-end visibility in the supply chain, etc.
- **Knowledge of the technology** - Is the degree to which managers know about a technology
- **Top management support** - When managers believe in the technology it is a driver for its implementation.
- **Firm size** - Bigger firms are more inclined to implement blockchain technology.

- **Brand protection** - Blockchain technology brings a tool for organizations to prove that their operations are legal and according to the norms

D3.1:
Suppose, as a **decision-maker** in your organization, you have the opportunity to **adopt blockchain technology**.

Of the following **organizational drivers**, which one is, in your opinion, the **MOST IMPORTANT** driver when deciding whether to adopt blockchain technology or not?

- Reduce operational costs
- Knowledge of the technology
- Top management support
- Firm size
- Brand protection

D3.2:
Of the following categories, which one is, in your opinion, the **LEAST IMPORTANT** driver when deciding whether to adopt blockchain technology or not?

- Reduce operational costs
- Knowledge of the technology
- Top management support
- Firm size
- Brand protection

D3.3:
You have selected **"${q://D3.1/ChoiceGroup/SelectedChoices}"** as the **MOST IMPORTANT** organizational driver.
Please indicate how much you **prefer "${q://D3.1/ChoiceGroup/SelectedChoices}" over the other drivers.**
(E.g. if you select **9** for "${e://Field/Unselected13}", it means that **"${q://D3.1/ChoiceGroup/SelectedChoices}"** is **extremely more important** than "${e://Field/Unselected13}")
Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${D3.1/ChoiceDescription/1}									
${D3.1/ChoiceDescription/2}									
${D3.1/ChoiceDescription/3}									
${D3.1/ChoiceDescription/4}									
${D3.1/ChoiceDescription/5}									

D3.4:

You have selected **"${q://D3.2/ChoiceGroup/SelectedChoices}"** as the **LEAST IMPORTANT** organizational driver.

Please indicate how much you **prefer each of the other drivers over "${q://D3.2/ChoiceGroup/SelectedChoices}" .**

(E.g. if you select **1** for "${e://Field/Unselected14}", it means that "${e://Field/Unselected14}" is **equally important** as **"${q://D3.2/ChoiceGroup/SelectedChoices}"**)

Scale measurement from 1 to 9 where:

1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${D3.2/ChoiceDescription/1}									
${D3.2/ChoiceDescription/2}									
${D3.2/ChoiceDescription/3}									
${D3.2/ChoiceDescription/4}									
${D3.2/ChoiceDescription/5}									

D4 - ENVIRONMENTAL DRIVERS INFLUENCING BLOCKCHAIN TECHNOLOGY ADOPTION

In this section, the focus is on comparing the **Environmental drivers** that influence the **adoption of blockchain technology** in organizations.

The **drivers** and its **definitions** are the following:

- **Stakeholder pressure to adopt blockchain technology** - Relates to the external environment that details the high and persistent requirements of various stakeholders or investors in the pharmaceutical industry to adopt or not the technology
- **Competitive pressure to adopt blockchain technology** - The degree to which the competition has adopted the technology
- **Market dynamics** - Refer to the continuous changing state of an environment that is highly competitive and complex
- **Government standards and/or legislation** - The ability of relevant government agencies to provide aids and enact rules and regulations to encourage blockchain technology adoption
- **Customer safety** - Blockchain technology can help patients know if their medicinal products are falsified or not and therefore improve their safety.

D4.1:

Suppose, as a **decision-maker** in your organization, you have the opportunity to **adopt blockchain technology**.

Of the following **organizational drivers**, which one is, in your opinion, the **MOST IMPORTANT** driver when deciding whether to adopt blockchain technology or not?

- Stakeholder pressure to adopt blockchain technology

- Competitive pressure to adopt blockchain technology
- Market dynamics
- Government standards and/or legislation
- Customer safety

D4.2:

Of the following categories, which one is, in your opinion, the **LEAST IMPORTANT** driver when deciding whether to adopt blockchain technology or not?

- Stakeholder pressure to adopt blockchain technology
- Competitive pressure to adopt blockchain technology
- Market dynamics
- Government standards and/or legislation
- Customer safety

D4.3:

You have selected **"${q://D4.1/ChoiceGroup/SelectedChoices}"** as the **MOST IMPORTANT** environmental driver.

Please indicate how much you **prefer "${q://D4.1/ChoiceGroup/SelectedChoices}" over the other drivers.**

(E.g. if you select **9** for "${e://Field/Unselected15}", it means that **"${q://D4.1/ChoiceGroup/SelectedChoices}"** is **extremely more important** than "${e://Field/Unselected15}")

Scale measurement from 1 to 9 where:

1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${D4.1/ChoiceDescription/1}									
${D4.1/ChoiceDescription/2}									
${D4.1/ChoiceDescription/3}									
${D4.1/ChoiceDescription/4}									
${D4.1/ChoiceDescription/5}									

D4.4:

You have selected **"${q://D4.2/ChoiceGroup/SelectedChoices}"** as the **LEAST IMPORTANT** environmental driver.

Please indicate how much you **prefer each of the other drivers over "${q://D4.2/ChoiceGroup/SelectedChoices}" .**

(E.g. if you select **1** for "${e://Field/Unselected16}", it means that "${e://Field/Unselected16}" is **equally important** as **"${q://D4.2/ChoiceGroup/SelectedChoices}"**)

Scale measurement from 1 to 9 where:

1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${D4.2/ChoiceDescription/1}									
${D4.2/ChoiceDescription/2}									
${D4.2/ChoiceDescription/3}									
${D4.2/ChoiceDescription/4}									
${D4.2/ChoiceDescription/5}									

END OF SURVEY

We thank you for your time spent taking this survey.
If you would like to know more about the research conducted, please contact Mariana Lopes Vieira by sending an email to m.lopesvieira@student.tudelft.nl

D

Bayesian BWM Implementation

D.1. Preparing the data from the survey into MATLAB

Once the gathering of responses to the survey was finished, an excel file was extracted with the answers from the questions that were useful to create the matrices that serve as input for the Bayesian BWM.

D.1.1. Importing the answers from Qualtrics

In Qualtrics, it is possible to filter the answers and questions one wants to import.

Therefore, only the answers of respondents that have finished the survey and had answered to the Question: "Do you work in the pharmaceutical industry or are you familiar with it?" with "Yes, I currently work in the pharmaceutical industry" or "Yes, I am familiar with the industry even though I do not currently work in the industry" were selected.

After this, the right columns, meaning the right questions, were selected in order to serve as input to the Bayesian BWM.

These questions were (according to section C.2): B1.3, B1.4, B2.3, B2.4, B3.3, B3.4, B4.3, B4.4, D1.3, D1.4, D2.3, D2.4, D3.3, D3.4, D4.3, and D4.4.

Once the right answers and questions were selected, the data was imported into an excel file which was then copied and opened with MATLAB.

D.1.2. Filling empty cells

Some of the cells of this file were empty, because each column corresponds to each category (technology, organization, environment), barrier and driver that the respondents had to attribute a number in order to compare with the previous chosen most important or least important category, barrier or driver, depending on the question. Therefore, if the respondent had chosen "technology" as the most important category, this option would not appear in the question asking to compare the other categories to the most important category (technology). Meaning that the column of "technology" would be empty for this respondent. (Kouhizadeh et al., 2021)

In order to solve this, the empty cells needed to be replaced with "1" as this means that the factor is "equally important" as the one it is being compared to which is possible to do with MATLAB when importing the data.

D.1.3. IMPORTING THE DIFFERENT MATRICES

The second step is to import the different matrices that will be the input for the Bayesian BWM. To do this, one matrix per set of comparison will be generated so that each set of Best-to-Others (BO) and Others-to-Worst (OW) are able to be input to the MATLAB code for the Bayesian BWM found in the following website:

http://bestworstmethod.com/home/software/.

Once this is done, the average weights and probabilities are generated for the categories of barriers and drivers and then for each set of barriers and drivers per category as shown in chapter **??**.

D

MATRICES OF BARRIER CATEGORIES

Table D.1: "Best-to-Others" (A_B) and "Best-to-Worst" (A_W) matrices of Barrier Categories (Technology (T), Organization (O), Environment (E)) per respondent (R).

R	**A_B**				**A_W**		
	T	**O**	**E**		**T**	**O**	**E**
1	9	1	3		1	9	1
2	5	1	4		1	5	4
3	7	1	3		7	9	1
4	9	1	7		1	9	1
5	7	5	1		1	5	7
6	1	9	9		1	1	1
7	1	5	1		9	1	3
8	4	1	2		2	1	1
9	9	1	9		7	8	1
10	1	8	9		9	1	7
11	1	5	5		8	8	1
12	6	1	6		1	6	6
13	1	6	5		8	1	6
14	1	1	3		3	3	1
15	1	5	3		5	1	3
16	1	5	5		5	5	1
17	1	7	9		9	6	1
18	6	1	8		7	8	1
19	7	1	4		4	8	1
20	1	7	3		7	3	1
21	1	6	8		9	1	7

MATRICES OF TECHNOLOGICAL BARRIERS

Table D.2: "Best-to-Others" (A_B) and "Best-to-Worst" (A_W) matrices of Technological Barriers (Privacy concerns (P), Security concerns (S), Data governance concerns (DG), Complexity (C), and Compatibility / Interoperability (CI)) per respondent (R).

R	A_B						A_W				
	P	S	DG	C	CI		P	S	DG	C	CI
1	9	7	5	1	2		1	7	5	9	2
2	6	6	6	1	6		5	5	5	5	1
3	2	4	1	7	5		1	4	9	7	5
4	7	2	5	1	5		1	6	4	8	4
5	4	5	6	7	1		7	6	5	1	4
6	5	5	1	7	8		1	1	1	1	1
7	9	1	5	6	9		9	9	1	6	8
8	8	5	5	1	2		1	2	4	4	4
9	9	1	9	8	9		8	8	1	8	7
10	8	9	5	1	6		8	1	9	7	7
11	9	6	1	9	2		7	5	7	1	6
12	8	8	7	1	7		8	7	1	9	9
13	7	1	6	8	7		6	9	7	1	6
14	1	1	1	4	4		4	4	4	1	1
15	1	1	2	2	5		5	5	2	2	1
16	7	1	6	2	4		7	5	5	1	5
17	7	6	8	1	7		7	8	1	9	7
18	6	6	8	1	6		7	7	1	8	7
19	5	2	6	1	5		1	1	1	7	6
20	7	4	5	5	1		4	5	1	6	7
21	7	1	4	1	7		5	1	6	7	5

MATRICES OF ORGANIZATIONAL BARRIERS

Table D.3: "Best-to-Others" (A_B) and "Best-to-Worst" (A_W) matrices of Organizational Barriers (Perceived implementation costs (PIC), Lack of knowledge of the technology (LK), Lack of top management support (LTMS), Lack of tools to implement and support the technology (LTIS), and Organization culture (OC)) per respondent (R).

R	**A_B**						**A_W**				
	PIC	**LK**	**LTMS**	**LTIS**	**OC**		**PIC**	**LK**	**LTMS**	**LTIS**	**OC**
1	6	4	1	1	1		2	1	4	5	9
2	8	7	1	6	2		1	6	8	7	8
3	1	4	4	4	1		9	4	4	4	1
4	9	6	1	6	7		6	5	9	5	1
5	1	5	2	4	2		2	1	5	4	5
6	7	8	6	1	4		4	4	4	5	1
7	1	1	1	1	1		5	5	5	6	1
8	2	1	1	5	1		1	1	1	1	1
9	8	1	8	8	8		1	8	8	6	8
10	8	1	7	9	8		8	7	8	7	1
11	6	5	1	5	7		6	5	1	4	9
12	6	6	6	6	1		6	1	6	6	6
13	1	6	7	8	7		9	7	8	7	1
14	4	4	1	2	2		1	1	4	1	4
15	1	1	2	2	4		4	2	2	2	1
16	7	7	6	1	4		7	6	5	5	1
17	1	8	6	5	9		9	6	7	5	1
18	1	7	8	7	8		8	7	6	7	1
19	4	7	1	5	4		6	1	9	5	6
20	7	1	5	6	7		4	4	6	4	1
21	1	7	8	8	5		6	2	6	1	7

MATRICES OF ENVIRONMENTAL BARRIERS

Table D.4: "Best-to-Others" (A_B) and "Best-to-Worst" (A_W) matrices of Environmental Barriers (Environmental Concerns (E), Lack of government standards and/or legislation (LGSL), Lack of collaboration, communication and coordination in the supply chain (LCCC), Lack of inter-organizational trust (LIOT), and Cultural differences between stakeholders (CD)) per respondent (R).

R	A_B						A_W				
	E	LGSL	LCCC	LIOT	CD		E	LGSL	LCCC	LIOT	CD
1	2	4	5	1	6		1	2	5	9	7
2	7	5	2	2	1		1	7	7	7	7
3	2	2	1	2	1		2	2	5	2	1
4	9	1	6	2	6		5	9	7	7	1
5	4	5	5	6	1		6	5	5	1	4
6	2	2	1	5	4		1	1	1	1	1
7	5	1	1	1	1		1	5	4	4	5
8	4	4	4	1	4		1	4	4	4	4
9	8	8	8	8	1		1	9	8	7	8
10	8	8	1	7	8		7	8	8	7	1
11	1	7	7	6	9		7	7	6	7	1
12	6	6	6	6	1		6	6	1	6	6
13	7	7	1	7	7		8	1	8	8	8
14	2	2	1	2	2		1	2	2	2	2
15	2	2	1	2	1		2	1	2	1	2
16	4	1	8	6	7		5	5	4	1	5
17	9	6	7	1	9		1	7	8	9	7
18	8	1	7	7	8		4	7	5	4	1
19	5	6	2	1	6		1	5	6	8	1
20	4	5	1	7	5		4	1	7	6	5
21	2	1	6	8	7		4	6	2	1	4

D

MATRICES OF DRIVER CATEGORIES

Table D.5: "Best-to-Others" (A_B) and "Best-to-Worst" (A_W) matrices of Driver Categories (Technology (T), Organization (O), and Environment (E)) per respondent (R).

R	**A_B**				**A_W**		
	T	**O**	**E**		**T**	**O**	**E**
1	9	1	4		1	9	4
2	5	1	8		1	6	2
3	1	8	1		9	8	1
4	9	1	7		1	9	7
5	7	5	1		1	5	7
6	1	8	9		1	1	1
7	1	1	1		1	1	1
8	4	2	1		1	2	3
9	9	9	1		9	1	9
10	1	8	8		7	1	8
11	7	1	8		6	1	7
12	6	1	6		6	6	1
13	8	1	7		8	8	1
14	2	1	2		1	2	2
15	2	1	2		2	2	1
16	1	5	3		4	1	5
17	1	8	6		8	6	1
18	1	4	5		5	4	1
19	1	1	4		5	1	2
20	1	7	7		7	4	1
21	1	6	7		7	1	5

MATRICES OF TECHNOLOGICAL DRIVERS

Table D.6: "Best-to-Others" (A_B) and "Best-to-Worst" (A_W) matrices of Technological Drivers (Privacy enhancements (PE), Security enhancements (SE), Immutability (I), Traceability (T), and Compatibility / Interoperability (CI)) per respondent (R).

R	A_B						A_W				
	PE	SE	I	T	CI		PE	SE	I	T	CI
1	9	7	1	2	5		1	7	9	2	5
2	5	5	1	5	8		5	5	5	5	1
3	8	8	1	8	1		8	8	9	8	1
4	9	2	2	1	2		1	8	8	9	5
5	7	5	5	1	2		1	5	5	9	7
6	5	1	9	5	8		1	1	1	1	1
7	1	1	1	7	8		1	1	1	6	8
8	5	7	5	1	5		5	1	4	5	5
9	8	1	8	7	7		7	8	8	8	1
10	9	8	7	1	7		9	8	1	7	7
11	8	1	2	7	7		9	9	1	9	8
12	6	1	6	6	6		6	6	1	6	6
13	8	7	9	9	1		1	8	9	9	9
14	1	1	4	1	4		4	4	2	4	1
15	1	1	2	2	2		1	1	1	2	2
16	7	1	5	7	7		5	6	6	1	7
17	8	7	8	1	6		7	5	1	8	6
18	2	2	2	1	2		1	1	1	2	1
19	6	4	7	1	2		5	7	1	8	6
20	7	2	7	6	1		6	1	7	6	7
21	7	1	2	1	5		1	4	7	5	2

D

MATRICES OF ORGANIZATIONAL DRIVERS

Table D.7: "Best-to-Others" (A_B) and "Best-to-Worst" (A_W) matrices of Organizational Drivers (Reduce operational costs (ROC), Knowledge of the technology (K), Top management support (TMS), Firm size (FS), and Brand protection (BP)) per respondent (R).

R	A_B					A_W				
	ROC	K	TMS	FS	BP	ROC	K	TMS	FS	BP
1	1	9	4	6	8	9	1	4	6	8
2	6	7	1	8	7	7	1	8	8	7
3	1	1	1	1	1	1	1	1	1	9
4	1	9	1	9	1	9	7	9	1	9
5	5	4	2	9	1	5	6	7	1	9
6	1	6	7	9	9	1	1	1	1	1
7	1	1	1	1	8	1	7	6	1	1
8	1	9	9	9	9	9	1	1	1	1
9	8	7	7	1	8	8	8	1	7	9
10	8	1	7	8	7	8	8	6	1	8
11	6	1	7	2	8	8	8	1	9	9
12	1	6	6	6	6	6	6	6	6	1
13	1	8	9	8	9	9	9	9	1	9
14	2	2	1	5	5	4	4	5	1	4
15	1	2	2	4	4	1	1	1	2	4
16	6	1	6	4	8	5	5	5	1	5
17	1	8	7	8	9	7	6	7	1	9
18	1	6	7	7	2	7	6	5	1	7
19	4	7	1	7	4	7	7	9	1	5
20	9	4	1	5	7	7	6	9	1	6
21	7	2	1	5	1	1	8	7	5	2

MATRICES OF ENVIRONMENTAL DRIVERS

Table D.8: "Best-to-Others" (A_B) and "Best-to-Worst" (A_W) matrices of Environmental Drivers (Stakeholder pressure to adopt blockchain technology (SP), Competitive pressure to adopt blockchain technology (CP), Market dynamics (MD), Government standards and/or legislation (GSL), and Customer safety (CS)) per respondent (R).

R	**A_B**						**A_W**				
	SP	**CP**	**MD**	**GSL**	**CS**		**SP**	**CP**	**MD**	**GSL**	**CS**
1	5	4	6	7	1		5	4	1	7	9
2	7	7	8	7	1		5	5	1	5	5
3	2	2	2	2	1		1	2	2	2	5
4	5	1	5	2	1		1	9	5	7	9
5	2	4	8	5	1		6	5	1	4	8
6	1	1	6	2	6		1	1	1	1	1
7	1	1	1	6	1		1	2	1	5	8
8	1	1	1	1	1		1	1	1	1	1
9	8	8	1	7	9		8	1	9	8	8
10	8	8	8	1	7		8	1	8	7	7
11	5	8	1	8	7		8	1	9	9	9
12	6	1	6	6	6		6	6	1	6	6
13	7	7	9	9	1		1	7	9	8	9
14	2	2	5	2	1		2	4	1	2	4
15	4	1	2	4	4		1	2	2	1	2
16	6	6	4	7	1		5	5	1	4	4
17	6	7	8	1	6		5	7	1	9	8
18	7	7	8	1	1		2	2	1	7	7
19	7	7	8	5	1		6	6	1	6	9
20	9	1	5	6	6		1	6	8	6	7
21	7	8	1	2	5		7	7	8	1	9

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