Blockchain technology in pharmaceutical supply chains: a transaction cost perspective

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Abstract

Purpose – Adopting new technologies to improve supply chain activities and processes is essential due to increasingly complex and dynamic business environments. Particularly in the pharmaceutical industry, high-quality standards must be met, requiring transparency and visibility in the supply chain. This research aims at investigating the implementation of blockchain technology in the supply chain of an Egyptian pharmaceutical company.

Design/methodology/approach – The research applies a single case-study approach building on the theoretical underpinnings of transaction cost economics. Twenty-five semistructured interviews were conducted with pharmacies and employees of the case company to identify the blockchain technologies' potential for pharmaceutical supply in Egypt. Further analyzing the frequencies of the codes, the authors elaborate on specific relationships between the observed practices.

Findings – The research revealed the potential benefits of adopting blockchain technology. Transaction costs are indeed positively impacted by reduced contracting costs, processing costs and lead times, also ensuring the safe delivery of medications. However, the findings also highlight obstacles related to running costs, awareness and company culture. Regarding supply chain governance, blockchain technology can enhance collaboration within the supply chain as well as with important stakeholders.

Practical implications – Insufficient management of pharmaceutical supply chains (PSC) may affect a company's reputation but also disrupt the patient's healing process due to temperature damage and counterfeit medicines. Blockchain governance, in this vein, can ensure a safer and more reliable supply of pharmaceutical products. For intraorganizational purposes, however, cloud solutions, barcoding and generally digital platforms are rated more frequently than blockchain solutions.

Originality/value – The present study contributes to an advanced understanding how blockchain technology supports PSC, particularly in an emerging country context like Egypt. It thereby confirms and extends previous research as well as adds to the theoretical underpinnings of digitalized supply chains.

Keywords Supply chain digitalization, Blockchain technology, Pharmaceutical sector, Semi-structured interviews, Case study

Paper type Case study

1. Introduction

Supply chains become increasingly digitalized, thereby fundamentally transforming related supply chain practices (Cole *et al.*, 2019). The digitalization of supply chains can be defined as an intelligent, value-driven and efficient process to generate new forms of revenue and business value for organizations and to leverage approaches with new technological and analytical methods (Büyüközkan and Göçer, 2018). Digitalized supply chains improve related capabilities by allowing companies to decrease operating costs and improve quality while increasing sales revenue through expanding market shares, developing new products that meet customer needs, and creating a strategic advantage that improves all business operations (MacCarthy and Ivanov, 2022). In this context, blockchain applications in the supply chain have received high attention. Thus, utilizing blockchain technology within supply chain activities can significantly improve performance (Bischoff and Seuring, 2021).

Companies have already started implementing blockchain technologies throughout their supply chains (Seebacher and Schüritz, 2017). The advantage is that blockchains can establish a reliable and secure system that ensures transparency and immutability of data, while smart contracting enhances operational performance (Pournader *et al.*, 2020). Blockchains can further help supply chains to improve end-to-end data transparency, reduce costs and risks, and enhance sustainable operations (Saberi *et al.*, 2019). Hence, blockchain technology is promising for application in the pharmaceutical industry as they require more efficient and responsive supply chain handling techniques; insufficient supply chains could affect a company's reputation and customer satisfaction (Al-Hawary *et al.*, 2017). Pharmaceutical supply chains (PSC) deliver medicines and drugs to multiple stakeholders, such as pharmacies, hospitals and patients. With the ongoing COVID-19 pandemic, the shortage of medicine supplies has placed PSC at the top of several governments' priorities (Ghadge *et al.*, 2022).

In addition, the sensitive nature of pharmaceutical products requires specific procedures to preserve medical goods from any damage resulting from a temperature change (Atanasov *et al.*, 2015). To prevent the disruption or even worsening of the patient's healing process, regulatory bodies responsible for monitoring the safety, quality and effectiveness of drugs place high requirements on actors in PSC (Al-Hawary *et al.*, 2017). However, despite those strict policies by regulatory bodies, counterfeit drug incidents are still rising (Ghadge *et al.*, 2022). The issue of medicine fraud is particularly urgent in developing countries due to lower income, often weaker regulatory systems and higher corruption. In Egypt, for instance, the World Trade Organization estimates that up to 10% of the sold drugs are fake (WTO, 2018). In this vein, blockchain technologies feature a high potential to combat the lack of transparency and visibility within PSC (Ghadge *et al.*, 2022).

The use of blockchain technology may also affect transaction costs in the Egyptian pharmaceutical industry. Schmidt and Wagner (2019) already analyzed blockchain applications from the perspective of transaction cost economics (TCE). While shared information on a blockchain platform allows all supply chain members to update, integrate and participate in any transaction, research indicates that using blockchains can reduce or eliminate transaction costs (Queiroz *et al.*, 2020; Schmidt and Wagner, 2019). However, the current literature does not provide broad empirical evidence about the relationship between blockchain-based supply chain applications and related transaction costs. Therefore, this article uses a qualitative content analysis approach (cf. Mayring, 2015) to assess which supply chain management (SCM) practices can be affected by implementing digital technologies and how transaction cost theory can explain related effects.

To answer the research question of how blockchain applications can affect transaction costs in the pharmaceutical industry, we collect empirical data through a qualitative case study design in Egypt (cf. Yin, 2009). Case studies are particularly well suited for complex structures as they allow intense interaction with the informant and draw on multiple sources of information, leading to robust data (Eisenhardt and Graebner, 2007). The results reveal that blockchain technology allows companies to gain more visibility and control over their processes, get more accurate information, connect easier with partners, follow new demand patterns more quickly and decrease the levels of spoilage of medications. Transaction costs are positively impacted by reduced contracting costs, processing and lead times, also ensuring the safe delivery of medications that maintain the companies' brand image and reputation. In turn, setup and running costs may be increased through new infrastructure and the storage database size. In addition, users still fear being exposed to the network.

Interestingly, blockchain solutions are rated less important for internal process management practices where cloud solutions, barcoding and generally digital platforms prevail. The present study contributes to the understanding how blockchain technology supports supply chain practices in PSC, particularly transferring the findings to an emerging country context like Egypt. It thereby provides a more comprehensive view on blockchain applications in PSC, tackling all theoretical dimensions of Pournader *et al.* (2020) general framework. The present study thus confirms previous research but also shows contradictions when applying blockchain solutions, adding to an advanced understanding on governing PSC. The remainder is structured as follows. Section 2 provides an overview of the literature with a particular emphasis on TCE, while Section 3 presents the research design. Section 4 presents the findings of the empirical analysis, which are discussed and concluded in Section 5.

2. Literature background

2.1 Blockchain technology in pharmaceutical supply chains

Blockchain, a distributed ledger shared among parties in a peer-to-peer network, consists of a linked sequence of blocks (a storage unit of a transaction), holding timestamped transactions secured by public-key cryptography (Seebacher and Schüritz, 2017). Once an element is appended to the blockchain, it cannot be altered, turning the blockchain into an immutable record of past activities. Based on these technical characteristics, it has been used in many application fields, such as the Internet of Things (IoT) or SCM. For example, blockchains can enhance traceability in safety-sensitive areas such as medicine and food supply (Blossey *et al.*, 2019). Related benefits are cost reduction, sustainability and risk management (Kshetri, 2018). Generally, blockchains are auditable by providing transparency, security, integrity, authenticity and privacy to enhance SCM. In addition, combining blockchain-enabled architectures and IoT improves the selective export of data communications, facilitating data management and analysis in operations (Casino *et al.*, 2019). Thereby, blockchains can provide solutions to enhance trust and promote the relationships between buyers and suppliers, supporting other parties in the supply chain (e.g. operator-supplier or financial institution-buyer) (Treiblmaier, 2018).

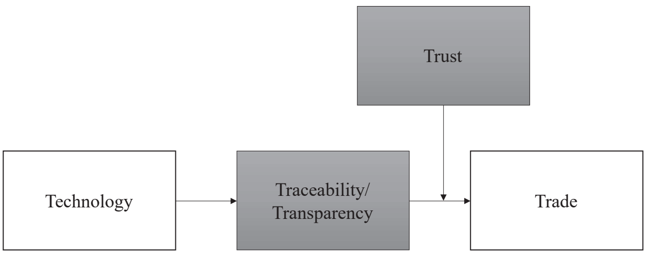
Blockchains further support more advanced concepts, such as smart contracts. A blockchain-based smart contract is a contract between two or more parties that is stored and digitally executed on the blockchain (Cong and He, 2019). According to Szabo (1997), a smart contract is a programmable contract that can be understood as an automatically executed clause contract; when the blockchain reaches a predetermined state, the contract will be automatically executed. Smart contracts are thus "computerized transaction agreements that enforce contract terms" (Szabo, 1997). Since smart contracts are entities on a distributed blockchain network, they can eliminate the need for trusted authorities to execute contracts (Christidis and Devetsikiotis, 2016) and reduce transaction costs. Based on the principle of decentralization to eliminate intermediaries, smart contracts are essential blockchain applications that can automatically transfer assets in an automated manner when certain conditions are met (Cong and He, 2019). They are also reconfiguring several business models such that producers and consumers can trade without intermediaries.

Particularly in the pharmaceutical sector, implementing blockchain technology can have a significant impact. Tapscott and Tapscott (2017) illustrated how the technology could help the sector to ensure information exchange within different processes and decreases the transaction costs incurred by contractual issues related to confidentiality. In this vein, active collaboration through blockchain systems increases trust and integrity between several stakeholders. Similarly, Sylim (2018) showed that applying a surveillance blockchain system will increase traceability and transparency for all stakeholders in the sector. To improve healthcare processes and services more generally, Hasselgren *et al.* (2020) found that electronic health records are the most targeted areas using blockchain technology. Bamakan *et al.* (2021) further studied how blockchains can meet the requirements of cold pharmaceutical chains in assuring digital identity, serialization and traceability, data integrity, transparency, and waste management. Recently, Badhotiya *et al.* (2021) proved that blockchain technology could increase trust and transparency in the pharmaceutical sector by recording transactions between various parties. Despite the increasing interest in pharma blockchains, however, it can be noticed that there is a lack of using this technology, especially in a developing country's context (cf. Kshetri, 2021).

To map existing research in PSC, Pournader *et al.* (2020) general framework on blockchain applications in supply chains can be used. They distinguish between four clusters, namely technology (addressing connectivity and security issues), trust (decentralizing supply chain data and providing proof of identity for supply chain transactions), trade (financial transactions and supply chain finance) and traceability/transparency (ensuring sustainable supply chain operations as well as inventory traceability and safety) (see Figure 1). For applications in PSC in particular, extant literature so far focused on studying trust and traceability/transparency issues while studies on technology and trade are underrepresented. To address these gaps and provide a more comprehensive view on blockchain applications in PSC, the present study aims at tackling all dimensions of Pournader *et al.* (2020) framework.

2.2 Theory background of transaction cost economics (TCE)

TCE explicitly views the firm and markets as governance structures that differ in transaction costs. Specifically, Coase (1937) proposed that the costs of conducting economic exchange in a market may exceed the costs of organizing the exchange within a firm under certain conditions. In this context, transaction costs are the "costs of running the system," which include *ex ante* costs, such as drafting and negotiating contracts, and ex-post costs, such as monitoring and enforcing the contractual agreement. Williamson (1975) has augmented Coase (1937) initial framework by suggesting that transaction costs include both the direct costs of managing relationships and the possible opportunity costs of making inferior governance decisions. Williamson (1975) microanalytical framework rests on the interplay between two main assumptions of human behavior (i.e. bounded rationality and



Source(s): Figure courtesy of Pournader *et al.*, 2020

Figure 1.
Blockchain applications in supply chains

opportunism) and key dimensions of transactions (i.e. asset specificity, transaction characteristics and uncertainty). The transaction is the TCE's unit of analysis and is understood as the exchange of information, goods or services (Williamson, 1975, 1985).

Three key constructs (i.e. asset-specific investments, transaction characteristics and uncertainty) within transaction cost theory directly influence the transaction costs of economic exchange (Schmidt and Wagner, 2019). First, asset-specific (relationship-specific) investments contribute to specific exchange relationships (Rindfleisch and Heide, 1997). Williamson (1975) mentioned location, physical- and human-asset specificity. Second, transaction characteristics mainly include the frequency and volume of a transaction (Schmidt and Wagner, 2019). These are often neglected in empirical studies on transaction costs (Rindfleisch and Heide, 1997). Third, uncertainty refers to "unanticipated changes in circumstances surrounding a transaction" (Grover and Malhotra, 2003). Transaction cost theory considers two forms of uncertainty to drive costs: environmental uncertainty, due to potential regulatory, political or economic changes, increases the difficulty of drafting sufficient agreements before an exchange (Ireland and Webb, 2007) and behavioral uncertainty which occurs if one party's performance after a transaction is difficult to measure, often due to implicitly or explicitly generated information asymmetry.

According to TCE, opportunism and information asymmetries constitute vital problems in any transaction relationship (David and Han, 2004). As information asymmetry can support opportunistic behavior, companies will conceal information and influence transaction parameters to get an advantage (Ireland and Webb, 2007). For example, a company can deliberately conceal information about its quality management procedures to avoid liability and blame for defective products. Thus, TCE is an excellent choice for studying how transactions in interorganizational supply chain relationships and technology adoption affect costs and related governance models. Liu *et al.* (2019) highlighted that using blockchain technology will improve the relationship between supply chain entities, increasing efficient operations and reducing transaction costs. They confirmed the potential of blockchain solutions in reducing the transaction cost between supply chain partners and increasing profitability. Therefore, cost related elements are essential factors that must be considered while designing blockchain applications and systems.

2.3 Blockchain governance from a TCE perspective

Blockchains provide enterprises and customers a platform for online transactions; transactions on this basis do not require the use of intermediaries (traditionally, middlemen are used to ensure the security of transactions), thereby reducing transaction costs and the time lag caused by their governance (Durach *et al.*, 2021). Williamson (2008) notably advocated TCE as a lens for analyzing intermediaries and transactions, especially while blockchains foster disintermediation (Gruchmann, 2022). The blockchain consists of digital applications that enable companies and supply chains to track, trace and verify how goods are transferred and moved throughout the supply chain from manufacturers to retailers via distribution centers and logistics facilities without intermediaries (Cole *et al.*, 2019). This shared information on the blockchain platform allows all supply chain members to update, integrate and participate in any transaction (Fahimnia *et al.*, 2019). Many studies thus have proven that blockchain can play an essential role in improving transparency, security, traceability, integration and information sharing in the supply chain (Kshetri, 2018).

Bounded rationality and opportunism are mainly viewed as risks in the supply chain. Since blockchain-based trust replaces opportunistic behavior, it can reduce the cost of opportunism (Roeck *et al.*, 2020). Blockchain technology can overcome obstacles to traditional vendor-managed inventroy (VMI) methods, such as lack of security, integration difficulties and opportunistic behavior (Dasaklis and Casino, 2019). Blockchain technology thereby creates opportunities to reduce opportunism, information asymmetry, insecurity and ambiguity by disclosing transactions (Pankowska, 2019). Schmidt and Wagner (2019) believe that distributed ledger solutions belong to a subcategory of functional information technology (IT) systems because they reduce the bounded rationality during the transaction process in the interorganizational environment and enable better decision-making. Therefore, supporting the auxiliary effect of blockchains helps to avoid the cost of making wrong decisions. Perboli *et al.* (2018) found that understanding the entire supply chain and avoiding providing inaccurate or credible information can help reduce the chances of human error and forgery while improving predictive capabilities.

In the context of transaction cost theory, uncertainty includes behavioral and environmental uncertainty, which directly and indirectly affect transaction costs in the supply chain. Blockchain can reduce the uncertainty of behavior, for example, when the behavior and performance of trading partners are difficult to measure (Schmidt and Wagner, 2019). Blockchain can further provide an effective solution to meet the urgent need to improve safety, traceability and transparency (e.g. Tan *et al.*, 2018). Recording information at each stage of the supply chain can ensure good sanitary conditions and identify contaminated products, fraud and risks as early as possible (Kamilaris *et al.*, 2019). Blockchain technology can also realize the tracking and supervision of contract execution, reducing the cost of supervision and tracking under traditional conditions (Antonucci *et al.*, 2019). The use of blockchain technology in the supply chain leads to enhanced supervision and power enforcement, changes the traditional form of supervision and reduces costs. Transparent product sources can prevent fraud and counterfeiting, thereby saving costs associated with controlling and monitoring current and potential suppliers and ensuring product or service quality (Schmidt and Wagner, 2019).

In sum, blockchain technology can significantly influence information asymmetries, opportunism and uncertainty through transparency, traceability, data immutability and smart contracts. For example, in agricultural production, manufacturers and suppliers can store detailed information on raw material sales and purchases in the blockchain, including technical information and quantities of products visible to all stakeholders, eliminating information distortion in the supply chain (Caro *et al.*, 2018). Further, blockchain technology based on a decentralized database can effectively manage shared, unmodifiable information and reduce information distortion (Antonucci *et al.*, 2019). The use of blockchain technology thus solves the situation of "information asymmetry" among multiple stakeholders because traders are responsible for their actions when transacting on the blockchain.

3. Research methodology

Considering this study's objective, particularly to deepen the understanding of how blockchain applications can improve transparency and reduce transaction costs in the pharmaceutical industry, a single case study approach was used, as the nature, complexity and boundaries of the phenomenon are not completely understood (Yin, 2009). Although the potentials of blockchain technology are evident in the extant literature, how to develop, transfer and scale these potentials have not been addressed fully in the literature thus far, particularly in a developing country context like Egypt. In the Middle East and North Africa (MENA) region, Egypt is the largest producer and consumer of pharmaceuticals contributing 30% of the supply for this market (Blog.sina, 2021). The Egyptian pharmaceutical sector is currently facing critical challenges attributed to the governmental enforcement of drug pricing, the dominance of private multinationals in the market, the delayed implementation of a comprehensive increase in prices, the depreciation of the Egyptian pound and the widespread of counterfeit medicines (Moneim, 2020).

We, accordingly, conducted a single case study with one of the largest national pharmaceutical companies in Egypt and triangulated the findings with empirical data from interviews with pharmacies. The case company today employs 8,000 employees and exports medicines to over 50 countries worldwide, including tablets, syrups, hard gelatin capsules, ampoules, sachets, creams and other sterile products. The company already uses the prototype of a blockchain application to track products throughout the supply chain that customers, particularly the pharmacies, can access. This application is built to help customers check the legitimacy of the medications while helping the case company gather information regarding the usage of its products. The customers may scan the unambiguous identification tag embedded in the medication packages to access information regarding the unique tag identifier, product code, batch number, expiry date and manufacturer.

3.1 Data collection

Semistructured interviews have been conducted to collect empirical data in the field. Semistructured interviews “allow depth to be achieved by providing the opportunity on the part of the interviewer to probe and expand the interviewee’s responses” (Rubin and Rubin, 2011, p. 18). This research has formulated two interview groups. In the first group, fifteen interviews with pharmacies were conducted to collect data related to the current situation of Egyptian PSC. Each interview took between 45 and 60 min. In the second group, another ten interviews were conducted with the case company managers and employees to assess the main processes and activities needed for implementing blockchain technology and how the application would affect these activities. These interviews took between 60 and 120 min. All interviews were carried out in Arabic. In addition, the interviews were held with an interviewee topic guide, entirely recorded, transcribed and translated. Table 1 gives a brief overview and background about the interviewees.

3.2 Content analysis

The category system is the core of qualitative content analysis and constitutes the central tool of qualitative research. The premise of the subsequent coding is to gain new knowledge from the research materials and to specify the analysis through related categories (Mayring, 2015). It also contributes to intersubjectivity and helps others reconstruct or repeat the analysis

	Interviewees	Background/responsibility
I1	Warehousing Manager	is responsible for managing the information flows from orders received to accelerate the receipt and shipment of goods
I2	Purchasing Specialist	is responsible for obtaining the company’s several supplies
I3	Marketing Manager	is responsible for designing the company’s marketing campaigns and executing strategic marketing plans
I4	Supply Chain Coordinator	is responsible for demand forecasting, managing inventories, and purchasing materials and services
I5	Regulatory Affairs Manager	is responsible for qualifications for selling medical products
I6	Research Development Manager	supports the company’s objectives
I7	Chief Executive Officer (CEO)	guarantees business operations
I8	Distribution Manager	determines the routes of the products and implements sales actions defined in the sales strategy plan
I9	Supply Chain Manager	monitors the supply chain and logistics strategy
I10	Innovation and Digitalization Manager	evaluates new technologies for business processes

Source(s): Authors own work

Table 1. Interviewees

(Mayring, 2015). By categorizing the empirical data accordingly, the interview material was further divided into subcategories, so the recorded materials could be systematically investigated. In line with the theoretical underpinnings and related research questions, the study uses a deductive method for the first coding of main categories considering the previously defined categories of TCE. In the second step, subconstructs were built inductively when respondents mentioned them frequently regarding specific TCE theoretical dimensions. In sum, the coding was perused in an abductive manner. The coding scheme is displayed in Table 2.

In addition to the qualitative coding, the application of quantitative instruments during the analysis enhances the derived interpretations and helps researchers to better contextualize the findings (Frels and Onwuegbuzie, 2013). In this respect, the frequency of

TCE theoretical dimension	Analytical subcategories	Description
Blockchain benefits	Integration	Blockchain technology addresses the lack of integration between the current entities of the Egyptian supply chains
	Communication	Blockchain technology provides better communication with partners across the supply chain
	Transparency	In the blockchain, data regarding the medications' status is collected. Transparency throughout the supply chain makes detecting mistakes and those responsible for solving them more manageable
Opportunism	Counterfeit drugs	Blockchain technology helps medical firms to decrease medicine fraud risks
	Privacy concerns	Some companies still fear putting their information online – the threat of hacking by actors having superior control over the network
Uncertainty	Legal situation	The legal situation is still relatively uncertain. Blockchain systems, therefore, require a legal framework
	Network security	Decentralized systems feature a higher level of network failure security given by the large number of nodes storing data
Bounded rationality	Lack of trust	The blockchain's privacy model based solely on anonymity may result in a loss of trust, fearing that their identity will be uncovered
	Change resistance	The employee culture may hamper the implementation of the technology
ex ante costs	Setup costs	Blockchain systems require high initial costs for implementation, particularly when current systems are incompatible
	Contracting costs	Blockchain may reduce contracting costs through a trustless environment and smart contracts
Ex-post costs	Running costs	With a scalable system, the more data it stores, the more it requires storage and speed
	Control cost	Increasing the control over the firms' supply chain activities ensures the safe delivery of medication by monitoring the specific requirements of the medications regarding temperature and other aspects. In this vein, blockchain may help to decrease control costs
Information asymmetries	Visibility	Blockchain technology provides firms with more visibility across their supply chains
	Immutability	Blockchain technology provides authentic data that cannot be adjusted or altered

Source(s): Authors own work

Table 2.
Coding scheme

the observed SCM practices and related digital technologies were counted when named in same context. This approach allowed for structuring the relations among the constructs and deducing the strength of the observed relationships.

3.3 Quality procedures

According to Yin (2009), quality procedures concerning internal validity, external validity, construct validity and reliability must be in place when analyzing qualitative data. The transcript coding was performed by two researchers and cross-checked independently regarding internal validity. Comparisons with existing conceptualizations were conducted to target external validity, thus allowing for theory-led abstraction and a certain degree of theoretical generalization of the results (Riege, 2003). Construct validity was pursued by basing the analysis on sound conceptual underpinnings and strengthened by collecting data from multiple sources, particularly triangulating the findings of the two interview groups. Extending the qualitative analysis with quantitative instruments led to more reliable results (Frels and Onwuegbuzie, 2013), particularly exposing relevant parallels across the multiple analyses.

4. Findings

4.1 Current situation in egyptian PSC

Pharmaceutical suppliers are responsible for the medications until they reach the distributors' warehouses. Then, the medications' conditions are solely the distributor's responsibility as an intermediary. Unfortunately, nonprofessional distributors can spoil the medications due to improper transportation or storage, where temperature requirements are disregarded, or the medications have been left in the sun for too long. This can result in worsening the consumer's health. The case company faces this problem mainly within the national distribution of medications in Egypt. Within international trade, where most foreign importers of medication require the availability of data loggers inside each container, the company can track the transported goods from its warehouses to the factory of the importer. The marketing manager I3 stated that the company needs a tracking system in the local market to track and trace the shipments to the customers, as well as record storage activity yet.

The case company produces over 300 different types of medications supplied by over 1,000 suppliers. The material supplied passes multiple stages till it can be received successfully at the company premises. The considerable number of partners needs a unified database to ensure timely delivery. When the demand is generated at the pharmacies, it is not yet transmitted immediately to the factory. This delay significantly impacts the lead time, as most raw materials are imported from overseas. Even if the company has no delay in providing the public with the finished products or the company does not suffer from loss of sales problems, it still leaves room for improvement. The regulatory affairs manager I5 stated that the challenge of medication damage in the process of inbound transportation and storage at other facilities requires real-time data about the medication conditions and their surrounding temperature.

In general, the pharmaceutical industry suffers from the problem of counterfeiting medications, where other companies can imitate the products in large quantities, and trusted companies then sell them in the market under the names of these companies. As a result, the medications produced are ineffective; moreover, the unknown ingredients of the medication can affect consumers' health. The company can only discover imitations by re-testing the drugs. For that, the company chooses its distributors carefully to limit related risks. According to the regulatory affairs manager I5, the company must ensure authentic medications to protect its image in the market. According to the supply chain coordinator I4, IT systems should be used to decrease the risk of fake drugs. Original products must be recorded on a shared database to be easily checked by the consumer.

4.2 Blockchain technologies' relevance for PSC

Transparency: All interviewees consider the traceability of information in the manufacturing process and supply chain very important. The following quote clarifies this: *"Oh yes, of course, it is also important that you can understand [. . .]where something was manufactured. How was it made? How was the delivery? Cold supply chains until it was used in pharmacies, hospitals [. . .] this immutable information is, of course, very important in the process."* (I3). Correct quantities, ingredients and deliveries are critical to the patient. The importance of maintaining a cold chain for medical products and drugs was particularly emphasized in the interviews. *"This whole issue of the cold supply chain, not just tracking a container but tracking the status of a product through the supply chain, is, of course, relevant. From the consumer's point of view, you mentioned the topic of seals of approval; of course, it also plays a role"* (I8).

Counterfeit drugs: In this vein, the packages should be attached with an unambiguous identification tag that gives complete information regarding each package from the suppliers to the pharmacy. The customers thus can track the pharmaceutical products throughout the supply chain. The drug packaging could be scanned by a barcode through a mobile application, documenting where the drug ownership changes. The information record is delivered on the blockchain system in real-time, giving the company complete visibility regarding the medications and drug identification, tracing, verification and notification in case an illegitimate drug is found. CEO I7 stated that blockchain technology implementation would enhance customer satisfaction, as the company will interact with customers in case of any problems related to packaging or the product itself.

Integration and communication: The interviewees have elaborated on further benefits the blockchain technology through immediate and more accurate forecasts: *"the visibility it provides, starting from purchasing the raw material till the finished goods reach the customers, the control provided in the transportation and storage activities, the ability to make smart contacts with partners, providing a database of encrypted data that cannot be adjusted after entry, and the complete safety it provides through its trustless environment provided between partners"* (I9). Such an integrated system will provide complete visibility regarding medication exchanges, quantities ordered and forecasts and can reduce transaction costs. The supply chain manager I4 stated that blockchain technology would enhance active communication between the company and its partners; this system should include all upstream and downstream supply chain actors.

4.3 Barriers to blockchain implementation in PSC

Setup costs: First, the technical infrastructure has to be provided by the case company since there is no running network yet. The benefits of the technology for the company are within the investments so far. An interviewee states that higher investments are required for digitization in the corporate sector: *"Digitalization is costly, so it needs a lot of investment, and not every company can invest in the digital technologies, and that's quite the same situation for blockchain"* (I10). These investments relate primarily to the beginning of development and implementation when a new blockchain project is implemented within a company or in cooperation with several companies. This disadvantage represents a hurdle for many companies. A merger of several global players would also be helpful, for instance, to carry out larger pilot projects or to use blockchain technology in real applications (I7).

Running costs: All departments confirmed that applying blockchain technology might increase the company's running costs to a certain extent, particularly regarding the data storage on blockchains. On the one hand, much information needs to be recorded, such as the manufacturing, delivery and cold chains of medical and pharmaceutical products. On the other hand, the amount of data on a blockchain should be kept low. *"It's smart to avoid large amounts of data on the actual blockchain. Whenever possible, I would always recommend using the blockchain only for proof of authenticity and mapping the actual clear data off-chain in a classic database"* (I10). The lack of availability of a spacious database platform at the company to cope with the vast amounts of data that will be stored on the system accordingly represents a hurdle.

Lack of trust and privacy concerns: Another barrier to blockchain technology is a lack of trust in it: *"Trust in the technology itself is not already there"* (I4). In principle, some business sectors are skeptical about new technologies, and the pharmaceutical sector is no exception. Another disadvantage related to trust, especially for pharmaceutical companies, is the issue of the control or noncontrollability of the processes or the solution within the blockchain (I4). The public blockchain is often criticized from a company perspective: *"I lose my privacy if I go public. I don't have control over it"* (I9). However, the supply chain manager assumes this problem can be solved technologically in the next few years. Due to the decentralized peer-to-peer network, all network participants still have to give up control or commit to a consensus algorithm.

Legal situation: *"The legal situation is still relatively uncertain"* in Egypt (I10). Therefore, a change must be seen such that laws and data protection components provide answers in favor of this new technology. The innovation and digitalization manager speaks of necessary legal framework conditions, without which blockchain technology can only be used with difficulty: *"Legal framework conditions, but there is also a lot going on at the EU, in order to clarify who owns which information and which status contracts actually will have. Without legal certainty, blockchain systems will not exist on a broad scale."* (I10). These legal frameworks represent a hurdle for blockchain technology and, therefore, must be clearly defined.

Change resistance (internal and external): In addition, the company would need to train their employees on using and dealing with the new technology or start recruiting employees with better qualifications. The case company would need to work on spreading awareness regarding digitalized processes and the importance of innovation within the Egyptian market to educate downstream supply chain entities about the blockchain to help the new system succeed. All the interviewees agreed that the employees need training programs on implementing blockchain technology internally and externally. The main challenge while implementing a blockchain will be convincing and motivating all actors involved to use the technology because only some are willing to convert existing systems. Almost all experts take up this aspect to *"keep companies motivated to join the blockchain"* (I7).

4.4 Benefits of blockchain implementation for PSC

Visibility: All experts see visibility as a result of transparency within the blockchain as an advantage. Regarding sourcing, blockchain technology can track where the products come from and the quality of the raw materials (I2). When a company can better understand where its sourced products come from, a product's origin can be traced along a supply chain (I2). Therefore, it makes no sense for a company in the supply chain to provide false or manipulated information, as these can be verified. At the same time, visibility increases trust in a company, as it can demonstrate a transparent supply chain. The purchasing specialist stated that *"every year, they are becoming cheaper, and it is more, let's say, visible to make investments and implement them in more supply chains"* (I2).

Immutability: One of the most significant advantages of blockchain technology, on which all experts agree, is the security against manipulation (immutability) and the possibility of carrying out processes without intermediaries: *"The advantage is simply the unbelievable* *security against manipulation and traceability, which then makes it possible to design processes without intermediaries would normally be processed with intermediaries"* (I9). If certain information cannot be manipulated by any actor or a third party because the technical conditions of blockchain technology do not allow this, then this creates trust (I9). Trust in blockchain technology is accordingly becoming more important than trust in the business partner. The technical components of a blockchain enable security against manipulation, which applies to all actors and strengthens trust in the technology.

Contracting costs: Another advantage of blockchain technology is that processes can be carried out without intermediaries. The information and data are no longer bundled centrally, for example, on a server, but decentralized on each individual node in the network. The processes, thereby, can be made more efficient and cheaper (I10). There are increasing costs for network operation (see running costs) but no costs for larger intermediaries. At the same time, the processes are more efficient because each participating node can access the same information without obtaining permission from an intermediary actor. However, it should be mentioned that the efficient and cost-effective processes through blockchain technology were addressed by only some experts, which does not mean that the other two experts hold a contrary opinion.

Network security: Another aspect that comes from using one of these blockchain systems, regardless of whether private or public, is a high level of network security. I10 only takes up this aspect, but it is a logical conclusion from a decentralized system. A high level of network failure security is given by the fact that a large number of nodes, i.e. participants in the network, leads to a high level of redundancy (I10). The blockchain is replicated on a single node, so the truth is preserved. Individual nodes can be located anywhere in the world, such that there are no problems in the blockchain network in the event of a failure in certain regions. It is assumed that any node in the network is unaffected, and all the information at one or more nodes persists.

4.5 Blockchain's influence on transaction costs

The experts see the most significant potential for influencing (transaction) costs in applying smart contracts in blockchain systems. I9 speaks of automation through smart contracts in a supply chain: *"I think there is quite a lot of potential for blockchain, especially if we are talking about smart contracts that can also help to fully automate the supply chains*." Interviewee I10 also speaks of process automation across company boundaries. This aspect takes advantage of carrying out processes without intermediaries, which are also unnecessary in a smart contract. The application of smart contracts within a blockchain system can, in turn, become relevant for companies to standardize their processes. Taking up the potential to decrease contracting costs, as elaborated on in the last subsection 4.4, blockchain systems lead to more decentralized governance of PSC. Nonetheless, all conditions that constitute the successful completion of a contracted step (or the whole contract) need to be clearly agreed upon and measurable. Otherwise, the automatic execution of the smart contract would take a lot of work. As an essential contingency factor, high uncertainties may constitute potential problems for smart contracts and immutability, as blockchains are resistant to change.

The results also show that opportunism leads to higher transaction risks, particularly medicine fraud risks, requiring more effort to prepare for such risks, thus increasing transaction costs for building trust. As blockchain's visibility increases trust, transaction costs for building trust might decrease transaction costs; particularly in the long run, when new reputation is created, *ex ante* costs will fall. However, this radical transparency makes the data available to all, which can lead to protective behavior by the data provider, additional information asymmetries and even additional permissioning for data access. Thus, it is vital to have the right mindset of the users when starting blockchain projects.

Becoming a network member triggers specific investments concerning decentral storage, interfaces and a shared understanding of the participants. Many small and medium-sized Egyptian businesses probably need more financial resources to implement blockchain technology in their company, resulting from the high setup- and running costs (see subsection 4.3). In addition, current legal uncertainties as well as internal and external change resistance, point to still preferencing more centralized governance of PSC. Although or even because multinational companies dominate the Egyptian market, the experts agree that national companies need to invest more in blockchain technology to progress in applying this technology. While the success of blockchain applications relies largely on a PSC-wide adoption, more pilot projects should be implemented to research further possible uses of blockchain technology in practice.

Overall, the interviewees believe blockchain technology can reduce transaction costs and improve efficiency. For the specific application context of PSC in Egypt, the application of blockchain technology can positively impact transaction costs through a reduced level of opportunism and uncertainty. In addition, decreased information asymmetries may also lead to better performance due to fewer risks. In summary, the following effects can be reached.

(1) Integrating the company and the downstream supply chain members can provide the company with better demand forecasts.

(2) Providing more visibility and control regarding upstream activities may avoid medication damage.

(3) Blockchain technology can help the company prevent the counterfeiting of its medications. Additional serialization technology applied to packages decreases the risk of imitations at distributors and pharmacies.

(4) Blockchain technology allows customers to track their medications' status beyond ensuring the effectiveness of the medicine and potentially saving lives.

4.6 Digital technologies' influence on SCM practices

Considering the relationships between SCM practices and digital technologies, only a few studies conceptualized concrete causalities between them in PSC. By analyzing the empirical data in the context of the pharmaceutical industry, digital technologies can be assigned to single SCM practices according to their frequency (see Figure 2 and Table A1 in the Appendix). In this respect, the thickness of the arrows indicates how often the interviewees mentioned the relationships in the interviews. It becomes obvious that blockchain technologies are not the only way to operate digital platforms for SCM, but cloud solutions can also play a significant role for executing process management, stakeholder management and risk management practices. Accordingly, blockchain solutions are supposed to be embedded in a larger IoT infrastructure addressing mainly external functions such as collaboration and stakeholder management. This, in turn, stresses the relevance of blockchain solutions for decreasing transaction costs.

5. Discussion and conclusion

The present research aims at investigating the adaptation of blockchain technology in PSC by conducting a single case study on an Egyptian pharmaceutical company. Applying a qualitative-empirical research design, the paper assesses the current situation in Egyptian PSC. To do so, semistructured interviews were conducted with different Egyptian owners of pharmacies and managers from the case company. Following that, the case company deals with distributors, who act as intermediaries between the focal company and pharmacies and

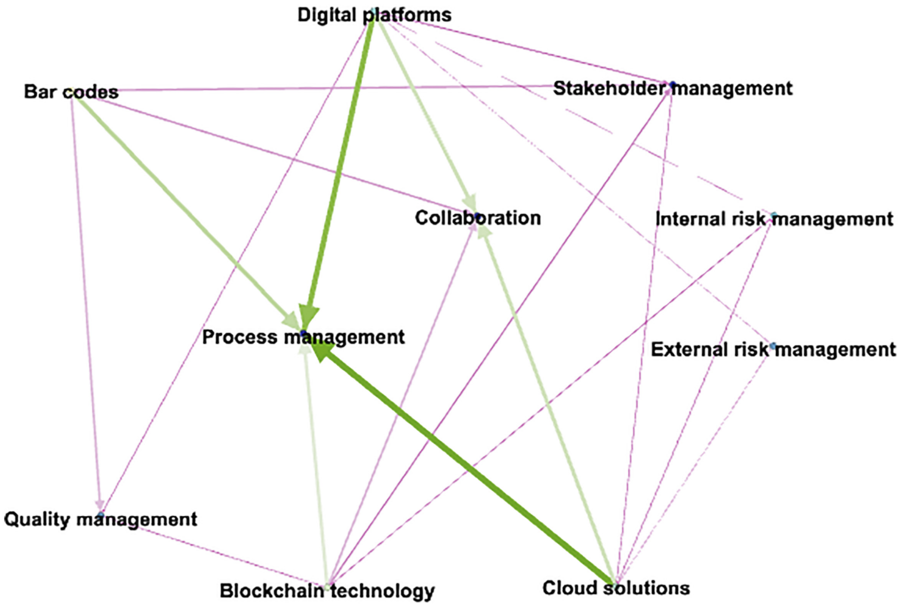


Figure 2.
Frequency analysis

Source(s): Authors own work

sell to hospitals, patients and other organizations. As a result of the interview analyses, the interviewees confirmed that the technology enhances the integration, coordination and communication between supply chain members, which can also lead to enhanced supply chain performance and reduced transaction costs. In addition, the external medicine fraud risks will be decreased. These findings confirm previous work (e.g. Paul *et al.*, 2021) and transfer them to the specific sector of the pharmaceutical industry. However, many barriers hinder the implementation in the Egyptian context, as employees might reject the change toward blockchain systems.

While the interviewees highlighted essential points related to blockchain features such as transparency and visibility leading to increased levels of trust (Saberi *et al.*, 2019), the present research extends the scope towards all four dimensions of Pournader *et al.* (2020) framework. In this vein, the study not just confirms the positive impact between the four clusters of their framework, but also observed existing paradoxes when implementing blockchain solutions (cf. Gruchmann and Bischoff, 2021). Particularly the tensions between transparency and privacy become apparent in the interviews. While I4 reports: *"I think the general benefit of blockchain technology is creating transparency*," interviewee I10 also stresses that transparency in a corporate context is not always desired. This leads to a conflict between the use of private and public blockchains. All data in the network can be viewed within public blockchains, while the data in a private blockchain is only withheld from a specific group of participants. Accordingly, greater transparency in terms of transaction history might lead to resistance from single business partners when rival business relations are present (Sternberg *et al.*, 2021).

From a theoretical TCE perspective, the interviewees demonstrated essential points related to transaction costs. *ex ante* costs of adopting blockchain technology will be high, especially when current systems are incompatible with blockchain applications. However, long-term technology adoption will reduce contracting costs when smart contracts are present. Ex-post costs show an ambiguous picture similarly. While control costs are supposed to fall (Bocek *et al.*, 2017), running costs remain high. Nonetheless, blockchain applications in PSC create opportunities to reduce opportunism, and information asymmetries alike (Pankowska, 2019), while (legal) uncertainty remains. In sum, disintermediation seems to substantially affect general transaction costs, while smart contracts affect control costs strongly. Removing third-party service providers to manage transactions between stakeholders provides an opportunity to save costs. In this vein, the present study transfers the empirical findings to an emerging country context like Egypt as well as adds to the theoretical underpinnings of digitalized supply chains.

From a practical perspective, a company should acknowledge the following points when implementing a blockchain system: first, training the employees to understand how they will use the new technology so that they can operate successfully without any human error, or starting to recruit new employees with better qualifications in order to cope with the technology implementation (Kumari *et al.*, 2021). Secondly, it should be explained why the company will shift to this technology, showing its benefits that can be an excellent opportunity for managing the external relationships of the company. Third, monitoring the implementation at each stage is necessary to ensure the technical implementation's success. Fourth, blockchain solutions should be embedded in larger IoT infrastructure managing internal processes of the company. Here, the integrating internal and external information from other entities in the supply chain supports benefiting from the technology, particularly for quality, process and risk management purposes.

While providing an opportunity to empirically advance our understanding of how blockchain technology can affect transaction costs in the pharmaceutical industry, the applied research design has limitations. In aiming to complete the picture on blockchain implementations, the interviews might have been biased by the personal expectations and desires of the interviewees. However, we used the indirect questioning technique to decrease the social desirability bias. Another area for improvement lies within the sample size, not allowing for statistical generalization of the findings; instead, in the tradition of qualitative research, we strived for generalization through theory-led abstraction of the findings, iteratively comparing data with transaction cost theory. Nonetheless, future research can build on the specific insights generated in this qualitative-explorative study and test the empirical results with survey research. Besides applying quantitative research, engaged methods such as action research have the potential to both refine and extend the present study's insights more closely.

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Appendix

Digital technology	SCM practices	Frequency
Bar codes→	Quality management	7
	Process management	12
	Stakeholder management	6
	Collaboration	6
Digital platforms→	Quality management	2
	Process management	15
	Internal risk management	1
	Stakeholder management	4
	Collaboration	11
	External risk management	1
Blockchain technology→	Quality management	2
	Process management	10
	Internal risk management	2
	Stakeholder management	5
	Collaboration	7
Cloud solutions→	Process management	17
	Internal risk management	2
	Stakeholder management	2
	Collaboration	11
	External risk management	1

Source(s): Authors own work

Table A1.
Frequency of codings

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