UNIVERSIDADE FEDERAL DO RIO DE JANEIRO

LUIZ OCTAVIO ALEIXO LUSTOSA ROSEMBERG

THE IMPACT OF THE BLOCKCHAIN ON TRANSACTION COST ECONOMICS

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ABSTRACT

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Since the arrival in 2008 of the first blockchain application, Bitcoin, a number of new types of applications has emerged. Those applications are set to impact the transaction cost economics theory, by reducing transaction costs and possibly changing governance modes in relationships across industries and supply chains. This study examines this impact by breaking down blockchain applications and transaction costs into categories and then establishing how each category of blockchain applications can impact each category of transaction costs. It also identifies the main technologies and antecedent factors that will play a vital role in the development of blockchain applications, and investigates the nature of this role. Finally, by conducting a series of one-on-one interviews with experts, this study compares the relationships derived from the literature with those discussed in the interviews, and points some differences between them. The study offers relevant contributions to this discussion. First, the study shows that Guaranteed Transactions is the type of blockchain application most associated with reducing transaction costs. Second, smart contracts are one key technological enabler to blockchain adoption, but the physical-digital interface, previously underdiscussed in the literature, surpasses governance issues as one of the most relevant factors to blockchain adoption.

Key words: Blockchain, Transaction Cost Economics, Dimensions of Transaction Costs, Categories of Blockchain Applications, Antecedent Factors

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1. INTRODUCTION

1.1. RELEVANCE

Since the Bitcoin was first proposed as an alternative, electronic payment system based on cryptographic proof instead of trust (NAKAMOTO, 2008), the popularity of bitcoin has exploded. In 2016, it was expected that the total value of bitcoin transactions would reach USD 92 billion dollars (IANSITI & LAKHANI, 2017). But the fact is that bitcoin is just the first "killer app" of the underlying technology, blockchain (ITO ET AL., 2017), which has the potential to fuel a host of other applications in fields as distinct as healthcare (HALAMKA ET AL., 2017) to utilities (BASDEN & COTTREL, 2017) and the auto industry (ALAM, 2016). With all the hype surrounding Bitcoin and blockchain, combined with its relative novelty, it is natural that researchers try to understand the impact of the technology on established academic fields. One academic field that is particularly apt to be impacted by the emergence of blockchain technology is that of transaction cost economics (TCE). Its basic idea is to assign modes of governance to transactions in order to economize on the sum of production and transaction costs, which are the costs to coordinate economic activity (WILLIAMSON, 1985). The reason why this theory has such a big potential to be impacted by the blockchain relies on the fact that opportunistic behavior (together with bounded rationality) gives rise to transaction costs (GROVER & MALHOTRA, 2003). The risk of opportunistic behavior, in turn, is influenced by information impactedness, or asymmetry (MCIVOR, 2009), meaning that some parties might have try to hide information or present distorted information to others in order to benefit themselves. Because the blockchain is a decentralized ledger where you cannot change information once it is inserted there (IANSITI & LAKHANI, 2017), it can be a solution to the trust problem (SHERMIN, 2017), reducing information asymmetry and therefore the risk of opportunistic behavior, potentially having a huge impact in transaction costs. The Figure 1 below summarizes this line of reasoning:

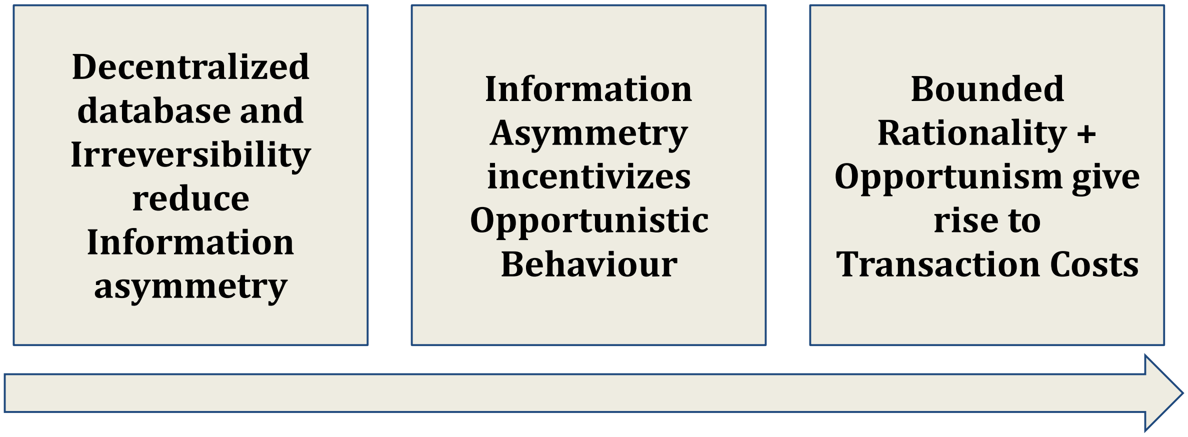

Figure 1: Expetected Blockchain's Impact on TCE
Source: The Author

The extant literature offers inconclusive advice on the relationship between the blockchain and transaction costs. Some, like TAPSCOTT & TAPSCOTT (2016) believe the blockchain will lower transaction costs the same way the internet did, increasing the potential for outsourcing. Others, like SHERMIN (2017) believe the blockchain, together with smart contracts will radically reduce transaction costs, but instead of outsourcing the result will be new forms of decentralized organizations that were not possible before. DAVIDSON ET AL. (2018) synthesizes previous views of the blockchain technology as either a general purpose technology that increases productivity or a transaction cost reducing technology that moves the modes of organization closer to markets rather than hierarchies. Then he proposes still a third view where the blockchain technology would an institutional technology, having a role equivalent of that of markets and hierarchies. The point here is that, while there are several authors agreeing about the potential impact of the technology on TCE, how that impact is going to happen is still an open question. There is, therefore, a need for further research to better understand the way that impact will actually play out.

1.2. OBJECTIVE

The main goal of this study is to understand the many different ways in which the blockchain can impact the TCE. Because the blockchain is a foundational technology (IANSITI & LAKHANI, 2017) the focus will be on a more practical level, on the applications of the blockchain, both existing and possible. Because the theory deals with both transaction costs and governance structures given those transaction costs, the impacts on both macro constructs must be considered. Also, since complementary technologies, like smart contracts, can be used in combination with the blockchain technology (IANSITI & LAKHANI, 2017) and several antecedent factors, like regulation, can impact the applications themselves (CASEY & WONG, 2017), those constructs must also be included in the analysis. Therefore, the main research question must be divided into four sub research questions:

1. How can blockchain affect transaction costs across different governance structures?
    a. How can different types of applications affect different types of transaction costs?
    b. How can the choice of governance structure be affected by the development of the blockchain?
    c. How the development and application of complementary technologies can impact the potential of blockchain applications?
    d. What antecedent factors can impact the development and adoption of blockchain applications?

1.3. METHOD AND DATA

To operationalize this research, first a review about the possible and existing applications of the blockchain was conducted, leading to a classification of applications in five categories that will be explained in the next chapter: identity systems, reputation systems, real time monitoring, access control and guaranteed transactions. Then, from the literature, a measure of transaction costs which divides them into four dimensions that will also be explained in the next chapter: effort, monitor, problem and advantage (GROVER & MALHOTRA, 2003). Having these categories, together with Williamson's (1985) four modes of governance this study can analyze the impact of the blockchain on TCE by studying the relations among them.

Then, as suggested by MORSE & FIELD (1996), this study has chosen a qualitative method for the research, because of the incipient nature of research on blockchain and the qualitative nature of the measures of transaction costs, conducting a series of one-on-one interviews with experts from the areas of finance, consulting, technological solutions and academy, in order to get different points of view on the subject.

1.4. CONTRIBUTION

The main contribution this study aims to bring to the blockchain and TCEis to study the impact of the blockchain on a more granular level. Instead of looking to the impact of the blockchain as whole and on all types of transaction costs at the same time, I first separated different types of applications and costs to understand how they relate to each other. Even though email and Facebook are both applications of the internet (IANSITI & LAKHANI, 2017), they are different among themselves, and have different kinds of impacts. The same is true for blockchain applications as different as Bitcoin (NAKAMOTO, 2008) is from Decentralized Collaborative Organizations (DAVIDSON ET AL., 2018). The same is true for transaction costs like the cost of establishing a relationship and monitoring a partner (GROVER & MALHOTRA, 2003), they are very different from each other even though both are transaction costs. By disaggregating those very different constructs and analyzing their relationships it could be possible in future studies to better understand the impact of the blockchain on TCE and understand which of the different views about the blockchain impact (DAVIDSON ET AL., 2018) is more likely to represent reality.

1.5. DISSERTATION STRUCTURE

In chapter 2, the existing literature about TCE, blockchain, and their relationship is discussed. In chapter 3 the research method is presented, including data collection, data analysis, validity and reliability. In chapter 4 are presented and discussed the findings of this research, starting with the relationships between variables based on the analysis of the interviews to present propositions about those relationships, including differences from what would be expected from the literature and a model representing those relationships on a macro level. In chapter 5 is presented the conclusion, including limitations of this study and suggestions for future studies.

2. THEORETICAL BACKGROUND

2.1. TRANSACTION COST ECONOMICS (TCE)

The study of TCE began with the question of why the coordination of economic activity is sometimes the work of the price mechanism (market) and sometimes the work of the entrepreneur (firm),and noted that those two are very different coordination mechanisms (COASE, 1937). Later, Williamson explained the problem of economic organization as the one of a task that has to be accomplished and can be organized in any of several alternative ways, or governance modes (WILLIAMSON, 1985). The transaction to which a governance mode will be assigned is the basic unit of analysis (WILLIAMSON, 2008), for which the most efficient governance mode needs to be chosen (GROVER & MALHOTRA, 2003).

Even though TCE deals originally with buyer-supplier dyads, if we accept a network as a "in between" form of markets and hierarchies (THORELLI, 1986) and a supply chain as a network (CARTER ET AL., 2015), then the understanding of why we assign transactions to governance structures has obvious implications for the configurations of supply chains as well.

2.1.1. Transaction costs

Williamson argues that the efficient allocation of governance structures to transactions should consider the total costs incurred in each alternative (WILLIAMSON, 1985). Those costs can be divided into two types of costs: Production costs and transaction costs, the latter being the "costs of negotiating, implementing and revising the contracts under which the company obtains its inputs" (EMERY & MARQUES, 2011). Because transactions vary in their attributes and governance structures in their costs and competences, the efficient alignment hypothesis predicts that different structures will be assigned to different transactions to achieve a transaction cost economizing outcome (WILLIAMSON, 2010). Then, the answer to Coase's question on why firms exist is that they exist because of both economies of scale and specialization and ability to reduce transaction costs (THORELLI, 1986).

2.1.2. Assumptions

In order to assign governance structures to transactions the theory relies on some assumptions about the world and the type of transaction analyzed: bounded rationality, opportunism, asset specificity, uncertainty and frequency of transactions.

Bounded rationality assumes that cognitive competence is a limited resource, so modes of governance that make large demands of cognitive capacity will tend to be costly. For that reason all complex contracts will be incomplete (WILLIAMSON, 2008).

Opportunism assumes that economic actors, in order to seek their self-interest, may engage in incomplete or distorted disclosure of information(WILLIAMSON, 1985). The existence of information impactedness, or the fact that either the buyer or supplier may have more knowledge than the other (MCIVOR, 2009) may incentivize that behavior. In supply chains, the lack of complete visibility of the supply chain beyond a certain range (CARTER ET AL., 2015) may also influence opportunistic behavior. Bounded rationality, together with opportunism, will give rise to transaction costs (GROVER & MALHOTRA, 2003).

It is possible, however, to attenuate the threat of ex-post opportunism by employing cost effective safeguards (WILLIAMSON, 2008). Dyer has shown in the context of American and Japanese automakers how demonstrating commitment to future interactions, engaging in intensive information sharing (which reduces information asymmetry) and using self-enforcing safeguards like reputation and financial hostages can reduce the risk of opportunism (DYER, 1997). Emery and Marques showed that the risk of opportunism can be lowered in the case of raw material inventories by employing financial hostages (EMERY & MARQUES, 2011).

Asset specificity is a variable associated with parties in a transaction decidingif the technology used to supply the good/service in question will be a general purpose (less efficient) or special purpose (requires investment in transaction specific assets, that cannot be easily redeployed to other purposes) technology (WILLIAMSON, 1985). This condition of specificity may develop at the outset of the relation or only latter (WILLIAMSON, 2010).

Over time, even if the initial condition in which the contracts were made had numerous possible suppliers, because of the investment in non-redeployable assets, a condition of small numbers bargaining develops (MCIVOR, 2008; GROVER & MALHOTRA, 2003) and the parties become over time effectively locked in a condition of bilateral monopoly in what Williamson called the fundamental transformation (WILLIAMSON, 1985), increasing the risks of opportunistic behavior.

Another assumption is that uncertainty is present in a high enough degree to make it impossible to enumerate all possibilities and possible responses to them in advance (WILLIAMSON, 1985). In general, transaction costs are higher under conditions of high asset specificity and high uncertainty (GROVER & MALHOTRA, 2003) for any governance structure, but different governance structures will adapt to uncertainty in different ways (Hayek's marvel of the market and Barnard's marvel of hierarchy, for instance) (WILLIAMSON, 2008) and they differ in their capacity to respond effectively to disturbances (WILLIAMSON, 1985).

Frequency of transactions is relevant because of reputation effects and setup costs (WILLIAMSON, 2008). Specialized governance structures come at a greater cost (WILLIAMSON, 1985) than standard ones, but if frequency is higher those setup costs can be shared among more unitary transactions. The reputation built among buyers and suppliers over frequent transactions will prevent opportunistic behavior because of the increased risk/cost of losing the business (DYER, 1997).

2.1.3. Types of governance structures

While markets and hierarchies represent governance mechanisms in their purest mode (GROVER & MALHOTRA, 2003), hybrid structures exist with characteristics in between them. The three critical dimensions used to describe governance modes are incentive intensity (strong in autonomous stages and weak in cost plus reward schemes), administrative command and control (strong if successive stages are subject to coordination and dispute resolution by a common boss) and contract law regime (strong under court ordered and weak under private ordered regime) (WILLIAMSON, 2010; WILLIAMSON, 2008).

While the TCE originally envisioned the governance modes for buyer supplier relationships, it can be extended to the governance of the whole supply chain, were the limits of the governance structures can be defined using the visibility of the focal agent concept (CARTER ET AL., 2015). Each mode of governance in a supply chain will have its own mechanisms for coordinating the flow of materials and services through steps in the value chain (GROVER & MALHOTRA, 2003).

A. Market Governance

Market governance is characterized by strong incentive intensity, weak command and control at the interface and strong contract law regime (WILLIAMSON, 2010). They coordinate the flow of materials and services using demand and supply forces (GROVER & MALHOTRA, 2003). They rely on classic contracts to describe all (which presumably are relatively few) future contingencies on the transaction (WILLIAMSON, 1985).

B. Hybrid Governance

Hybrid forms of governance are located between markets and hierarchies on all three critical dimensions/attributes (WILLIAMSON, 2008) and entail long term contracts for which credible commitments are critical (WILLIAMSON, 2008). They can be divided into bilateral and trilateral forms of governance. A trilateral for of governance will rely on neoclassical (long term) contracts where the parties will rely on arbitration of a third party to affect adaptations to the contract (WILLIAMSON, 1985). A bilateral form of governance will rely on relational (long term) contracts where the focus of the adaptations is less the original contract and more the relationship as a whole (MACNEIL, 1978). The parties will establish some areas, like quantities, where the risk of opportunistic behavior is smaller, that can be automatically altered without having to alter the contract itself (WILLIAMSON, 1985).

C. Hierarchy

Hierarchies are characterized by weak incentive intensity, strong administrative command and control at the interface and weak contract law regime (WILLIAMSON, 2010). They coordinate the flow of materials and services at a higher level of management hierarchy (GROVER & MALHOTRA, 2003). They are considered the “organizational form of last resort” when all else fails (WILLIAMSON, 2008).

2.1.4. Choosing between governance structures

Generally, lower transaction costs favor markets, while higher transaction costs favor hierarchies (GROVER & MALHOTRA, 2003). In transactions with low asset specificity, where the fundamental transformation is avoided, and the risks of opportunism are lower, the market governance is indicated (WILLIAMSON, 1985). At a point where asset specificity increases to where economies of scale no longer exist, and the risks of opportunism are the highest, unified ownership, the organizational form of last resort, is indicated (WILLIAMSON, 2008, WILLIAMSON, 1985). For medium levels of asset specificity, the hybrid forms are indicated. For transactions where asset specificity is not low, the higher the frequency of transactions the more diluted the setup costs will be and because setup costs for bilateral forms are higher but adaptation costs lower, they will have an advantage over trilateral forms of governance (WILLIAMSON, 1985).

Credible commitments and information sharing can also have a big influence on the choice of governance structure. A failure to provide safeguards might contribute to outsourcing failure (WILLIAMSON, 2008), because of their capabilities to reduce the risk of opportunism (DYER, 1997). The importance of information sharing is highlighted in the problem of "non-convergent expectations", where in a situation in which outsourcing is viable it doesn't happen because of a lack of ability to pool and communicate information to reach an agreement between parties (WILLIAMSON, 2008).

Finally, the choice between governance structures must consider other aspects besides the ones proposed by TCE. McIvor proposes a framework combining the resource-based view of the firm and transaction cost economics to decide on outsourcing, arguing that neither alone is sufficient (MCIVOR, 2008). Even Williamson suggests to look at the TCE assignments of make or buy as provisional, to be “revised by reason of system considerations” (WILLIAMSON, 2008).

2.1.5. Measuring transaction costs

While *"empirical research on transaction costs matters almost never attempts to measure such costs directly"* (WILLIAMSON, 1985, *page 22*), some measures have been proposed. In the context of American and Japanese automakers, Dyer proposed to measure transaction costs as the total number of individuals employed in procurement for production divided by the total value of the goods they produced (DYER, 1997). It has also been proposed to assess transaction costs as perceived by an informed party (GROVER & MALHOTRA, 2003). Such a measurement further operationalizes the TCE and allows for better comparisons between alternative governance structures in a given context.

Grover and Malhotra developed and validated a multidimensional conceptualization of transaction costs that relies on the perceptions of informed parties to measure transaction costs (GROVER & MALHOTRA, 2003). In their operationalization, they start from the division of transaction costs into coordination costs (costs of exchanging information and incorporating that into decisions) and transaction risk (the risk that other parties in a transaction will shirk on their obligations) proposed by CLEMONS ET AL. (1993) and end up dividing transaction costs into four dimensions: (1)Effort required in developing the relationship (effort); (2)Monitoring the performance of the supplier (monitor); (3)Addressing problems that might arise in the relationship (problem); (4)Likelihood of the supplier taking advantage of the relationship (advantage). These dimensions can be compared with the decomposition of transaction costs into search costs, monitoring costs, contracting costs and enforcement costs (DYER, 1997).

This operationalization can be used to facilitate inquiries about the impact of information technology on transaction costs and outsourcing (GROVER & MALHOTRA, 2003), which will be especially useful in this study.

2.2. BLOCKCHAIN

The Blockchain is an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way (IANSITI & LAKHANI, 2017). It builds on the invention of the relational database in the 1970’s (GUPTA, 2017). The first blockchain to run was the Bitcoin blockchain, and like email for the early internet, bitcoin was the first "killer app" for the blockchain (ITO ET AL., 2017). But even though bitcoin has taken most of the public attention, attention is shifting towards the underlying technology, blockchain (BUTERIN, 2014).

There are five basic principles in which the way the blockchain works is based. First, every party has access to the entire database and no one controls all the data and information (IANSITI & LAKHANI, 2017; CASEY & WONG, 2017), meaning power is distributed across the database (TAPSCOTT & TAPSCOTT, 2016; CHANDRAYAN, 2018), and no single point of failure exists (LORENZ ET AL., 2016). Second, instead of using a central node to communicate, nodes broadcast information to all other nodes (IANSITI & LAKHANI, 2017; CASEY & WONG, 2017), meaning no need for a central authority to approve transactions (ZUBERI, 2017). Third, transactions are recorded between public keys, and the identity behind those can be disclosed only when desired (IANSITI & LAKHANI, 2017; CASEY & WONG, 2017), but nodes can authenticate which parties (identified by their public keys) participated in a transaction or own an asset (LORENZ ET AL., 2016), providing a combination of transparency and pseudonymity. Fourth, once a transaction is included in the blockchain, it becomes almost impossible to alter the records because transactions are linked with each other (IANSITI & LAKHANI, 2017; CASEY & WONG, 2017) and algorithms like proof of work are used. Fifth, it is possible to write computer programs on the ledger to trigger transactions automatically (IANSITI & LAKHANI, 2017; CASEY & WONG, 2017), making possible decentralized applications (MOUGAYAR, 2016).

The way the blockchain works makes it a foundational technology instead of a disruptive technology (IANSITI & LAKHANI, 2017). That means its potential depends on the applications that will use it instead of the technology itself. Those applications can leverage the five basic principles above to create new solutions for problems. Bitcoin for instance allows two parties to transact directly without the need for a trusted third party (NAKAMOTO, 2008). To do that it relies specially on the peer to peer transmission and irreversibility of records principles.

2.2.3. Types of Applications

In order to understand how different types of applications may have different implications for transaction costs, it is necessary to first classify the existing blockchain applications in categories. In the existing literature, different authors approach this task in very different ways:

The most trivial way to classify blockchain applications is by the type of economic sector or industry they target. Authors like TAPSCOTT&TAPSCOTT(2017) and LAURENCE(2017) divide applications into sectors like health care, transportation and insurance. Even though this type of classification is relatively straight-forward (one just needs to follow a standard classification of sectors), it suffers from the major problem that many applications within a sector are completely different from one another and at the same time many applications from different sectors are very similar to each other. So, for instance, in the transportation sector, a company like Maersk may use the technology to monitor in real time the location of containers (KSHETRI, 2018), while another one may be using it to comply with know your customer regulations (LAURENCE, 2017). At the same time, an insurance company might use the blockchain in a similar way as Maersk, to get real time data from IoT devices on cars (LAURENCE, 2017).

Another approach is to classify applications by their degree of novelty or future prospects. So one can classify by their novelty relative to existing solutions (IANSITI & LAKHANI, 2017), their novelty in relation to other blockchain applications, meaning the generation of blockchain application they belong to (EFANOV & ROSCHIN, 2018), or their need for coordination (network effects) in order to be successful (IANSITI & LAKHANI, 2017). But obviously this approach will group wildly different applications together, having the same problem as before.

A third approach focuses on the mechanics of the applications. One way to do it is dividing the applications based on how frequently is the information stored updated, so you have a spectrum from static to dynamic information (CARSON ET AL., 2018). Another way is dividing applications by how much the interactions between users are mediated by the blockchain, being either a “system of record” or a “platform” (BAUERLE, 2017). This approach tends to group less diverse applications together, since it focuses in similarities between how they actually operate. So, in CARSON ET AL.(2018), for instance, both the Maersk (KSHETRI, 2018) and IoT insurance (LAURENCE, 2017) cases would be grouped together into the dynamic category, even though they pertain to very different sectors.

There are of course many other possible classifications of the applications besides those mentioned so far. One could classify applications by their role in the overall ecosystem (NUSSBAUM, 2017), or could use the fact that the blockchain can be used to store different kinds of information like about goods, identity, credential and digital rights (CATALINI, 2017) to categorize based on what kind of entity the information pertains to. The goal in this section is not to describe every possible classification of blockchain applications, but to look into existing classifications to develop one that can be used to analyze the applications themselves, and their relation to transaction costs.

Because of the tendency to classify less diverse applications together, in this study the basis for the classification will be the one described in the third approach, above. Combining the classifications proposed in CARSON ET AL (2018) and BAUERLE(2017) four types of applications are obtained.

In the applications where the information is mostly static and used by the inquisitors (MAINELLI, 2017), their design might either look more like a database where they can consult that information or like a platform where the subjects (MAINELLI, 2017), or entities that control the information, can negotiate and control access by the inquisitors. The first type can be called

Identity Systems (because the focus is on establishing the identities of entities) and the second Access Control applications (because the focus is in the use of control over the information by those who possess it).

In the applications where the information is mostly dynamic the information about the entity of reference is constantly changing, be it ownership, location, or something else. In that case too, the focus might be on consulting some information about that entity or in negotiating and interacting with other users over the blockchain. In the case where the focus is on consulting the information the applications may be called Real Time Monitoring Applications, because that is, effectively, what is being done, be it a Maersk container (KSHETRI, 2018) or the actions of a supplier (KOETSIER, 2017). When the focus is on interacting with the other users the applications might be called Guaranteed Transactions Applications, because the focus is in the mechanisms of negotiation and transactions, like smart contracts (IANSITI & LAKHANI, 2017).

Even though the four categories obtained provide already a good base for studying the differences between blockchain applications in terms of their impacts on transaction costs, it can be useful to use a fifth category obtained by dividing the Identity Systems category into two, based on the nature of the information stored, either objective or subjective. The reason for that is that most of the applications in this category that are based on subjective information are really a redesign of old reputation systems (EFANOV & ROSCHIN, 2018) like Tripadvisor, for instance, and markedly different in the way the information is used from other identity systems like the ones used to track the origins of parts from suppliers (ALAM, 2016). Because of that the Identity Systems category will be divided in two, with the applications based on subjective information and peer evaluation being called Reputation Systems. A summary of the classification method used can be seen in Figure 2:

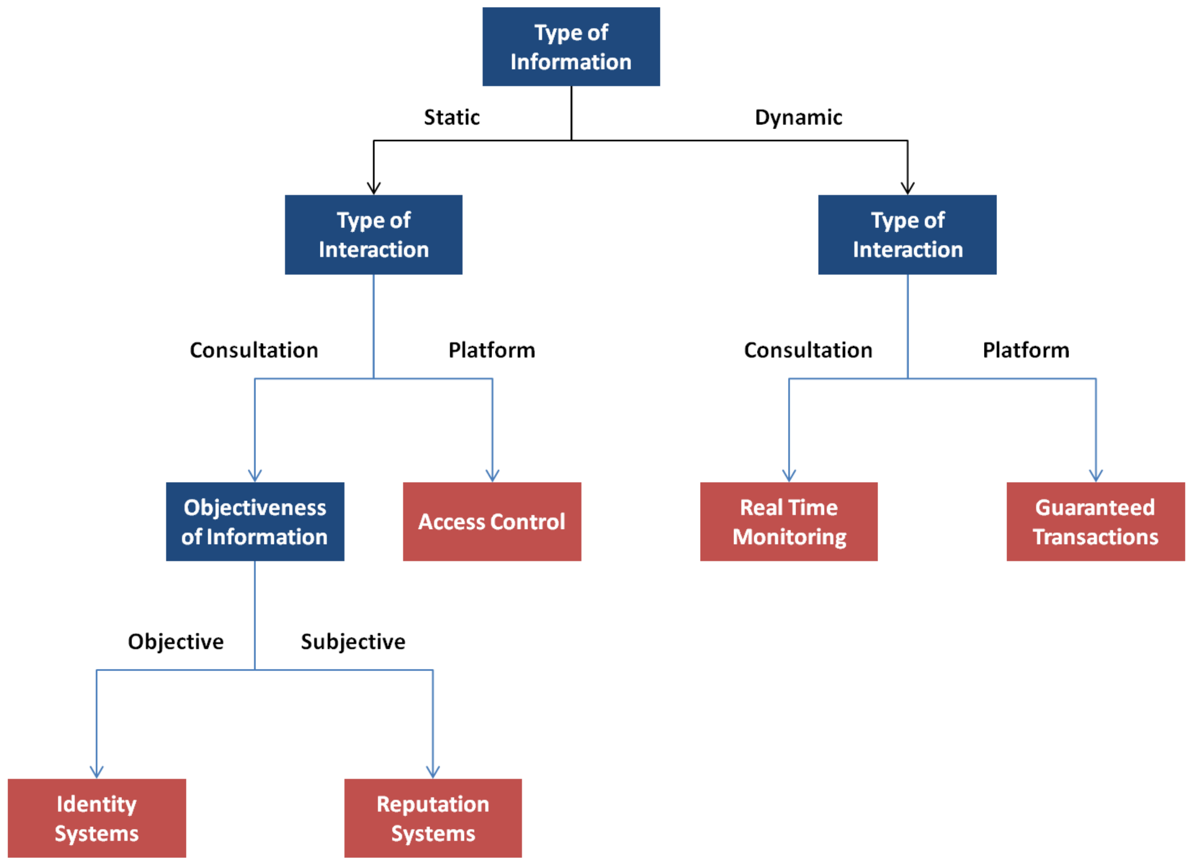

Figure 2: Proposed classification summary
Source: The Author

Having established the basic five types that will be used in this study, now each of them will be described in more detail below.

2.2.3.1. Identity Systems

Identity systems are based on the secure storage and transmission of digitally signed documents with a solid audit trail (MAINELLI, 2017), that can be used to establish facts (identities) not only about people and assets (MAINELLI, 2017), but companies (LAURENCE, 2017) and even devices (KSHETRI, 2018). They have typically three parties (that might overlap): A subject, from which the information is related, an inquisitor, that needs to know that information for some purpose, and a certifier, that might add some kind of proof like a digital signature that the information inserted in the blockchain is true (MAINELLI, 2017).

Companies like Provenance, Alibaba, Everledger, Walmart and BHP are already using or developing solutions based on this kind of application (KSHETRI, 2018; CASEY & WONG, 2017; ALICKE ET AL., 2017). Car companies could use it to make sure car parts came from where the suppliers say they did (ALAM, 2016) and they could deal with recalls by tracing any product to the origin of the raw materials (KSHETRI, 2017). It can be used to trace materials, components and even minerals ("Purchasing and supply management: From efficiency to effectiveness in an integrated supply chain", 2016). It can be a foolproof method to confirm the identity of IoT devices (KSHETRI, 2018) and companies could use it to know whether a certain employee has the qualifications for the job (BRIDGERS, 2017). It can even be used by banks to establish the identities of companies they are interacting with and comply with know-your-customer regulations (LAURENCE, 2017), and by governments to offer services like benefits collection and giving licenses (MOUGAYAR, 2016).

2.2.3.2. Reputation Systems

Blockchain based reputation systems use the blockchain technology as a new opportunity to redesign current reputation systems (EFANOV & ROSCHIN, 2018). They also store information about entities, but in their case the information stored refers to other entities evaluations of that entity instead of their identities. They should help counter problems of current reputation systems like the existence of fraudulent raters (EFANOV & ROSCHIN, 2018).

Acolyte, a system that runs on the Factomblockchain and allows users to build a reputation for the information they provide the network is one example of such system (LAURENCE, 2017), and Steem, a social media organization based on blockchain in which members evaluate contributions of other members is another example (DAVIDSON ET AL., 2018).

2.2.3.3. Access Control

Access Control applications are used in a contexts were entities have to share data with more stakeholders while at the same time ensuring data integrity and protecting privacy (HALAMKA ET AL., 2017). Data is not managed or stored centrally, but shared among only the parties involved in the transaction (KSHETRI, 2017).

This kind of application can transform the way electronic health records are managed, by substituting push, pull and view systems with a blockchain based system where every database sends data to that ledger, permitting reconciliation between databases and the control of the data by the patient, who can decide what data do give access to whom (HALAMKA ET AL., 2017). The individuals can also give (and control) access to that data to academic researchers, fitness apps or commercial drug development (TUCKER & CATALINI, 2018). It can also be used in the supply chain context, like an information sharing system proposed to prevent inefficiencies like the double marginalization problem(NAKASUMI, 2017).

To further control access to data, permissioned ledgers can be used to control access to the blockchain itself, and therefore to the data (PECK, 2017). The use of networks like Enigma, based on blockchain technology, can take this kind of system to the limit, by allowing parties to run computations on data from another party without the need for the data to actually be shared (ZYSKIND ET AL., 2015).

2.2.3.4. Real Time Monitoring

Real time monitoring involves inputting information in real time on the blockchain, which can then be read and analyzed by interested parties. The monitored entities might be goods (KSHETRI, 2018; KSHETRI, 2017), people (KSHETRI, 2018; CASEY & WONG, 2017; KNIGHT, 2017) or even transactions (ITO ET AL., 2017). It is technologies like RFID, GPS and IoT that, combined with the blockchain, allow it to track goods in real time and to know who is performing what actions (KSHETRI, 2018). With real time monitoring, the need for middlemen auditors is eliminated as individual suppliers can easily perform their own checks (KOETSIER, 2017).

The most developed types of these applications are for tracking goods in a supply chain, with examples like Maersk already using it to track shipping containers around the world (KSHETRI, 2018). Blockchain might promise an *"infinitely scalable system of supply chain visibility"* (O'MARAH, 2017, *page 1*). In insurance services, data from IoT devices on cars can be collected for determining payments (LAURENCE, 2017). More innovative applications include the use of the blockchain to monitor transactions and reduce opacity in the financial system, enabling better monitoring by regulators (ITO ET AL., 2017), monitoring data about employees clocking in and out of a factory to gauge whether the factory is complying with labor regulations (KNIGHT, 2017), or improving transparency in data-driven marketing by allowing advertisers to monitor where the ads they paid for are being placed (GHOSE, 2018).

2.2.3.5. Guaranteed Transactions

Guaranteed transactions applications use the blockchain in combination with technologies like smart contracts to automate the terms of an agreement (TAPSCOTT & TAPSCOTT, 2016). They can explore the ability of smart contracts to self-enforce in order to trigger mechanisms like forfeiture of previously verified cryptocurrency (BRIDGERS, 2017) or the automatic transference of other digital assets like real estate titles (LAURENCE, 2017) or stocks without the need of third parties to verify or transfer ownership (IANSITI & LAKHANI, 2017).

Bitcoin can be considered the first guaranteed transaction blockchain application, replicating the ability of financial systems to transfer value without the labor typically involved in running and securing transactions (CATALINI, 2017). This type of application can be a huge enabler of micropayments, by reducing payment friction, which can be used, for instance, by marketers, to obtain customer data directly, instead of using platforms like Facebook (HARVEY ET AL., 2018). But the applications go way beyond that, from using smart contracts in collective bargains (BRIDGERS, 2017), to making peer to peer trading of energy possible (BASDEN & COTTREL, 2017), to allowing new business models centered on the sales of data from internet of things devices to consumers (ZHANG & WEN, 2017) and even substituting platforms like ebay with blockchain based platforms like OpenBazaar that use escrow accounts controlled by smart contracts that transfer the money to the seller when the product is received to operationalize sales (DE FILIPPI, 2017).

2.3. IMPACT ON TRANSACTION COSTS

2.3.1. Impact on the four dimensions of transaction costs

Another way to look at the blockchain is as a solution to the problem of trust (SHERMIN, 2017). Since bounded rationality and opportunism give rise to transaction costs (GROVER

&MALHOTRA, 2003), if the blockchain applications described above can reduce the risk of opportunism then it can have a big impact on transaction costs. Some authors explicitly affirm the capacity of the blockchain to eliminate transaction costs (TAPSCOTT & TAPSCOTT, 2016). There are, however, many different ways in which the blockchain can reduce transaction costs and it can be useful to use the four dimensions of transaction costs (GROVER & MALHOTRA, 2003) to understand how the blockchain applications could impact each dimension.

2.3.1.1. Reducing the effort to develop relationships

A key component of that dimension is the effort required to gather information to outline the relationship (GROVER & MALHOTRA, 2003). The identity and reputation systems mentioned above could in theory dramatically reduce those costs. If the blockchain based reputation systems can solve the problems with current reputation systems like fraudulent ratings, buyers could use those systems to establish the trustworthiness of the potential sellers/suppliers (EFANOV & ROSCHIN, 2018). If, because of the super audit trail (MAINELLI, 2017), buyers can trust the identities of the suppliers established on the blockchain based identity systems, they could eliminate the need to gather and audit the information themselves. This could be especially useful in areas like trade finance shipping and insurance where validating identities is a big problem (MAINELLI, 2017). Even for the unified mode of governance the effort required to develop relationships with the employees could be reduced, since with information about the employees stored in the blockchain, tasks like checking references could be eliminated (BRIDGERS, 2017).

2.3.1.2. Simplifying performance monitoring

The real time monitoring of performance applications have the potential to reduce the costs of monitoring performance. They can facilitate "valid and effective measurement of outcomes and performance of key SCM processes" (KSHETRI, 2018), therefore reducing the cost to monitor the performance of supply chain partners. As part of this dimension Grover and Malhotra (GROVER & MALHOTRA, 2003) include not only the effort, but the time incurred to monitor the performance, which obviously can be reduced in real time monitoring. The elimination of middlemen auditors (KOETSIER, 2017) further reduces the costs to measure performance. One aspect of the monitoring cost that merits special attention is the effort required to detect conformity to specifications and quality standards (GROVER & MALHOTRA, 2003). It is argued that in the infamous Chipotle food contamination case the lack of capacity to monitor the suppliers in real time made it impossible to prevent quality standards to be breached (KSHETRI, 2018).

2.3.1.3. Helping to address relationship problems

A clear cut approach to solve problems in a relationship and the existence of standard solutions to solve problems are two of the items of the problem addressing dimension of transaction costs (GROVER & MALHOTRA, 2003). The irreversibility principle of the blockchain (IANSITI & LAKHANI, 2017) allows the deployment of smart contracts with the parties trusting that the rules of the contracts will not be tampered with. Rights and obligations defined in the smart contract can be automatically executed once the conditions of the agreement have been met (SHERMIN, 2017). The combination of smart contracts with the internet of things can extend the capacity of smart contracts to provide a clear cut approach to solve problems in different areas like insurance (LAURENCE, 2017). Therefore the Guaranteed Transactions type of applications is especially well positioned to reduce those costs.

2.3.1.4. Reducing the risk of opportunism

Two components of this dimension proposed by Grover and Malhotra are the easiness for a party to alter the facts to get what they want and the difficulty of for a party to promise to do something and not doing it latter (GROVER & MALHOTRA, 2003). The irreversibility principle (IANSITI & LAKHANI, 2017) of information stored in Identity and Reputation Systems makes it hard to alter the facts, and the combination of the self-enforcing mechanisms of smart contracts (BRIDGERS, 2017) with data from IoT devices to feed those contracts makes it harder to promise to do something and not do it latter. In the case of car insurance, for instance, smart contracts can verify information from IoT devices on cars and automatically issue a payment (LAURENCE, 2017), eliminating the risk of the insurance company refusing to pay. So, in theory, Identity Systems, Reputation Systems and Guaranteed Transactions applications can help reduce those costs.

2.3.2. Shift in governance structures

Since the assignment of governance structures to transactions is made with the goal of economizing on the sum of transaction costs and production costs (WILLIAMSON, 1985), if the blockchain can eliminate or significantly reduce transaction costs (TAPSCOTT & TAPSCOTT, 2016; SHERMIN, 2017) its adoption could have, in theory, implications for the choice of governance structures. Some argue that the elimination of transaction costs will help companies to use outsourced resources as easily as in-house resources (TAPSCOTT & TAPSCOTT, 2016).

Nevertheless, even though in the literature relating the blockchain and TCE the former is usually portrayed as a possible reducer of transaction costs (TAPSCOTT & TAPSCOTT, 2016; SHERMIN, 2017), some propose that it is in fact a new way of coordinating economic activity, being therefore a new type of economic institution like markets, firms and relational contracts (DAVIDSON ET AL., 2018). If that is true, then Williamson's operationalization of TCE should be extended to include a fifth type of governance structure, the blockchain.

In order for the organization of economic activity via blockchain to be considered an alternative way of organizing economic activity from markets, firms and relational contracts it must be fundamentally different from each one of them. The so called decentralized autonomous organizations (DAOs) could be the embodiment of this new form of organization. In these organizations, the governance is embedded in the code of smart contracts (SHERMIN, 2017) that are themselves written on the blockchain (benefiting from the irreversibility principle). DAOs have internal capital (BUTERIN, 2014), which separates them from the market form of governance. However, when compared to firms, the DAO "in some fashion, makes decisions for itself" (BUTERIN, 2014), because the rules are set on the code of the smart contracts that, once in the blockchain, cannot be changed, because of the irreversibility principle. Even though the DAO might use subcontractors to serve some of its needs, central coordination and administrative and executive functions can be automated (SHERMIN, 2017). Therefore this mode of governance could be potentially considered different from the existing ones and a new mode of governance.

2.4. ANTECEDENTS: UNCERTAINTY ABOUT ADOPTION AND IMPACT

While some companies, like Maersk, Provenance, Walmart and others are already using or developing applications of the blockchain to improve supply chain objectives (KSHETRI, 2018), some argue that the full impact of the blockchain will take decades to be felt (IANSITI & LAKHANI, 2017). To develop its full adoption potential there are many obstacles or uncertainties to be overcome, and the Table1 below indicates the antecedent factors found in the literature to be crucial for the success of blockchain applications, together with the authors that mentioned them. Among those factors three have been mentioned the most : Scalability, or the capacity for the blockchain to function well in comparison with existing systems even at much bigger scale (PECK, 2017; NAKAZUMI, 2017; SHERMIN, 2017; LAURENCE, 2017; TAPSCOTT & TAPSCOTT, 2016; ZUBERI, 2017; CARSON ET AL., 2018; ALICKE ET AL., 2017; LORENZ ET AL., 2016; GHOSE, 2018), Regulation, in its various forms (CASEY & WONG, 2017; BASDEN & COTTREL, 2017; KSHETRI, 2018; LAURENCE, 2017; TAPSCOTT & TAPSCOTT, 2016; KASTELEIN, 2017; ZUBERI, 2017) and Governance Issues, with the need for several parties to cooperate and agree in many issues in order for many blockchain applications to work (CASEY & WONG, 2017; PECK, 2017; IANSITI & LAKHANI, 2017; KSHETRI, 2018; SHERMIN, 2017; LAURENCE, 2017; TAPSCOTT & TAPSCOTT, 2016; ZUBERI, 2017; ALICKE ET AL., 2017).

Table 1: Antecedent factors found in the literature

Obstacles	Authors
Scalability	Peck (2017), Nakazumi (2017), Shermin (2017), Laurence (2017), Tapscott (2016), Zuberi (2017), Carson (2018), Alicke (2017), Lorenz (2016), Ghose (2018)
Governance Issues	Casey (2017), Peck (2017), Iansiti (2017), Kshetri (2018), Shermin (2017), Laurence (2017), Tapscott (2016), Zuberi (2017), Alicke (2017)
Regulation	Casey (2017), Basden (2017), Kshetri (2018), Laurence (2017), Tapscott (2016), Kastelein (2017), Zuberi (2017)
Physical Digital Interface	Peck (2017), Kshetri (2018), Catalini (2017), Tucker (2018), Carson (2018)
Privacy Concerns	Bridgers (2017), Mainelli (2017), Laurence (2017), Tapscott (2016)
Padronization	Basden (2017), Carson (2018); Alicke (2017); Lorenz (2016)
Smart Contracts limitations	Tapscott (2016), Shermin (2017), Laurence (2017)
Data security Issues	Tapscott (2016), Lorenz (2016)
Interface with other digital systems	Bridgers (2017)
High Transaction Fees	Shermin (2017)
Limited Computing Power of IoT Devices	Laurence (2017)
User Friendly Interface	Tapscott (2016)

Given the important interactions between the blockchain and other technologies like the Internet of Things (KSHETRI, 2017) and Smart Contracts (SHERMIN, 2017), the developments related to those and other technologies can also affect the potential of the blockchain. The reason for that is that combining the blockchain capabilities with other technologies can provide an extremely fruitful way of creating new useful applications. In the literature, the most mentioned technologies in conjunction with blockchain applications are the Internet of Things and Smart Contracts:

Smart Contracts mimic the logic of contracts (TAPSCOTT & TAPSCOTT, 2016) but automatically move digital assets according to a pre-specified set of rules (BUTERIN, 2014). The way blockchain can unlock the potential of Smart Contracts is by storing them in transparent and shared databases where they are protected from deletion, tampering and revision (IANSITI & LAKHANI, 2017). On the other hand, as mentioned in the Guaranteed Transactions section, these types of application benefit from the self-enforcing ability of smart contracts to do things like transfer digital assets without the need for third parties to verify or transfer ownership (IANSITI & LAKHANI, 2017).

The Internet of Things is based on sensors and actuators embedded in physical objects that are connected through the internet (CHUI ET AL., 2010). Applied to the Internet of Things, the blockchain can reduce the risk of manipulation of the information, reduce vulnerability, and deal with capacity constraints of using a centralized cloud (KSHETRI, 2017). On the other hand, with IoT, the locations of products, packages or containers can be traced at each step (KSHETRI, 2018), making possible blockchain applications like Real Time Monitoring. It can also boost the potential of Guaranteed Transactions applications, by allowing Smart Contracts to link digital transactions with data from IoT devices (LAURENCE, 2017; ZHANG & WEN, 2017; EFANOV & ROSCHIN, 2018).

3. RESEARCH METHOD

According to MORSE & FIELD (1996), the choice of approach should depend on factors like the nature of the phenomenon and maturity of the concept. First, when we look at the nature of transaction costs, it must be noticed that *"empirical research on transaction costs matters almost never attempts to measure such costs directly"* (WILLIAMSON, 1985, *page 22*). Even the attempt at measuring transaction costs from GROVER & MALHOTRA (2003) is fundamentally a qualitative one, as it relies on the perceptions of participants. Then, when the incipient nature of the research on the blockchain concept and especially on the relationship between the blockchain and TCE is factored in, a qualitative approach becomes the obvious choice, and the one used in this study.

3.1. DATA COLLECTION

For the data collection were used qualitative, face to face or Skype (when interviewing a participant outside Brazil), one-on-one interviews with experts. Those interviews where focused on the views of the experts about the impact of the blockchain on the transaction costs dimensions and governance structures prescribed by the TCE. Following the call from MILES ET AL. (2014) to choose “purposive” qualitative samples, the choice of participants was based on two criteria. The first was to give a greater emphasis to practical blockchain expertise rather than extensive knowledge of TCE, because of the more limited number of experts with sufficient experience with blockchain applications and the relative simplicity of concepts like Grover's measure of transaction costs (GROVER & MALHOTRA, 2003), which made it easy to discuss even with participants without extensive knowledge about it. The second criteria was to choose participants from different fields of expertise: Consulting, Finance, Academy and Technological solutions. That had the goal of having a more holistic view of the subject, by using different points of view. To maintain their privacy the interviewees will be referenced by their number during the findings and discussion part. Table 2 below provides a general overview of the interviews.

Table 2: Data Collection - Interviews

Expert Code	Period of Interview	Length (min)	# of words	Experience	Reason of Choice
E1	jul/18	57	8252	Senior software engineer in a danish company that provides trading and payment solutions based on blockchain technology	Technological solution point of view and another country point of view
E2	jul/18	62	8984	Blockchain entrepreneur focused on providing consultancy services to companies	Consultant and entrepreneur point of view
E3	jul/18	54	6206	Doctorate student at COPPEAD and involved in blockchain related projects in healthcare	Academic point of view
E4	jul/18	52	7355	Analyst at a brazilian hedge fund who oversaw cryptocurrencies investments since 2014	Finance point of view focusing on investments
E5	ago/18	54	7671	IT specialist overseeing implementation of blockchain project in a major brazilian bank	Finance point of view focusing on operations
E6	ago/18	37	5523	Head of strategy at EOS blockchain developer, Co-founder and CEO of AI and blockchain innovation center and doctorate student at COPPEAD focused on blockchain technology	Technological solution combined with entrepreneur and academic point of view

As to how the experts were reached, expert 4 is a personal acquaintance of the author, and expert 1 was introduced by a mutual friend. Experts 2 and 3 were introduced to the author by his supervisor, and expert 2 introduced the author to experts 5 and 6. The six experts, as shown in the table above, cover the four fields of expertise discussed in the last paragraph, as well as having know-how about different kinds of industries, from healthcare to payments and finance, and different types of blockchain. Because of that this group of experts can provide the needed holistic view of the subject that this study needs.

The interview method was semi-structured interviews that were audiotaped, and then transcribed. The interview protocol can be found at the appendix. It consisted of three parts: The first part was focused on establishing the relation between the expert knowledge about applications of the blockchain technology and TCE concepts like the GROVER & MALHOTRA'S (2003) dimensions of transaction costs and WILLIAMSON'S (1985) governance structures. The second part dealt with establishing the main factors that generate uncertainty about the blockchain adoption and its impact on TCE. Finally, the third part dealt with the DAVIDSON ET AL. (2018) proposition of the blockchain as a separate governance structure rather than a technology that could simply impact existing ones, and the views of the participants about the differences and possible advantages of this type of governance structure.

3.2. DATA ANALYSIS

After the interviews were transcribed, the next step was to "winnow" the data. Because the text data is very rich, not all information can be used in the qualitative study, so the analysis must focus on some of the data and disregard other parts, and that can be done by aggregating data on a small number of themes (CRESWELL, 2014). To do that coding process the NVivo Software was used. Then the basic framework proposed by CRESWELL (2014) was used to do the analysis, consisting on transcribing, organizing, reading through the data, coding the data, obtaining the main themes, establishing the connections (interrelating) between the themes and finally interpreting the findings on the discussion part.

Because the four sub research questions connect the blockchain applications with the transaction costs, governance structures, complementary technologies and uncertain antecedent factors, those were the five macro constructs or themes chosen to code the interviews. The applications macro construct was divided in five according to the criteria explained in the literature review, with the basis being the static to dynamic division (CARSON ET AL., 2018) and the system of record to platform division (BAUERLE, 2017). The transaction costs were divided in four based on the four dimensions proposed by GROVER & MALHOTRA (2003). The governance structures were divided in five, considering the four types proposed by WILLIAMSON (1985) plus the fifth type proposed by DAVIDSON ET AL. (2018). For the related technologies the division was based on simply adding each new technology mentioned, like Smart Contracts and Internet of Things, inside that category, and for the antecedent factors the basis were the twelve factors mentioned on the literature, summarized on the literature review section, with the addition of antecedent factors mentioned on the interviews that were not mentioned in the literature.

The script from the interviews can be found at the appendix.

3.3. VALIDITY AND RELIABILITY

In the context of qualitative research, validity means employing procedures to guarantee the accuracy of the facts, while reliability means having a consistent approach (CRESWELL, 2014). In this study the main strategy to guarantee validity was triangulation. Triangulation is a procedure where researchers seek for convergence among many sources of information to form the themes in a study (CRESWELL & MILLER, 2000). By purposefully choosing experts from different fields of practice, it is possible to increase validity because of the heterogeneity of the sources of information. To increase reliability, two of the procedures suggested by CRESWELL (2014) were used in this study: checking transcripts to make sure there were no obvious mistakes during transcription and reviewing the codes obtained during data analysis to make sure there was no drift in their meaning during the coding process.

4. FINDINGS AND DISCUSSION

In this section the findings, based on the coding of the interviews and the relationships found between the themes, as explained in the methodology section, will be presented and discussed.

4.1. HOW CAN DIFFERENT TYPES OF APPLICATIONS AFFECT DIFFERENT TYPES OF TRANSACTION COSTS?

4.1.1. Descriptive Overview

The Table 3 below gives some quantitative perspective on the prominence of each group of applications in the interviews, both alone and in conjunction with the transaction cost dimensions from GROVER & MALHOTRA (2003). Clearly, the guaranteed transactions type of application has been more frequently cited and more often associated with reductions in dimensions of transaction costs. That was to be expected since, as mentioned in the literature review part, this type of application was the original type of application of the blockchain, and has been around since 2008 with the Bitcoin application (NAKAMOTO, 2008).

Table 3: Quantitative overview

Type of Application	Quotes	Quoted with a TC dimension
Guaranteed Transactions	29	18
Identity Systems	18	11
Real Time Monitoring	13	10
Reputation Systems	12	8
Access Control	11	2

Also, as will be explained in more detail in the next sections, and is indicated in the next Table 4 below, the Guaranteed Transactions type of application has more breadth in terms of the dimensions of transaction costs that it can affect, being linked by the experts with three out of the four dimensions of transaction cost defined by GROVER & MALHOTRA (2003), while no other type of application has been linked with more than two.

Table 4: Breadth of relationships between applications and TCE dimensions

Applications/Dimensions	Effort	Monitor	Problem	Advantage
Identity Systems	X			
Reputation Systems	X			X
Access Control	X			
Real Time Monitoring		X		
Guaranteed Transactions	X		X	X

Proposition 1*: Guaranteed Transactions applications are the most used among the five types, and the most associated with reducing transaction costs, both in terms of the number of applications with some impact and the number of dimensions affected.*

4.1.2. Identity Systems

Identity Systems applications can help one entity to know the previous actions of a prospective partner, making it easier to determine if they can be trusted. *"For this effort to establish the relationship...you use the blockchain technology, it's much easier...what is there is what really happened to the guy... his Karma is established, so you know exactly who are people"* (E2).

Entities can form their opinion based on the previous relationships of the prospective partner that are registered on the blockchain *"given that the other relationships of that partner might be registered on the blockchain, you have access to a history and (with) that history form an opinion about the person."* (E5).Evaluating those prospective partners becomes easier since there is a track record of their relationships, which are registered and accessible, reducing the cost to develop the association. *"When you talk about the cost to find (a partner), you have the cost to look (for a partner) and the cost to evaluate (the partner)...the cost to evaluate, since that person has to be registered in a database that is accessible, it can reduce that cost"* (E5).

Even though today there are ways to find out information about previous relationships and transaction histories of prospective partners, like hiring specialized companies to gather this information, the blockchain can reduce this cost by providing a history of transactions without the need to hire expensive services from specialized companies to get it. From the partner perspective, knowing that there is such an easiness of finding out information about their performance and previous actions contributes to reducing the likelihood that that partner will try to take advantage of the other partner in a relationship. From the company perspective, the cost to establish the relationship is reduced. *"You could see a history, a network, for instance, a history of transactions. The number of times he (the partner) delayed payment...You have that today...You have companies that can give information about the performance (of the prospective partner). (The blockchain) is a way for you to enter that cost, the cost for you to access that information, which is essentially asymmetric."* (E6).

Proposition 2*: Identity Systems applications can reduce the effort to develop relationships between entities and reduce the risk of opportunism.*

4.1.3. Reputation Systems

Reputation systems can reduce the effort to establish a relationship by eliminating the need to trust the middlemen that used to help entities understand the reputation of their prospective partners. *"You have to create third layer of trust: being decentralized...for you to trust the guy (when there is a middleman), you also have to trust Mercado Livre (middleman)."* (E2). Now suppliers like those of auto parts can simply show prospective partners their reputation on the blockchain among former buyers: *"You can say: 'I produce quality pieces'. How the guy is going to know? You show: 'Here is my blockchain, all the batches I produced... they were validated by my old assemblers'"* (E1).

If you were a supplier that had the information about your reputation stored in a centralized database you would even run the risk of that middleman going out of business and you losing all that information that could be used to validate your reputation. *"Suddenly that data is not yours anymore, so you could be unable to access it...Let's suppose that you have all your reputation base on the centralized database of Mercado Livre, so you built your career as an excellent seller for 20 years...In 20 years Mercado Livre says: 'we will terminate our services'. It's over....all that reputation you built for 20 years."* (E2).

As mentioned in the Identity Systems section, the reduced need to hire third parties to evaluate the prospective partner performance increases the incentives for them not to take advantage of the partner in a relationship. That increase in transparency is especially important in terms of reputation systems, where you are dealing with subjective information that can be harder to establish sometimes. *"You increase transparency. When you increase transparency, you increase the disincentives for people to be unreliable, especially when you have a long term view on reputation."* (E6).

Proposition 3*: Reputation Systems applications can reduce the effort to develop relationships between entities and reduce the risk of opportunism.*

4.1.4. Access Control

There is some evidence that Access Control applications can reduce the effort to establish a relationship. Access Control applications can give the control of the information directly to one of the parties, while keeping the irreversibility principle of the information on the blockchain. Because of that an intermediary can be eliminated in providing the information needed to establish a relationship. *"When it is in the blockchain you have to have control, the information is yours... now there is no more intermediary, (and) the big cost of the technology is the intermediation cost."*(E3). Nevertheless, with only two quotes to support that connection in the interviews, the evidence in this study is inconclusive in that respect.

4.1.5. Guaranteed Transactions

Guaranteed Transactions can reduce the effort to establish a relationship by, combining with smart contracts, establishing and simplifying the rules of that relationship instead of relying on an external agent, and ensuring those rules will be always available for consultation and use. *"It simplifies and establishes the rules of the relationship much more than with a financial operator. You never have those contracts (written with the aid of that third party)... It establishes the rules for a relationship in a simple way."* (E3).

Also, the risk of being taken advantage by another party is lowered both because it is harder for that party to hide/alter the facts and because it is harder for that party to avoid doing something it had committed to. It would be harder, for instance, for a party in a sale negotiation using a Guaranteed Transaction application to say it owns something that it doesn't. *"The only certainty that you have is that the guy is not selling something that does not exist or that he doesn't have"* (E4). In the case of a transaction involving digital assets like bitcoin this type of application can make sure the digital assets will be transferred as agreed upon. *"If someone signed a transaction it's because he has account balance, then it will happen"* (E4).

Finally, Guaranteed Transactions applications can reduce the cost of handling problems in a relationship by automating the actions that need to be taken when something falls out of the agreed upon parameters, therefore creating the standard, clear cut approach to solve problems mentioned by GROVER & MALHOTRA (2003). *"If you go out of that (agreed upon) limit you can have a fine that automatically goes from one guy to the other. You go from monitoring to a smart contract that reduces your cost to solve problems, because it is automatic."* (E6).

Proposition 4: *Guaranteed Transactions applications can reduce the effort to develop relationships between entities, reduce the cost of handling problems in the relationship and reduce the risk of opportunism.*

4.1.6. Real Time Monitoring

With real time monitoring applications it becomes easier to tell if the suppliers are conforming to quality standards, by shifting the monitoring from inspecting the final products to real time monitoring of processes. *"I believe there is a very good possibility to do process checking to have (good) quality processes. Imagine a supplier... today the (quality) validation is made on the final product...but if you had the blockchain...every process has to be validated and pass through some kind of blockchain, so it would be very good for the assembler"* (E1).

Also, because in Real Time Monitoring applications the information is concentrated on the blockchain, the effort to monitor that information is much smaller than if the information is spread through several different bases at any given time. *"there is this idea of being a chain of blocks, where you pull a little string and comes a whole wool ball. You don't have to look the same information on different bases."* (E4).

When one shifts from spot monitoring to continuous, real time, monitoring with the blockchain, the monitoring process is streamlined, since there is no need for employees to stop other activities to collect and pool the data from different databases, therefore reducing the monitoring cost. *"One thing is cost. It's you (not having to) stop to do the monitoring. It facilitates it, right? Everything is there, you don't need to collect, raise data. Everything is there, so you could really do something continuous"*(E3).

Therefore**,** Real Time Monitoring applications can reduce the monitoring costs by making it easier to tell if suppliers are conforming to standards, and reducing the effort involved in that monitoring

Proposition 5: *Real Time Monitoring applications can reduce the costs to monitor partners in a relationship.*

4.2. HOW CAN THE CHOICE OF GOVERNANCE STRUCTURE BE AFFECTED BY THE DEVELOPMENT OF THE BLOCKCHAIN?

Several of the authors linked the adoption of the blockchain technology with a shift in governance mode, or favoring some type of governance mode, indicating that the blockchain can be a driver in changes on the currently adopted governance structures. *"You are going to have less verticalization and be able to decentralize more"* (E2).On the other hand the direction of those changes was less clear, with some authors unsure about what mode of governance would be the big winner. *"We cannot see right now all the outcomes and I can't see one model that wins more than the others. It will depend a lot on the profile of the relationship you are in."* (E3). Therefore, even though the blockchain applications can impact in several ways the choice of governance mode, there is no one mode emerging as a clear winner so far.

4.3. HOW THE DEVELOPMENT AND APPLICATION OF COMPLEMENTARY TECHNOLOGIES CAN IMPACT THE POTENTIAL OF BLOCKCHAIN APPLICATIONS?

Although several technologies were mentioned as complementary to the blockchain applications, the smart contracts technology clearly dominated, with more than two thirds of the mentions. They complement and are complemented by the blockchain technology, which finally gave them applicability. *"The smart contracts were proposed I believe in 1995...but, conceptually, didn't have an application until the appearance of the Ethereum network."* (E2).

They enable blockchain applications when they are employed as part of them because of their automatic execution, helping reduce transaction costs like the addressing problems dimension. *"I believe the main thing, really, for that automatic resolution of problems are those smart contracts. The smart contract will have predefined rules for execution"* (E2).

On the other hand they have a clear limitation on the fact that they are not really smart, just executing the defined procedures, and would need further development of artificial intelligence to actually be smart contracts. *"The big problem is that it is not a smart contract. It doesn't have enough embedded artificial intelligence to make coherent decisions...the code we have today is a procedural code"* (E2).

Proposition 6: *Smart contracts are a key enabler of blockchain applications, but they are limited in their "smartness", possessing limitations of traditional contracts, and depending on the development and employment of artificial intelligence to achieve their full potential.*

4.4. HOW ANTECEDENT FACTORS CAN IMPACT THE DEVELOPMENT AND ADOPTION OF BLOCKCHAIN APPLICATIONS?

During the interviews the experts mentioned ten antecedent factors that could impact the development and adoption of the blockchain technology. Yet, only three of those factors were unanimously mentioned by all experts, and they were also the ones mentioned the most, with Scalability mentioned 19 times, Regulation mentioned 13 times and the Physical-Digital Interface mentioned 12 times. This indicates that those are the factors the experts as a group consider the most relevant. In general the experts believe the scalability is one of the main challenges of the technology today, with a clear disadvantage towards centralized systems. *"The main challenge of the technology today is to overcome the scalability problem. Once you decentralize, you lose efficiency"* (E2). But they also believe those problems will be overcome in the future *"It is a problem of short, maybe medium term that is going to be solved, it doesn't worry me for the long term."* (E6).

About regulation, even though the experts believe it to be an important factor *"I believe regulation can be a big question for the public blockchain"* (E5), they disagree on whether it will be a positive factor or a negative factor for the development of blockchain. *"There isn't much of a positive side of regulation"* (E1).*"There were countries that banished bitcoins. That's extreme regulation...so I don't think it's a positive thing."* (E1).*"It is a risk more for better than worse...serious governments...will want to encourage...the day it gets regulated...everyone will be more comfortable to use."* (E4).

Finally, the experts believe the potential of the blockchain technology today is much more limited when it has to deal with events happening outside the digital world (in the physical world). Therefore the development of an adequate physical-digital interface is crucial for the development and adoption of blockchain applications. *"When you are working with transactions that are electronic, virtual, it is much easier...When you have that real world layer...all your transaction* *costs enter for you to establish that that transaction of the real world really is going to be replicated in the virtual world"* (E2)

From the above, it is possible to conclude that scalability, regulation and the efficiency of the interface between the physical and digital world can be important factors for the development and adoption of blockchain applications, but they can impact in different ways:

a)The lack of scalability of blockchain applications is the main challenge today, but the experts believe this is a short-term barrier.

b) On the one hand, regulation can foster the development and adoption of the blockchain, by reducing regulatory uncertainty; but on the other hand, regulation can be a barrier if takes directions like the banishing of cryptocurrencies.

c)The physical-digital interface can limit the potential of some blockchain applications because of the difficulty to ensure that transactions in one side of the interface will be replicated on the other side of the interface

> ***Proposition 7:*** *The lack of scalability, regulation and physical-digital interface are some of the most relevant factors for blockchain adoption.*

The findings from the interviews show that mostly the expert views are in line with the literature (in terms of the relationships between applications and transaction costs, the key complementary technologies and antecedent factors), but there are some important added relationships, like between Guaranteed Transactions and the effort to establish relationships, between Smart Contracts and Artificial Intelligence and between the physical-digital interface and blockchain adoption, discuss among the seven propositions above. Figure 3 offers a theoretical model combining the relationships derived from the literature and those derived after data collection and analysis. The literature relationships are in blue and those derived from the interviews in red.

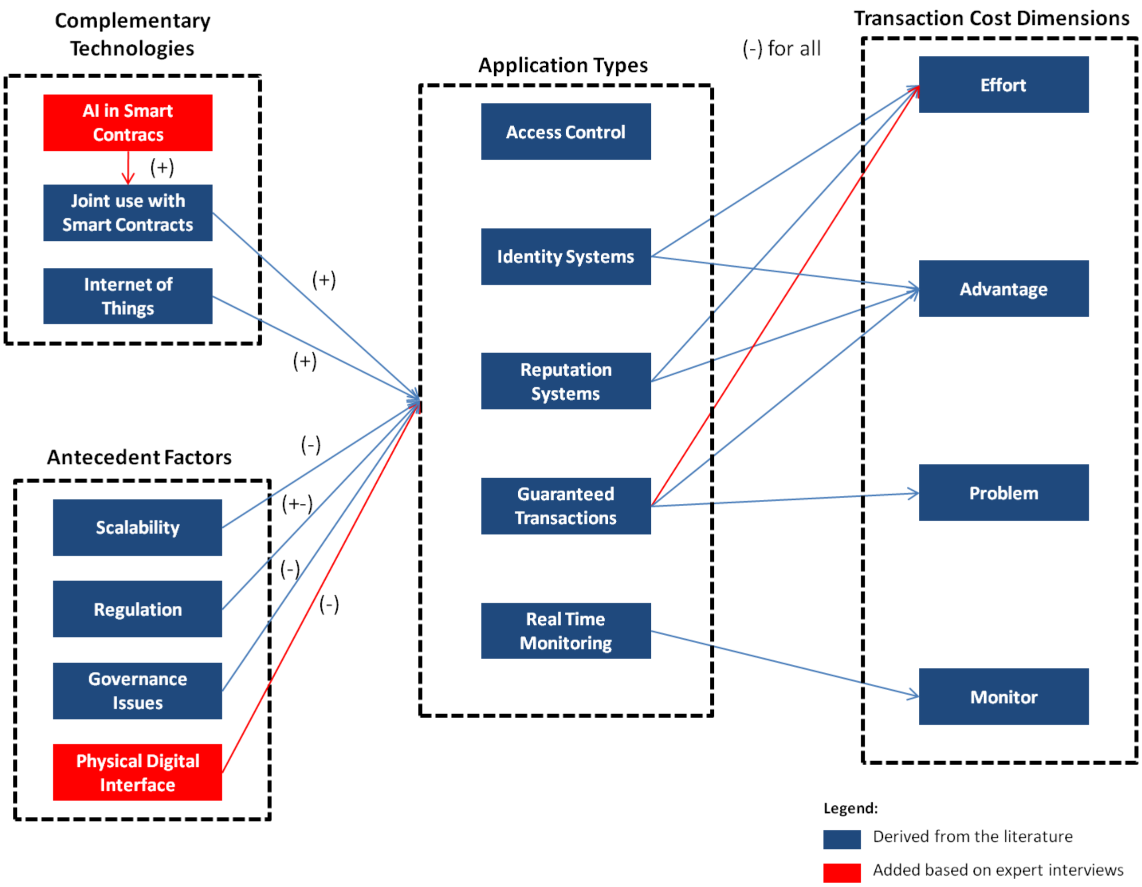

Figure 3: Combined Theoretical Model
Source: The Author

5. CONCLUSION

5.1. THEORETICAL IMPLICATIONS

The main goal of this study was to understand the many different ways in which blockchain applications can impact the TCE, the key idea being that since blockchain is a foundational technology (IANSITI & LAKHANI, 2017) the key constructs for the analysis must be the different types of applications that, being very different amongst themselves, can have very different impacts on the different types of transaction costs. The same logic was used to investigate complementary technologies and antecedent factors, in that, being very different amongst themselves, they too can have very different impacts on the development, adoption and potential of blockchain applications.

To investigate those relationships first the transaction costs were divided into the four dimensions proposed by GROVER & MALHOTRA(2003), then the blockchain applications were divided into five types based on their mechanics, with the key distinctions being between static and dynamic information (CARSON ET AL., 2018) and system of record and platform types of applications (BAUERLE, 2017). Then the relationships were establish by conducting and analyzing interviews with blockchain experts of four different areas: consulting, technology, financing and academy. The findings from the interviews conducted show that the key idea was clearly right, with most types of applications impacting only two or less of the dimensions of transaction costs defined by GROVER & MALHOTRA (2003), and half of the dimensions being impacted by only one type of application. The big differences between the types of applications in number of mentions, number of mentions in connection with a dimension of transaction costs and number of dimensions of transaction costs affected also suggest they have very different potential for impact, or that at least some are much more developed and mature than others. The findings also showed that different complementary technologies and different antecedent factors can have very different types and levels of impact.

Most of the relationships derived from the literature were confirmed, and some were added, as can be seen in the seven propositions below:

Proposition 1*: Guaranteed Transactions applications are the most used among the five types, and the most associated with reducing transaction costs, both in terms of the number of applications with some impact and the number of dimensions affected.*

Proposition 2*: Identity Systems applications can reduce the effort to develop relationships between entities and reduce the risk of opportunism.*

Proposition 3*: Reputation Systems applications can reduce the effort to develop relationships between entities and reduce the risk of opportunism.*

Proposition 4: *Guaranteed Transactions applications can reduce the effort to develop relationships between entities, reduce the cost of handling problems in the relationship and reduce the risk of opportunism.*

Proposition 5: *Real Time Monitoring applications can reduce the costs to monitor partners in a relationship.*

Proposition 6: *Smart contracts are a key enabler of blockchain applications, but they are limited in their "smartness", possessing limitations of traditional contracts, and depending on the development and employment of artificial intelligence to achieve their full potential.*

Proposition 7: *The lack of scalability, regulation and physical-digital interface are some of the most relevant factors for blockchain adoption.*

5.2. MANAGERIAL IMPLICATIONS

For managers looking forward to use blockchain applications to improve the way they relate with their suppliers and their supply chains by reducing one or more of the four dimensions of transaction costs (GROVER & MALHOTRA, 2003)this study can help in two main ways. First, it can help them understand what kind of application is more appropriate for their needs. It establishes a classification of blockchain applications and then relates each type to the dimensions of transaction costs that can be affected by it. Then, a manager that has a problem with, say, the cost to address problems (GROVER & MALHOTRA, 2003) once they appear in their relationship with a supplier and is thinking about using a blockchain application to help him with it, will look into the category of Guaranteed Transactions applications instead of all the possible applications, since this is the category associated with reducing this type of transaction cost.

Second, it can help managers understand possible risks and limitations of using blockchain applications by pointing out and analyzing the main antecedent factors related to them. So, for instance, if a manager wants to implement a very large scale blockchain application, he must mind the fact that scalability is still a big issue with current applications, and that centralized applications nowadays can be scaled up more easily. He must also be mindful of the double edged sword that is government regulation, and that the effectiveness of an application developed during the current regulatory environment might be affected by regulatory changes in the future. With the most relevant antecedent factors pointed out in this study, managers can better focus their attention instead of having to monitor factors that are not so relevant.

5.3. LIMITATIONS

This study has some limitations, the most relevant of which is that the relationships established are only qualitative, and the study doesn't provide a measure of their intensity. Therefore the study is answering the question about how the types of application impact the each dimension of transaction costs, but it is not answering the question of how much. The number of times each type of application has been associated with a dimension of transaction costs could be a proxy for how common is that association, but it would still not capture its intensity.

The second limitation of this study derives from the fact that, even though understanding the impact of each type of application on transaction costs, and the impact of each type of complementary technology and antecedent factors on the applications is a necessary step to understand the overall impact from the blockchain technology on the transaction costs theory, it is insufficient. Without understanding how (and how much) each type of application will develop and be adopted, and how will complementary technologies and antecedent factors behave in the future, one cannot forecast an overall impact, because of uncertainty about the independent variables of the equation.

Third, some authors argue that the TCE predictions should be combined with the predictions of other theories like the resource-based view (MCIVOR, 2009) in order to better understand the impact of the blockchain in issues like outsourcing, an aspect this study does not deal with.

Finally, because most of the experts live and work in Brazil, the results might be biased for the Brazilian perspective, and might not be generalizable for other countries (that limitation is mitigated by using an expert working with blockchain abroad).

Despite the limitations the study reaches its objectives, which was to understand the many different ways the blockchain applications can impact the TCE, not by how much, and not the overall, aggregated, projected impact given the discovered relationships, which can be investigated in future studies.

5.4. SUGGESTIONS FOR FUTURE STUDIES

First, future studies can utilize the same classifications of applications and transaction costs to replicate and therefore validate the findings of this study.

Second, as mentioned in the previous section, this study can be complemented by studies investigating the strength of the described relationships between types of applications and dimensions of transaction costs, complementary technologies and types of applications and antecedent factors and types of applications.

Third, as also mentioned in the previous section, this study can be complemented by studies investigating the evolution of each type of application, complementary technologies and antecedent factors, therefore, in conjunction with this study, being able to better understand the overall impact of the blockchain emergence on transaction costs.

Fourth, studies using different divisions of types of applications and types of transaction costs can offer different perspectives on the impact of blockchain applications on transaction costs. One could, for instance, divide applications by which generation they belong to (EFANOV & ROSCHIN, 2018) and then investigate the impact of applications from each generation.

Finally, as there was not a clear consensus by the experts on this study about which mode of governance would benefit the most, further studies are necessary to try to establish that, or at least establish clear conditions under which each mode should benefit from the blockchain applications.

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APPENDIX - Interview Script

Research Question: How can the blockchain affect transaction costs across different governance structures?

Part 1:

A. In the TC literature, Grover has proposed 4 dimensions of transaction costs (explain each one of them). For each one of them, how do you think using the blockchain can impact that dimension of costs? (focus on the applications of the blockchain and how they can be used to affect that dimension) Which one would be the most impacted?
   a. Effort required in developing the relationship (effort)
   b. Monitoring the performance of the supplier (monitor)
   c. Addressing problems that might arise in the relationship with the supplier (problem)
   d. The likelihood of the supplier taking advantage of the relationship (advantage)

B. Explain the 4 governance structures proposed by Williamson
   a. Market – When a farm owner buys fertilizer from some supplier
   b. Trilateral – The contractor for building a industrial facility and the company agreeing to use an outsider architect as an expert to determine if certain objectives have been met
   c. Bilateral – An outsourced catering service inside a company, where quantities, menu, etc can be constantly changed while some parts like prices remain more or less constant
   d. Unified – When the activities are performed by the company itself (For instance a verticalized oil company that extracts and then refines oil)

C. With the use of the blockchain, which of those 4 governance structures stands to benefit the most and/or become more common? Why? (Focus on the Applications/ can be for a sector that you know)

D. With the use of the blockchain, which of those 4 governance structures do you believe tends to become less common?Why? (Focus on the applications/ can be for a sector that you know)

Part 2: Key uncertainties

There are, of course, several big uncertainties related to the blockchain technology, like regulation, adoption by big companies, existence of an ecosystem of developers, etc. The way those uncertainties behave might affect the adoption of the blockchain, what kind of applications get developed and how they impact what we discussed before of the coordination (transaction) costs and the relations (governance structures) between companies.

A. Use list below to serve as examples in case interviewee doesn't understand question
    a. Internet of Things development/adoption
    b. 3D printing development/adoption
    c. Government Regulation
    d. Government Adoption
    e. Emergence of ecossystem of Developers for the platforms
    f. Big companies championing blockchain
    g. Data privacy concerns from the public
    h. Financial markets backing (e.g.: ICO activity)
    i. Data security development (e.g. : frequent exchange hacks)

B. Because of that, I would like to discuss what are the two main uncertainties regarding blockchain and why.

C. Then I would like to discuss how the different possibilities for those uncertainties can affect the applications for the blockchain and therefore the coordination costs and the trends for the shift between governance modes of the relations between companies.