Smart contracts and Transaction Costs Economics

RESEARCH MASTER THESIS

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I would like to thank my parents and my wife, whose unconditional love and support made this possible.

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CHAPTER 1

INTRODUCTION

1.1. Introductory remarks

Imagine that you are in a street market. Merchants offer you vegetables, fruits, eggs, fish and the like. If you are interested in a specific good, you give the offeror the amount of money that she requests. You take the article and continue your promenade. In such a scenario, the role of formal contract law, as developed by legislation and jurisprudence, is of nil importance.

Now, imagine that you are the chief executive officer of a Dutch firm that imports the vegetables that are later sold in the aforesaid street market and the main supermarkets in the country. After a debate with the managerial board, you decided to incorporate *exotic* fruits to the broad array of products that your firm offers. After doing your research, you decided to import dragon fruits. You identified an exporter in Ecuador who seems trustworthy and is offering you the product for an attractive price. However, it is a risky transaction. You do not know the exporter very well, he might deliver a product of inferior quality, or maybe he will not deliver anything at all. He is in a similar situation, though. He does not trust you; he is afraid that you might receive the fruit and do not pay him the amount of money that you both agreed. What to do? How to make the *wealth-maximizing transaction* happen?

That is when formal contract law comes into place. Consider the following. Neither of you trusts each other because it is in each other's best interest to keep some relevant information private (information about the quality of the good that is being exchanged or your actual willingness to abide by the agreement, for instance). Thus, it can be said that the information that each one possesses is not equal, nor in quantity nor in quality; and this is the source of uncertainty (Talley, 2009, p. 774) (Williamson, 1985, p. 66). Given this lack of information, which hinders the growth of trust between the parties, both of you decided that it is best to draft a contract that will serve as a backup system in case any of you decide to breach the agreement. The potential enforceability of a contract acts as a counterweight to the incentives for breaching the agreement. However, once the contract is signed, several questions arise. What is the law that governs the contract? In which jurisdiction will an eventual trial take place? How much will the proceedings cost? Even if you win the case, how likely is it to execute the judicial decision? Does this person have enough assets or liquidity that could be garnished to cover the ruling? Considering all the above, you both decided that the contract is not enough because no matter how good the contract seems to be, its enforcement (in case of a breach) is certainly good to be very costly and uncertain.

Now, you may not trust each other, but you both trust an international bank, whose reputation has been steadily built throughout the decades. After entering into an agreement with the bank (that is dependent upon the original import/export agreement), it issues a bank guarantee whereby it promises to cover the debt should the Dutch importer fail to settle it. Now, you both feel sufficiently safe to execute the transaction. The Ecuadorean exporter delivers the fruit, and you pay him as soon as you check that the fruit arrived in full satisfaction. Contracts helped to overcome the parties' distrust of each other; they made a transaction happen.

Two important lessons can be drawn from the short story told above. The first is that contracts are an important commitment – legal – devices, that help the parties to protect themselves against the opportunistic behavior the other. They offer a real (civilized) possibility to enforce a promise, should a breach occur. The second is that there is a multi-billionaire industry around trust. People need trustworthy intermediaries to secure their transactions.

This work is precisely about trust between the parties to a contract. We are going to discuss here how new technology, namely, blockchain, can be used to create a new type of contract, a digital one; one with which the execution of a contractual obligation is not up to the other party, but is programmed in software. The instructions coded in the software are immutable and hack-proof; therefore, the parties can be absolutely certain that they will get what was promised to them. Not as a matter of trust, moral or law; but as a matter of logic. They do not need to trust one another; they just need to trust the technology. As a consequence, transactions can be done through the internet with anonymous users. It does not really matter who is on the other side, as long he has the resources and signs the agreement. And perhaps, more importantly, because the software makes the agreement self-enforceable, the parties can do away with costly intermediaries and do businesses directly. This is the reality of smart contracts.

1.2. Literature review

In this work, we will analyze smart contracts and how well they perform at securing the enforcement of an agreement, facilitate efficient exchanges and reduce transaction costs at the same time, compared to traditional contracts. To our knowledge, no research has been done specifically about this topic. Therefore, we will need to address each element independently (*contracts, smart contracts, transaction costs and the elements of a transaction*) to draw normative conclusions about the use of smart contracts from the legal and economic perspective. So, the first thing we need to do is to define what a contract is. According to the American Law Institute, a contract is: "a promise or a set of promises for the breach of which the law gives a remedy or the performance of which the law in some way recognizes as a duty" (American Law Institute, 1981). From this definition, we draw attention to the notion of "promise" and "enforcement." Contracts are legal devices to make promises enforceable. They *back up* the agreement, so to say, thereby providing the additional trust that the parties need to manage the risk of a breach or incomplete, deficient or unsatisfactory performance.

Now, smart contracts also accomplish the role of securing the enforcement of promises, but they do so in a different way, without resorting to the legal system. There is still no solid consensus around the definition of the term "smart contract.", however, we will summarize here the most adequate definitions in the literature. Werbach and Cornell, for instance, define them as: "an agreement in a digital form that is self-executing and self-enforcing" (2017, p. 6). Savelyev defines them as: "agreements existing in the form of software code implemented on the Blockchain platform, which ensures the autonomy and self-executive nature of Smart contract terms based on a predetermined set of factors" (Savelyev, 2017, p. 1). Bartoletti and Pompianu define them as: "Computer programs that can be consistently executed by a network of mutually distrusting nodes, without the arbitration of a trusted authority" (2017, p. 1).

But the very first definition ever coined of the term smart contract was produced by Nick Szabo, more than 20 years ago. He defined smart contracts as a set of computerized algorithms that are coded to perform contractual obligations. He conceived them as a way to formalize and secure contractual relationships, as a replacement for the institutional arrangements offered by contract law. He proposed to add cryptographical measures as a way to secure the integrity of the code so that the parties can be certain that it will behave exactly as they wrote it (Szabo, 1997). Nowadays, those cryptographical measures envisioned by Szabo have been outperformed substantially by the absolute inviolability of blockchain technology.

For the purpose of this work, in brief, we will conceive Smart contracts as technological devices whose purpose is to code (into the software) the terms and conditions of a contract in order to automatize its performance in an immutable way. Hence, the parties can be absolutely certain that the obligations are going to be performed exactly the way they coded them. A piece of software behaves exclusively as programmed; it is intrinsically logical; thus, unlike in human contractual interactions, there is no room for opportunistic behaviors. Inextricably associated with smart contracts is blockchain, the technology that makes smart contracts' code inviolable. Blockchain will be defined as: "a decentralized distributed database of all verified transactions that take place across a P2P-network system operating on cryptographic algorithms" (Savelyev, 2017, p. 119).

As previously stated, this is work will offer a comparative view of the way in which traditional contracts and smart contracts help to advance the economic objectives of contract law. In very broad terms, we will assume that the main economic objective of a contract is to facilitate exchanges that "move resources from less to more valuable uses" (Posner, 2014, p. 124). Contracts and contract law become more relevant when the parties do not execute their obligations simultaneously. Then, the parties will have to face a *process of exchange*, that comes with two dangers, namely, opportunism and unforeseen contingencies (Posner, 2014, p. 124). Contracts are a devised to moderate these dangers. So, the exchange has a cost; contracts are part of those costs. They help to carry out the exchange, and they can do so in a more or less efficient way.

Paramount to this comparative study is the notion of transaction costs, which Coase defined as the costs associated with using the market to find more valuable uses and move the resources accordingly. Some of these costs involve finding a trustworthy trading partner, learning what the prices are for every relevant item and location (*searching*), negotiating and concluding a separate contract (*bargaining*) for each transaction to safeguard against opportunism (*supervising and enforcement)* (Coase, 1937, p. 390).

A different approach was advanced more recently by Williamson, Nobel laureate (2009) and one of the founders of the *transaction costs economics* field of study. For him, the notion of transaction cost is tied to that of **governance**. In essence, transactions need to be governed to avoid potential conflicts to derail the opportunity to conduct a mutually beneficial exchange. Contracts are a mean through which the parties can infuse order into the exchange process. Indeed, conflict without order works as a counterweight that may trump the mutual gains stemming from the transaction; the transaction is, therefore, the unit of analysis (Williamson, 2005, p. 3).

In this view, to study transaction costs is to study *what exacerbates conflict and complicates governance*. Informational deficits (unobservability, unverifiability, information asymmetry), uncertainty, opportunism and asset-specificity are *the main forms of **contractual hazards***; and therefore, *the main **sources** of transaction costs*. Williamson studied all informational deficits as a problem of bounded rationality (1985, p. 44); however, for a more comprehensive analysis, we relied on the aforementioned distinction advanced by Hart and Holmström (Hart & Holmström, 1987).

So, the parties need to identify and understand these contractual hazards in order to mitigate them through governance. Williamson defined governance as: "the means by which to infuse order, thereby to mitigate conflict and realize mutual gains" (2005, p. 3) or "the means by which order is accomplished in a relation in which potential conflict threatens to undo or upset opportunities to realize mutual gains" (1996, p. 12). He further stated that the economics of governance is "an exercise in bilateral private ordering, by which I mean that the immediate parties to an exchange are actively involved in the provision of good order and workable arrangements" (Williamson, 2005, p. 1). The central point of that bilateral private ordering is concerned with the "identification, explication, and mitigation of all forms of contractual hazards" (Williamson, 1996, p. 5). We need to keep that in mind as we develop the argument of this work.

The aforementioned contractual hazards are variable, in the sense that they do not always affect transactions in the same way. They all have to be considered when designing a governance structure that works efficiently under the given circumstances. In consequence, we will proceed to provide a definition for each one of those contractual hazards, which has been obtained from a systematic review of the relevant literature.

Inherent to the notion of transaction costs and governance is the notion of **information**. For some authors, at the root of all the forms of contractual hazards (from which transaction costs – governance costs – emerge) is the lack of sufficient information, both in quantity and quality. As Professor Allen puts it: "Regardless of which stream of literature is examined, the underlying theme for transaction costs is the notion of ignorance. Negotiation, fraud, communication and contract stipulation all come about because knowledge is incomplete and not common" (2000, p. 906).

This assertion could be illustrated with a simple example: a contract with a taxi driver to take a passenger from point A to point B, might seem like a simple one; however, many things could go wrong. The taxi driver doesn't know if the passenger is planning to flee from the car without paying the bill, the parties have not established who would bear the risk of a car accident that could impede the taxi driver from fulfilling his obligation; furthermore, they have not discussed the route to take, or what to do in case the road is closed. In sum, there are many "gaps" in this contract, and they can all be attributed to the lack of information. Therefore, if parties wanted to overcome some of the aforementioned issues, they would need to devote some resources (time, energy and money) to make the information available, to himself or to both parties. As can be readily seen, without information, governance is not possible.

The information that each party has is hardly ever the same. This is referred to in the literature as the information asymmetry problem. Mankiw defines information asymmetry simply as: "a difference in access to knowledge that is relevant to an interaction" (Mankiw, 2015, p. 462). The circumstances would make one of them control some relevant information referring to his part of the deal; and, since it is in the best interest to keep some of that information private, the other party would need to make some investments to try (perhaps unsuccessfully to unravel and reconstruct the missing information. Meanwhile, that important information would remain "**unobservable**" to one of the parties or both (Bag, 2018, p. 6). What remains unobservable to one of the parties, by definition, cannot be described and if it cannot be described it is, in essence, non-contractible (Bag, 2018, p. 93).

In the end, this situation of bilateral information asymmetry prevents the parties to act in a full information environment. Without full information, the decision-making process is hindered. Hence, after going through an expensive and time-consuming negotiation process, the best possible outcome is an *incomplete contract* that is very likely to be suboptimal. We mean suboptimal, in the sense that the bilateral information asymmetry and the fear of disclosing key information to the counterparty, prevents the parties from finding the most efficient (profit maximizing) arrangement. Again, without sufficient information, adequate governance mechanisms cannot be devised.

Another important source of informational problems is that of **unverifiability**. Sometimes, even if the information is observable by both parties (meaning that it is not private; i.e., it is symmetrical), it is not *verifiable* to third parties who are vested with the responsibility of adjudicating contractual disputes, such as courts or arbitrators. It occurs when: "the parties to a contract share the same set of information (i.e., information is symmetric between the parties), but no third party (such as a court) can observe this information" (Bag, 2018, p. 27). Hart and Holmstrom explain that, in this case, the contract is rendered incomplete because "the states of the world, quality, and actions" are observable to the parties, but not verifiable to the outsiders such as courts (Hart & Holmström, 1987). This is also a form of information asymmetry, not between the contractual parties, but with respect to the outsider adjudicators. Unverifiability is, at least, as important because these outsiders accomplish a crucial role in the contractual relationship, namely, enforcing the agreement and undermining the profitability of opportunistic behavior.

Both unobservability (ex ante and ex post) and unverifiability are elements which bolster **opportunism**, which is approached by some authors as "moral hazard." Mankiw, for example, defines a moral hazard as: "the tendency of a person who is imperfectly monitored to engage in dishonest or otherwise undesirable behavior" (Mankiw, 2015, p. 462). Williamson, on the other hand, defines opportunism as "self-interest seeking with guile" (Williamson, 1985, p. 47).

Opportunism is, again, a core issue in transaction costs and the *governance* of transactions. It is what drives conflict. It involves pervasive efforts to "to lie, cheat, steal, mislead, disguise, obfuscate, feign, distort, and confuse" in order to claim dishonestly some of the other party's surplus that is being created by the transaction; in short, to take advantage of the other party in a deceitful manner (Williamson, 1985, p. 51).

Opportunism refers to the intention to deceive, which could not be realized but for information asymmetry. The adverse consequences of opportunism could be suppressed from the outset if parties had full information and full rationality, which might help the parties to avoid being deceived. If both parties knew in advance how the other one will behave and what future events will take place, they could device appropriate safeguards that would make it inefficient for each one to breach the agreement. However, even with contractual safeguards in place, the vulnerable counterparty still needs to invest a considerable amount of resources in supervising or monitoring the contractual performance, in order to avoid being deceived.

Another issue that affects the *governance* of transactions is **uncertainty**. Williamson understood uncertainty as the probability with which – disturbances in the original conditions that require sequential adaptations – arise (Williamson, 1985, p. 57). There are some other definitions, though. Ellsberg, for example, referred to uncertainty as ambiguity, which arises when the parties do not know and cannot estimate the probability of an event taking place (Ellsberg, 1961).

There is, yet, another distinction to be made with regard to the randomness of events. This alternative view relates the concept of uncertainty with ignorance of the future. Events of the future are then classified as a) those that can be conceived and managed (ex ante) through a contract that will purportedly allocate the probability of its occurrence in favor (or in detriment) of one party or the other; and b) those that are so unfamiliar to the parties that they simply cannot conceive them ex ante, and, hence, must be handled by the parties ex post by resorting to general principles extracted either from the contract or the law. The first category refers to the notion of risk, while the second refers to the notion of uncertainty.

In the economic literature, the first one to advance this distinction was Knight. He argued that since our knowledge of the world is incomplete, there will be several instances in which we cannot properly classify the possible outcomes; either because we do not know what the possible alternatives are, and or because we cannot order those alternative (future) states of nature into meaningful categories that make sense not only to ourselves but also to the other party with which we are trying to establish a contractual relationship (Knight, 1921, p. 231). This is usually the case when the parties are dealing with new products or services (emerging markets) for which the relevant community (the participants of the market) has not yet built widely shared conceptual categories. This is what an insurance company does, for example, when they organize concepts such as "the destruction of a house due to force majeure," a "traffic accident," "medical malpractice" and so on (Langlois & Cosgel, 1993). This exercise demands not only creativity and/or imagination, but also to be familiarized with the specifics of the object of transaction and the conditions of the market (consumer preferences, for instances) in order to create categories (estimates) that are effective at reducing ex ante negotiation costs, and facilitate renegotiation and dispute resolution.

Greater uncertainty, in the Knightian sense, accounts for larger contractual gaps which, in turn, account for contractual incompleteness. It is contractual incompleteness what generates the opportunity for ex post haggling and costly renegotiation. The parties to a contract where the uncertainty is high will be more likely to face situations where sequential adaptations will be required as the unforeseen circumstances unfold (allowing for the opportunistic behavior from the advantaged party) hinder satisfactory contract performance. Thus, ex ante (searching and negotiation) and ex post transaction costs (renegotiation, supervision, and enforcement) are positively correlated with uncertainty; the greater the uncertainty, the higher the transaction costs.

There is still another relevant sense in which the term "uncertainty" has been coined, namely, "behavioral uncertainty." The term is defined by Williamson as a type of uncertainty that arises from "strategic non-disclosure, disguise, or distortion of information" that translates into "the possibility that the parties make strategic plans in relation to each other that are the source of ex ante uncertainty and ex post surprises" (1985, p. 57). This type of uncertainty derives from opportunism, which was previously presented as a source of transaction costs.

Finally, the last element that complicates the contracting process and, hence, affects the choice of governance structures is that of **asset specificity**. Joskow conceptualizes specific assets as investments that are *sunk*, in the sense that, once initiated, the investor is locked up with the trading relationship, for the assets *cannot be* *redeployed* to a second alternative best use without significant detriment (Joskow, 1984). For their very nature, specific design or function, they are produced to be deployed to the benefit of the counterparty, almost exclusively. It could be the case that they could be redeployed to an alternative use but at a significant cost (sometimes, even higher than the cost of the initial investment). Whyte posits that asset specificity refers to "the existence of significant transaction-specific sunk costs, which are durable on re-deployable investments in a transaction that thus have little use or economic value outside the buyer-supplier relationship" (Whyte, 1994, p. 288).

Think for example, of an application (software) designed to be run on a specific operative system, like a GPS navigation system that runs exclusively on the operative system of a particular automaker; or of a contract between a business that produces turbines for airplanes and Boeing, to design and produce the turbines of its new and revolutionary airplane model; or of a medium-size business that moves its factory right next to his major trading partner (located in a faraway region) in order to curtail transportation costs. In all these cases, the physical and human capital cannot be redeployed outside of that commercial relationship.

In this respect, Joskow argues that: "sunk investments generate a stream of potentially appropriable quasi-rents equal to the difference between the anticipated value in the use to which the investments were committed and the next best use" (1984, p. 37). Indeed, once an investment with a high degree of asset-specificity has been initiated, the investor places himself in a position where he is extremely vulnerable to the opportunism of his counterparty. In all the previous cases, the investor's counterparty can behave unscrupulously and request to renegotiate the contract after the investment has initiated; or else, cancel the ongoing relationship and procure the good or service from another supplier.

Indeed, in such cases where the degree of asset-specificity is significant, costly ex post haggling and renegotiation is likely to occur, motivated by the opportunism of the advantaged party. That is why it is an important element to consider when evaluating the costs of governing a transaction. However, these ex post transaction costs (namely, haggling and renegotiation) can be reduced through contractual safeguards (maybe, even better, smart contracts). Still, the costs and uncertainty associated with resorting to the judicial system (to enforce the contractual safeguards) make it less attractive as an alternative to deal with opportunism. This hurdle, in turn, increases the payoff of ex post opportunism. On the other hand, in conditions where the reputation of the participants in a market is transparent, there is a strong incentive to respect the initial terms of the contract, for doing otherwise might affect the prospect of future business with other participants of the same market. Reputational constraints disincentivize the misbehavior consisting of holding-up maliciously to renegotiate the initial terms (Joskow, 1984). Therefore, as a corollary, we may say that asset specificity is a notion closely related to that of opportunism. Asset specificity is a characteristic of the reliance investment incurred with the purpose of executing a contract that leaves one party particularly exposed to the other party's ex post opportunism.

Now, part of this research focuses on understanding whether or not smart contracts help to moderate contractual hazards; and if they do, which ones and how? Indeed, understanding the purpose of contracts and the hazards that the parties have to face when using one (*to secure the exchange*) is vital to understanding in which way can smart contracts help. But that is an analysis on *smart contracts as governance mechanisms*; the analysis would not be complete without exploring the different transactions to which we intend to apply those governance mechanisms. Transactions are not uniform; they have different characteristics or *dimensions*. Even if we conclude that smart contracts are efficient at attenuating certain contractual hazard, that would not mean that they are always a good governance choice. On the contrary, sometimes they will perform very well, while other poorly, depending on the attributes (dimensions) of the transaction. If we want to know when to use smart contracts, we still need to study the ways in which transactions differ.

Transactions differ in their attributes. In principle, all the contractual hazards that were previously studied are also their attributes, since they could affect a transaction to a larger or smaller extent. So, for example, in one transaction the parties could face high uncertainty and asset-specificity (for example, because they are investing in a new technology that will benefit specifically one of the parties), while in other the level of uncertainty and asset-specificity could be low (because they are trading standardized items). We could try to mix all the contractual hazards to create a matrix from which we could derive a typology of transactions but that would be unnecessarily complex. Williamson simplified the analysis by selecting three critical attributes of the transactions, which he called the *dimensions*, namely, *uncertainty*, *frequency,* and *idiosyncrasy* (that is closely related to asset-specificity) (1979, p. 239).

Williamson was the first one to *dimensionalize* transactions (which is necessary to determine in which types of transactions it is efficient to use smart contracts as governance mechanisms). He contended that one should approach the study of transactions from three different **dimensions**, we have already studied uncertainty. Frequency is a self-explanatory concept that refers to the repeating pattern with which a transaction takes place (Williamson, 1985, p. 60). It has implications on the extent to which the costs of setting up a contract can be recovered. The last dimension of transactions is idiosyncrasy. It is theoretically connected to the notion of *asset specificity* and the *discreteness* of a contract. A transaction is highly idiosyncratic whenever the investment that one party makes is tailored to the specific needs of the other party, and, thus, would not be useful to other customers without incurring in significant adaptation costs. Hence, the parties tend to experience a lock-in effect, with respect to one another. On the contrary, when the object of exchange is not specifically tailored to the need of the counterparty but is highly standardized, a discrete transaction can take place. A discrete transaction is that in which the parties exchange a non-specific object at the given market price, thus, there is no need to establish a significant long-term relationship, as they can readily switch to another provider in the event that transaction is not satisfactory. The continuance of the relationship is not essential for realizing the profit from the exchange (Williamson, 1979, p. 249).

Recognizing that transactions are not uniform, he purported to advance a typology of transactions for their better understanding. He proposed to use a matrix considering uncertainty, investment specificity (idiosyncrasy), and recurrence of transactions (frequency) as the defining characteristics of transactions. To further simplify the analysis, he assumed that all transactions have an intermediate degree of uncertainty. From there, he used three different degrees of frequency, namely, one-time, occasional and recurrent transactions; and three different degrees of investment specificity, i.e., non-specific, mixed and idiosyncratic. Since one-time transactions are unrealistic (they may exist, but in such extraordinary circumstances that it is not worth complicating the analysis, Williamson argued), he disregarded their analysis. The result was the 2x3 matrix that is presented below (1979, p. 247):

		Investment characteristics		
		Non-specific	Mixed	Idiosyncratic
Frequency	Occasional	Purchasing standard equipment	Purchasing customized equipment	Constructing a plant
	Recurrent	Purchasing standard material	Purchasing customized material	Site-specific transfer of intermediate product across successive stages

Table I: A typology of transactions (Williamson, 1979, p. 247)

What Williamson did was to match each governance mode, namely, market, hierarchy, and hybrids with each type of transaction. A fundamental insight of his work was that the way in which a transaction is to be governed effectively (the characteristics of the bilateral ordering) differs across the different types of transactions (depending on their dimensions). An intuitive consequence is that simple contractual relations should be governed by means of a simple governance structure, otherwise the parties would incur in significant unnecessary costs. This assertion was named the “discriminating alignment hypothesis”. It has fueled an ongoing debate in the field of transaction costs economics, with regard to the optimal governance structures for each kind of transaction. Indeed, governing a transaction (mitigating the contractual hazards) of a transaction performed under conditions of high uncertainty and high asset specificity is not as extenuating and costly as governing one where the object of a simultaneous exchange is a highly standardized object (a discrete transaction).

So, to summarize, smart contracts are mechanisms through which the purpose of a governance structure is realized. They are qualitatively different than traditional contracts in the sense that they offer the parties the possibility to preestablish a self-executable remedy in the case of breach. The enforcement itself is predetermined and unavoidable from the outset, which means that all opportunities to behave opportunistically are suppressed. Another critical difference is that they are written in computer code, which makes them inflexible and unable to include open-ended terms and conditions. Because they are qualitatively different, the existing theories with regard to the governance of contractual relationships cannot be readily applied to smart contracts.

After reviewing the body of knowledge, we have concluded that both traditional and smart contracts accomplish the task of mitigating contractual hazards (for which, the parties must incur in transaction costs). However, we do not know how well-suited are smart contracts to moderate each contractual hazard, compared with traditional contracts (i.e. which ones perform better at the lower transaction costs). Neither has the literature answered the lingering question of when to use smart contracts. We can anticipate, though, that there is no conclusive right-answer. Nevertheless, the use of a well-established typology of transactions and theories from transaction costs economics contributes to make this work as systematic as possible.

1.3. Objectives

This research purports to study smart contracts from the perspective of their transaction costs to determine in which cases their use is convenient. This research does not intend to provide the ultimate and conclusive answers. Instead, the scope is more limited. It will offer theoretical clarification to provide sound criteria to decision-makers. It intends to do so by revisiting the literature of the law and economics of contracts, which has been profoundly disrupted by the emergence of smart contracts. Indeed, for the reasons that will be later explained, the law and economics literature on contracts is not entirely applicable to smart contracts. It has not been discussed exactly to what extent. Hence, the body of knowledge is in need of a work that updates the literature and fills that gap. The outcome will serve as a guide to business lawyers and will clear the path for further legal (perhaps empirical) research in the field.

1.4. Relevance

The example previously mentioned in the introduction is no science-fiction. Samsung SDS (the division of logistics and IT of the company of the same name) recently announced an alliance with ABN Amro Bank (one of the largest Dutch banks) and the authority of the Port of Rotterdam. The purpose of the alliance is to conduct safe international trade and logistics operations through the blockchain, using smart contracts. The authority of the Port of Rotterdam will track the container through its shipment from Asia to Europe, offering reliable external information to the smart contract. Other logistics operators, such as Societé Générale, have also announced that they have successfully concluded their first tests using smart contracts to deliver agricultural commodities internationally.

What this tells us is that smart contracts are a reality and that they are likely to become mainstream instruments in the near future. However, the legal and economic scholarship is still showing fundamental gaps. The traditional law and economics analysis of contracts still operates under assumptions that smart contracts have overthrown. It is, therefore, fundamental to conduct research to fill those gaps in order to make economic predictions grounded in sound theories that would prevent us from making a hasty and inefficient use of the technology.

1.5. Research question and methodology

Given the complex and new scenario posed by smart contracts, the researcher posits that it is necessary to advance the legal knowledge by answering the following research question:

> Considering the different dimensions of transactions, as studied by transaction costs economics, under which conditions are smart contracts a better governance mechanism than traditional contract provisions?

To answer the main research question, it is necessary to go through the following research sub-questions:

1. What are the attributes of smart contracts as governance mechanisms?
2. How well do smart contracts moderate contractual hazards?
3. What do we gain and lose, in terms of transaction costs, when using smart contracts instead of traditional contracts?

1.6. Methodology

This will be a theoretical research which will rely on the commonly accepted economic and legal theories to analyze contracts as a bilateral ordering whose function is to mitigate the hazards associated with non-simultaneous exchanges, at the lowest cost possible. This work will not contain empirical research on its own; instead, it will rely on the most updated academic legal and economic articles published in journals of law and technology to survey the actual capabilities, features, and limitations of smart contracts.

In order to answer the research question and sub-questions, we will begin by describing the generally accepted theories regarding the economics of contracts, to proceed then to study the defining features of smart contracts. Then, as one of the purposes of this research is to understand the transaction costs that the use of smart contracts entails, we will proceed to describe *in extenso* the economic theories of transaction costs and we will determine the ones upon which we are going to base our study of the efficient use of smart contracts as governance mechanisms within governance structures. We will proceed in the same way with regard to the different dimensions of transactions. Paramount to this analysis is the field of transaction costs economics and the work of Oliver Williamson for which he received the Nobel Prize in Economics in 2009.

Our goal is to establish a reliable theoretical framework to analyze the efficacy and efficiency of smart contracts as governance mechanisms. For that purpose we will base our analytical framework in the "*discriminating alignment hypothesis*", which contends that: "transactions, which differ in their attributes, are aligned with governance structures, which differ in their costs and competencies, so as to effect a (mainly) transaction-cost-economizing result" (Williamson, 2005, p. 5). That framework was used to match transactions with different attributes with governance structures (which also have different competencies). It involves, three analytical steps, namely: classifying transactions according to their most relevant attributes, classifying governance structures according to their competencies, and matching one with another to achieve transaction-cost-economizing results.

However, this research is not about governance structures (some examples of which are the market, hierarchies, hybrid structures and the public bureaucracy) but about the comparative efficiency of a specific governance mechanism, namely, smart contracts. From the aforementioned hypothesis we derive that some governance mechanisms are well-suited for some purposes, but poorly suited for others. Hence, our objective is to determine for which transactions are smart contracts well-suited and why? So, we will rely on the same approach with a slight modification. The typology of transactions developed by Williamson for this purpose is fully applicable but we will not match a type of transaction with a particular governance structure but each type of transaction with a particular governance mechanism (smart contracts), to predict how well-suited the mechanism is to deal with the contractual hazards associated with each type of transaction. Following this methodology, we will obtain the answer to the question of how and when *should* smart contracts be used?

For this endeavor, it is crucial to understand that transactions differ in their attributes. We will discuss what the most appropriate typology of transactions is, in order to align each one with smart contracts as a governance mechanism and predict, according to the defined economic theories, how well a smart contract would perform in each one of them at mitigating the hazards of the and facilitate the allocation of resources from less to more valuable uses, at the lowest cost possible. The analytical exercise will yield a guidance to determine how and when to use smart contracts for governing transactions and make the exchange process more efficient.

1.7. Outline

In the second chapter we will review the literature of contracts from the economic and legal perspective. From an economic standpoint, we will study how contracts are a necessary element to conduct a transaction where the exchange is not simultaneous. We will also define the concept of the costs of transactions and the different types of costs, with which we will be working throughout the remainder of the thesis. Next, in chapter 3, we will explore the attributes of smart contracts in general and as governance structures. In chapter 4, after having acquired a general knowledge of smart contracts and their attributes, we will study their advantages and disadvantages with regard to transaction costs; that is to say, which kind of costs are increased and reduced (in general) when using smart contracts to conduct an economic exchange. In chapter 5 we will start by describing a typology of transactions, considering that they vary in frequency, uncertainty and investment specificity (some will be occasional but highly specific, others will be recurrent but non-specific, and so on). Using the knowledge that we have previously acquired about smart contracts and their transaction costs, we will draw normative recommendations as to whether or not economic agents should use smart contracts to conclude the exchange, depending on the characteristics of the particular transaction. Only then we may proceed to tackle the research question and answer what the types of transactions for which smart contracts represent a better governance mechanism (considering the comparative advantages and disadvantages of traditional contracts) are; we will do so in the concluding remarks of this work.

CHAPTER 2
CONTRACTS, TRANSACTIONS AND THEIR COSTS

2.1. Introduction

In this chapter, we will critically review the literature to establish a consistent definition of the most fundamental concepts that we will use throughout this work, namely, contracts and transaction costs. We will review the economic and legal literature on contracts with the aim of understanding what their function in law and economics is. In this section we will deal with the question, why do we need contracts? And what do we need to consider to determine the costs associated with contracting? If they are costly, why do we insist on drafting them? Would we be better off without them? This is a necessary step to understanding the basics of transaction costs, which, in turn, is paramount to understand the ways in which smart contracts can help to reduce (or sometimes increase) the overall costs of concluding an economic exchange in a secure (safeguarded) way.

2.2. Back to basics, what is a contract?

To answer that question, we must start first by understanding what a contract is, in the ordinary sense. As previously stated, according to the American Law Institute, a contract is: "a promise or a set of promises for the breach of which the law gives a remedy or the performance of which the law in some way recognizes as a duty" (American Law Institute, 1981). For a civil law scholar, a contract is: "An agreement between two or more parties, whose object is to create obligations" (Alessandri, Vodanovic, & Somarriva, 1999, p. 109). The fact they create obligations distinguishes them from conventions, which can also settle obligations.

As it can be readily seen, the notion of "promise" has not brought much attention to scholars of the civil law tradition (Gordley, 2004). Under that line of reasoning, promises belong to the moral domain. Thus, they create nothing but moral obligations (Klass, 2014); while the defining feature of contracts is that they create *legally binding obligations*. Of course, there is a general moral obligation to comply with contracts, but its study is not part of the field of contract law. Actually, in the civil law tradition, the notion of promise has a different connotation. It denotes an independent contract itself, the contract of promise. In a contract of promise, one party obliges to conclude a specific contract in the future, upon the materialization of a predetermined condition (Alessandri et al., 1999). So, for example, parties can conclude a contract in which one of them promises to sell an office in a building that is still under construction.

The civil law scholars have focused on the notion of "legal act," instead. It is "an expression of a person's will whose object is to produce binding legal consequences" (Gómez Estrada, 2008, p. 2). Hence, a contract is formed when a person responds to a legal act addressed to him (whose object is to create an obligation) with another legal act by means of which, he accepts to create a legal relationship that binds him to the other party. The object of that legal bind is the obligation. Once a contract is concluded, it is, thereafter, enforceable. This approach is also supported by Barnett, who asserts that the core of a contract is not the promise but the "consent to be legally bound" (2014, p. 1). Indeed, this approach is convincing since the theory of contracts as promises cannot explain the presence of default rules (*that apply to contracts when the parties have not specifically addressed a situation that is, nonetheless, relevant*) or mandatory rules in contract law (*which institute prohibitions or mandates that the parties cannot leave unobserved, even when they would wish to do* *so*) (Barnett, 2014). Hence, a contract will be defined as a legal bind that is created with regard to the enforceability of a promise (with the limitations introduced by legislators and courts) upon the consent of the parties.

Nevertheless, even when we have established that a contract is not merely a promise, promises certainly are an important element of any contract; be it in the context of the civil law or common law tradition. It is just the case that that crucial function has been widely neglected by the civil law scholars. Indeed, the communication of one's will to be bound around an obligation (i.e., a legal act) carries a promise (to do something, to refrain from doing something, to give something, or to refrain from giving something). Every contract starts with the communication of a promise (which may or may not be offered in exchange for consideration). Hence, there would be no obligation without a promise for what one is obliged to fulfill is, precisely, the promise. The promise, then, lays at the core of the obligation.

2.2.1. What is a promise and why should we keep them?

So, a universal defining feature of contract law is that it serves the purpose of enforcing promises. But what is a promise and why should we keep them? A promise is, formally defined, "an invitation to trust" (Fried, 1982, p. 16). Materially, a promise may involve an undefined array of topics; but, generally speaking, one party *invites the other to trust* that he or she will behave in a specific manner. The promise has the intended effect on the other party because there exists a social convention (and a moral principle) that dictates that promises must be kept (Fried, 1982). If promises are to be enforced by means of the coercive power of the State, there must be a justification for such intervention. In the following sections, we will analyze such justifications, from the moral and the economic perspective.

2.2.1.1. Moral reasons

The moral justification for the exercise of State power to enforce contracts is provided by the moral principle of autonomy and trust (Klass, 2014). With regard to autonomy, the idea is that individual freedom is advanced by providing persons with the power to be legally bound to others around an obligation. For the right to create legal binds to be effective, it is necessary that the law prohibits one from reneging on a promise. In the battle of the future self against the present self, the present self must prevail and must be able to successfully bar the future self from reneging promises made in the past, for if one were allowed to retract after making the commitment, the power to shape one's relationships with others by creating legal binds, simply, would not exist. This is illustrated by the case of minors and contracts. Minors are allowed to withdraw from contracts that they conclude at any time and without any further justification. In doing so, the law denies their autonomy (Scott & Kraus, 2013).

Now, with regard to trust, the person who makes a promise and breaks it is committing an abuse of the confidence that the other party placed upon him. He is free riding on the public trust that society has built around the institution of promises. His behavior undermines the efficacy of the whole social enterprise that brings about important collective benefits. In terms of Finnis, one who breaks a promise is acting against the social pursuit of the "common good" (2011).

2.2.1.2. Economic reasons

The legal enforcement of promises can, however, be justified not only on moral but also on economic grounds. Several theories have been coined to explain the economic importance of enforcing promises. From the economic perspective, contract law is the body of law that “sets the rules for exchanging individual claims to entitlements and, thus, determines the extent to which society is able to enjoy the gains from trade”(Hermalin, Katz, & Craswell, 2007, p. 7). It is important to remember that those entitlements are established by property law in the first place. The primary role of contract law is to determine how those entitlements can be traded.

As previously stated, the trade of legal entitlements begins with a promise. The promise becomes necessary when the exchange is uncertain. In a simple situation, like the exchange of one kilo of potatoes on the street market for EUR 1, there is no use for a promise. The merchant hands the bag of potatoes, and the customer gives one coin representing EUR 1. However, when the exchange is not going to be performed directly and immediately, the parties have reasons to doubt as to whether the correlative obligation is going to be fulfilled or not. Cases like these, when the obligation is not fulfilled immediately, raise uncertainty (about what the other party will do). If parties do not trust each other, the uncertainty will triumph and will prevent the transaction from taking place. So, for example, if the party A expects to gain EUR 200 by selling a 1 Ton of bananas (worth EUR 1.000 to her) to her counterparty B in a distant city, but she is uncertain as to whether counterparty B will pay or not (she estimates that there is a 70% chance that she will receive the payment), the transaction is not expected to take place. A detailed explanation follows:

Let Pr be the probability that the transaction is going to be successful; Pf represents the profit that she is likely to obtain if the transaction is successful, and EV the expected value that is obtained by multiplying Pr by Pf. First, we are going to analyze the total payoff of the decision to sell, considering that there is a 70% chance that she will get gain EUR 200 and a 30% chance that she will lose EUR 1.000. In other words, if the exchange is successful, she will receive EUR 1.000 (gross billed value) from which she will get a profit of EUR 200 (after deducting the costs, which amount to EUR 800); but if she delivers the bananas and the counterparty does not pay, then she loses EUR 1.000 (worth in bananas) completely.

Decision to sell

$$Pr \ \ x \ \ \ Pf = EV$$
$$0.7 \text{ x } \ \ 200 = 140$$
$$0.3 \text{ x } -1000 = -300$$

Payoff of the decision to sell: -160

So, the decision to sell represents (mathematically) a loss of EUR 160 for her. This dismal result could be altered if we introduced a legally binding device (i.e., a contract) to enforce the promise to pay the money. In that way, we could lower the probability of a breach of the promise to pay, down to a, let’s say 2% (for instance). The result would then be that the decision to sell would yield a payoff of (positive) EUR 120 (EUR 140 - EUR 20). Now, we will study the decision not to sell. If she decides not to sell, she can be absolutely certain that she will not gain any money (there will be no profit), but she can also be absolutely certain that she will not lose anything (assuming she has other trustworthy trading partners).

Decision not to sell

Pr	*x*	*Pf*	=	*EV*
0	x	200	=	0
1	x	0	=	0

The payoff of the decision not to sell: 0

Thus, the decision not to sell the bananas represents a payoff of EUR 0. Even so, she would be better off by not selling the bananas, for selling them would mean that she would actually lose money. Hence, it is not in her best interest to enter into the transaction. Assuming that she is a rational actor, this model predicts that, without an enforceable contract, she will not sell the bananas. A transaction that could have made better off both parties will not take place; the surplus is not created.

The same principle holds for party B. He values the bananas at EUR 1.300 (perhaps he can resell them at that total price), but after bargaining with his counterparty, he got them at only EUR 1.000. That means that if the transaction is successful, he will receive a surplus of EUR 300. However, he estimates that there is a probability of 30% that he will pay the money and would not receive the bananas in exchange. If this happens, he will lose all his investment, i.e., EUR 1.000. That leaves him with a probability of 70% of getting EUR 300 in profits.

Decision to buy

Pr	*x*	*Pf*	=	*EV*
0.7	x	300	=	210
0.3	x	-1000	=	-300

Payoff of the decision to buy: -90

In this example, absent a contract, by buying the bananas he would actually lose EUR 90 in expected value. In the same fashion as before, if he decides not to buy, he can be absolutely certain that he will not gain any money (there will be no profit), but he can also be absolutely certain that he will not lose anything (assuming he has other trustworthy trading partners).

The decision not to buy

Pr	*x*	*Pf*	=	*EV*
0	x	300	=	0
1	x	0	=	0

The payoff of the decision not to buy: 0

Thus, it is not in his best interest to enter into the transaction neither. If we assume that he is a rational economic agent as well, the transaction will not take place.

Indeed, the main economic reason to enforce contractual promises is that the trade that they endorse creates a surplus. But the benefits extend beyond the creation of surplus. Bargaining, a necessary process in contracts, helps to distribute the surplus between the parties, thus allocating resources to the users that value them the most (Cooter & Ullen, 2013). Hence, to understand the economic role of contracts we must study further "bargaining," the process through which surplus is created and distributed.

Let's suppose that Muriel owns a tablet that he bought with the expectation that it would replace his big and sturdy laptop; it did not. He uses hardly ever uses it, so he wants to get rid of it and is willing to transfer its ownership to anyone who offers him more than EUR 50 (he values the tablet in EUR 50, so anything above that would be a surplus for him). On the other hand, Maria is a first year Law student. She is desperately looking for a tablet that she expects to use during her studies. Maria found the ad placed by Muriel on a website, where he was offering his tablet for EUR 175. He found the offer really interesting. She considers that the item is in good condition and it has some high specs, more than adequate for the kind of use that she expects to give to the tablet. Hence, she would have been willing to pay up to EUR 250 for the gadget. Even though, she thinks that she can get a bit more from the deal, so he writes Muriel and offers him EUR 150, Muriel responds by counteroffering EUR 160. Maria accepts, and the contract is concluded. Muriel will send the tablet over the mail and Maria will deposit EUR 160 on his account, once she receives the device at home.

As can be readily seen, there is a difference of EUR 200 between the reservation values of Muriel (50) and Maria (250). From the perspective of Muriel, at the selling price of EUR 160, he is gaining EUR 110 of surplus (since he gets EUR 160 for something that he values at just EUR 50); while from Maria's perspective, the deal is still good since she is getting for EUR 160 an article that she values at EUR 250 (therefore, she is gaining EUR 90). That is how bargaining helps to create a surplus. This particular kind of surplus receives the name of *cooperative surplus* and is defined as "the value created by moving the resource to a more valuable use" (Cooter & Ullen, 2013, p. 75).

Contracts play an important role in the creation of the *cooperative surplus*. They secure the enforcement of the promise offered in consideration against the promise offered by the counterparty during the bargaining process. Such is the central premise of the bargain theory of contracts: "A promise is legally enforceable if it is given as part of a bargain; otherwise, a promise is unenforceable" (Cooter & Ullen, 2013, p. 278). So, we can distinguish three core elements of the bargain: the offer, the acceptance, and the consideration; it is not, however, in the scope of this work to go deeper into the analysis of those concepts.

2.3. Economies of scale, markets, and contracts

Another reason that explains the existence of contracts is the efficiency that is realized through what economists call economies of scale, and through specialization. The idea behind this premises is that the marginal costs of producing one extra unit of a product or a service diminishes progressively with each extra unit produced. So, for example, if the firm "A" needs screwdrivers to produce chairs, it would make little or no sense to produce them themselves from scratch. The aforesaid firm would have to invest a prohibitively high amount of capital in obtaining just a few low-quality screwdrivers. The most efficient outcome is realized by acquiring the screwdrivers through the market mechanisms, from a specialized firm that produces the required items in such a large scale that allows it to amortize the fixed costs and sell them at a competitive price. By reducing the costs of producing those items, the final cost of producing the chairs is thereby reduced, which, in turn, will allow the firm "A" to sell the items at a lower price, to the benefit of the consumers (Sowell, 2010).

So, if an economic agent needs to acquire certain good or service, she has two options: a) acquire it through the market; or b) procure it to herself. Enormous economic efficiencies can be realized by using the market (*especially when the economic agent is an end-user*). But using the market to obtain the desired goods and services comes at a cost. The information may not be readily available to the parties, who may use this information asymmetry in their favor in an opportunistic manner. Hence, a considerable amount of resources needs to be deployed to devise safeguards against the other party's opportunism and the uncertainty that comes with it. Plus, costly and exhausting bargaining needs to be incurred in to devise those safeguards; and later, to supervise that the agreement is fulfilled in a satisfactory way, or otherwise to enforce it. In essence, those are the reasons why contracts exist, to secure the transactions performed through the market (Coase, 1937).

For now, it is important to bear in mind that, in order to realize the benefits of economies of scale that the market provides, some costs need to be incurred in. These are the costs of *contracting*. Sometimes the costs of engaging in contractual exchanges in the market are so high, that it is more efficient to integrate the unit that produces the required item into our own organization (by creating a new unit of production or acquiring an existing one through vertical integration) (Williamson, 1985); sometimes it will be more efficient to incur in those costs and obtain the item through contractual market exchanges.

Acquiring a good or service in the market necessarily involves two parties with irremediably opposing interests. They both wish to get the most out of the transaction, which is not possible, for market exchanges work, in many respects, as a zero-sum game (one party wins what the other loses). Since opportunism and bounded rationality (limited knowledge of the world) must be assumed from both of them (Williamson, 1985), they both must incur in costs (*ex ante* and *ex post*) to secure that the transaction takes place in a profit-maximizing manner. The logic of exchange disappears (*and all of its related costs*) once the good or service is produced within the organization.

Indeed, firms can also find it more advantageous to produce the good or service themselves. They can always hire new workers with the needed expertise, and invest in assets to produce the good or service themselves (if the expected utility of the operation justifies the investment). Alternatively, they could vertically integrate the independent producer into their own organization through a merger or an acquisition. However, they should also consider that, as the firm grows bigger, the managerial costs increase exponentially.

Coase goes so far as to state that the reason why firms exist is to reduce the transaction costs; that is to say, the costs of market exchange (Coase, 1937, p. 390). Indeed, it was Ronald Coase who most developed the concept as it is understood by the current economic theory. In his influential 1937 article "The nature of the firm," he pointed out that the firm was an entity whose economic function was to reduce the cost of using the price mechanism available on the market. Indeed, Coase's main contribution was the insight that using the market comes at a cost; i.e., the costs of information (learning what the prices are for every relevant item and location) and the ex ante and ex post costs of contracting for safeguarding against opportunism. This cost can be avoided by substituting the acquisition of an item in the market, with the production of that item within the firm (Coase, 1937, p. 390). At some point, under particular circumstances, it starts to make sense for an entrepreneur to hire workers and produce the items within his own organization than to conclude contracts with third parties. Clearly, this course of action will make the firm bigger; and bigger firms are harder to manage. Coase suggests that the optimal size of a firm is reached when the marginal cost of making one more transaction using the managerial system, equals the cost of making that transaction by using the price mechanism (Coase, 1937).

As long as the good or service is procured by an external source (namely, an individual whose stream of profit is separate and independent from the recipient of the good or service) the buyer (and, certainly, the supplier as well) needs to incur in some costs to make the transaction happen. Finding the right trading partner would be the first step, for which a thorough search and an ex post screening of the potential candidates is of the essence. Ever since, in that situation, opportunism is a serious threat, it is wise for the parties to safeguard against it. The most frequently used safeguarding mechanism is a written contract. These and many others are referred to in the literature as the transaction costs.

2.4. Transaction costs

After the previous introduction, it is now clear that using the market comes at a cost. Transaction costs are, indeed, commonly defined as "the costs of running the economic system" (Arrow, 1969, p. 59). Transaction costs may be so high that they could deter people from making a transaction they deem valuable. They may prevent transactions from happening. Thus, they constitute a deadweight loss that dilutes part of the potential social surplus. That is why some scholars have compared them with friction in physics, which hinders the economic and social machinery from running (Wicksell, 1906).

To illustrate the last point, let us reconsider the previous example of Muriel's tablet. Previously we assumed that the cost of making the transaction was 0, we went on with the example without considering what the parties had to pay in order to conclude the transaction satisfactorily. That is, of course, an unrealistic assumption. Let us assume that the website by means of which both parties found each other charges a publication fee of EUR 50 (which is paid by Muriel) and a contact fee of EUR 50 (which is paid by Maria to get the contact details of the seller, Muriel). Besides, the parties would need to incur in transportation costs to get the tablet delivered. The cheapest delivery service is offered for EUR 125. In the example, the cooperative surplus was EUR 200 (which we divided at 110 for Muriel and 90 for Maria). If we consider these new costs, it turns out that they exceed the cooperative surplus, meaning by making the transaction the parties would be worse off. From Muriel's perspective, he values the tablet at EUR 50, but he has to pay a EUR 50 publication fee and would have to pay the transportation costs valued at EUR 125, so his reservation value is now EUR 225, the lowest. He would not sell the tablet for less than EUR 225, or else he would lose money. Now, from Maria perspective, she is willing to pay as much as EUR 250 the tablet, but she has to pay a EUR 50 fee to negotiate with Muriel, so the tablet now must be sold for EUR 200, the highest. Since Muriel's reservation value is EUR 225, the least, we can anticipate that the transaction should not take place, for there is no surplus to be created; on the contrary, the parties would lose money by entering into the transaction. The parties would be better off by not making the transaction.

This example is also useful to illustrate what could be the single most important contribution in economic science, made by Ronald Coase in his influential article "The problem of social cost." There, he posited that the original allocation of resources (made by law or otherwise) does not really hinder the realization of the most efficient outcome if transaction costs are low enough." Let us consider for a moment that if there were no transaction costs involved, no matter who was the original owner of the tablet it would always (invariably) end up in the hands of the user who values it the most, be it Maria or some other potential buyer who was willing to pay even more for it.

Coase explains this idea with his famous example of the rancher and the farmer whose land is situated next to each other. First, he assumes that the law establishes that the rancher would be liable for the eventual destruction of the farmer's crops made by his cattle. If this is the case, the rancher will end up negotiating with the farmer to get to an efficient outcome for both of them, a result that makes everyone internalize the costs of his actions (externalities). Maybe the rancher would pay damages to the farmer, or perhaps he would pay the farmer to stop cropping his land or to crop something that is not likely to be damaged by the rancher's cattle. Maybe he would build a strong fence to protect the farmer's crops, or maybe the rancher would reduce the number of cattle to avoid paying more damages (Coase, 1960).

The same is true if the law determines that cattle are free to move around, even beyond their owner's land, and that it is other people's responsibility to protect their property from the cattle. The theory predicts that parties involved (the rancher and the farmer) would end up negotiating. The farmer may consider paying the rancher a fair amount to reduce the number of cattle; he may also consider building a fence or even reducing the volume of his crops to stop losing money.

The most important insight is that in both scenarios (regardless of who is liable for the lost crops: the farmer or the rancher), the number of cattle and crops produced will be the same. This intuition is the case because rational economic actors that are allowed and able to participate in a costless bargain, and will do so to achieve the optimal outcome. Hence, the cost imposed by externalities will end up being allocated (internalized) to the party that can deal with them more efficiently; or, what is the same, rights will end up being allocated to the party who values them the most (Coase, 1960).

In Coase's words: "It is necessary to know whether the damaging business is liable or not for damage caused since without the establishment of this initial delimitation of rights there can be no market transactions to transfer and recombine them. But the ultimate result (which maximizes the value of production) is independent of the legal position if the pricing system is assumed to work without cost" (1960, p. 8)

However, parties are never able to participate in costless transactions. Every transaction has a cost. Coase names a few examples: "In order to carry out a market transaction, it is necessary to discover who it is that one wishes to deal with, to inform people that one wishes to deal and on what terms, to conduct negotiations leading up to a bargain, to draw up the contract, to undertake the inspection needed to make sure that the terms of the contract are being observed, and so on" (1960, p. 15).

2.4.1. A typology of transaction costs

Dahlman formulates a taxonomy of transaction costs which he divides into a) Search and information costs; b) bargaining and decision costs; and c) policing and enforcement cost. He then admits that such classification, albeit functional, is "unnecessarily elaborate" because every single category could be explained in terms of lack of information. The potential buyer does not know where to find the good or service that he wants; once he finds him, he does not know his reservation price (which makes bargaining costly); and finally, a party must spend money to police compliance because he does not know if the other party is abiding by the agreement (Dahlman, 1979, p. 9).

Other authors like Williamson make a useful distinction between ex ante and ex post costs. In that respect, ex ante costs include the costs of finding a trading partner and then negotiating with him to put in place mutually satisfactory contractual safeguards. Finally, the agreement must be drafted to serve as evidence if disputes ever arise in the future with regard to compliance (Williamson, 1985). Ex post costs are the ones in which the parties must incur to police noncompliance and enforce the agreement, the latter only if deemed necessary.

In this point, it is important to introduce the notion of **complexity**. Complexity is positively correlated with transaction costs. The object can be complex because it involves several tasks that cannot be accomplished altogether at the inception of the transaction; and/or because they are indescribable, in the sense that it involves "events, objects or activities that are well known and understood to all the parties involved but that are impossible to describe in an exhaustive manner" (Al-Najjar, Anderlini, & Felli, 2016, p. 362). Both attributes prevent presentiation from being fully realized, for it is not possible to foresee, at the inception of the transaction, how the inevitable changes in circumstances during the execution of the contract will render the initial agreement inadequate. With complexity comes ***uncertainty*** and ***risk*** (two concepts often mistakenly taken as synonyms) which is a topic that we will later explore. A textbook example of a complex transaction is an employment contract, whereby the worker commits to perform several tasks "*to the full of his capacity*."

No matter how carefully and thoroughly the parties draft the agreement, it is always going to be incomplete in a meaningful sense. As Galanter puts it: "The variability of preferences and of situations, compared to the small number of things that can be taken into account by formal rules and the loss of meaning in transforming the dispute into professional categories suggest limits on the desirability of conforming outcomes to authoritative rules" (1981, p. 4). In other words, reality will always exceed the human capacity to foresee future contingencies; and even when a specific contingency was thought of by the parties and included in the agreement in the form of a formal rule, it will not be rich enough to fully encompass the will of the parties, given the actual context.

Furthermore, no matter how close to perfection a formal rule expressed in a contract is, the efforts to draft a detailed contract assumes the existence of expert courts of law that will provide full redress, in exact accordance with the contract, at a reasonable cost. That is, by no means, the case. Even if it were possible to enumerate all the eventual contingencies that could affect the course of the contract execution (which is not), in practice, the black letter of the contract will be irrelevant for the parties. Most disputes will be either overlooked, solved by self-help or friendly negotiation with the aim of maintaining the continuity of the (*so far*) fruitful contractual relation (Galanter, 1981, p. 2).

Complexity and non-discreteness are interrelated in the sense that the fact that the parties intend to continue the exchange relationship beyond the boundaries of a single exchange, necessarily blurs the object of the exchange, making it harder to delimit. In the same sense, one cannot expect to be engaged in a fairly complex transaction in which the parties do not create a relation (commercial or otherwise). The relation is created in the process of dealing with complexity. In other words, complexity forces the parties to commit to one another in finding a common understanding with regard to satisfactory compliance of the mutual obligations.

Having to deal with complex and non-discrete transactions complicates the task of defining the contractual terms and conditions that are expected to govern the exchange. This is likely to increase the (ex ante) transaction costs associated with negotiation and drafting; but, as Williamson points out, it is also likely to alter the nature of bargaining costs. Indeed, because contracts do not contain a solution for every possible contingency, in complex non-discrete transactions there will be plenty of occasions to ***adapt*** the initial agreement to the new circumstances. Hence, the risk of opportunistic *ex post haggling* is exacerbated by complexity and non-discreteness. Thus, he identifies a new type of hazard associated with these attributes, namely, the risk of ***maladaptation***.

In that line, ex post costs include: "a) the maladaptation costs incurred when transactions drift out of alignment; b) the haggling costs incurred if bilateral efforts are made to correct ex post misalignments, c) the setup and running costs associated with the governance structures (often not the courts) to which disputes are referred, and d) the bonding costs of effecting secure commitments" (Williamson, 1985, p. 21). As a brief explanation, we can say that a maladaptation occurs when the parties later discover that the most efficient course of action was not A, *as defined ex ante in the contract*, but B. Then, the parties need to renegotiate (ex post) to get from A to B. That renegotiation is problematic since one of the parties is likely to have invested in non-re deployable assets (*which constitute sunk costs*) in the course of the execution of the contract, which puts him in a vulnerable position before the other party. Anticipating this adverse scenario, the vulnerable party is expected either to refrain from renegotiating altogether or to act strategically to diminish the other party's advantage; thus, giving rise suboptimal outcomes.

It is noteworthy that the risk of opportunistic behavior associated with ex post haggling is nil in the case of discrete and simple transactions. If all the relevant aspects of the transaction can take place in a single exchange, then, there would be no opportunity to renegotiate, as the purpose of the contract would be exhausted with that single interaction. It is the complexity of the transaction which takes away its discreteness and makes it necessary to have future interactions which, in turn, generates the opportunity to renegotiate. Such is the remote cause of ex post maladaptations.

Ex post bargaining is constantly required to adapt the original agreement to the varying circumstances in the case of non-discrete complex transactions. Indeed, transaction costs economics acknowledges that the bargaining costs are transversal, rather than sequential (Williamson, 1985). So, bargaining is not a determined stage in the contracting process, as Coase seemed to imply, it is rather a pervasive reality, both in contract formation and execution.

Therefore, we may conclude this section by distinguishing ex ante from ex post transaction costs. Ex ante costs may be divided into a) search and information costs (related to finding the right trading partner), b) initial bargaining costs (referred to the costs associated with reaching an agreement that includes mutually satisfactory safeguards), c) drafting costs (which refers to the costs associated with putting the agreement in writing). Ex post costs may be classified into a) policing and enforcement costs (to secure that the agreement is satisfactorily complied with), and b) maladaptation and haggling costs derived from ex post opportunism from the parties.

Bargaining costs are pervasive in the case of transactions with low discreteness and high complexity; therefore, they cannot be classified either as ex ante or ex post transaction costs. So, the impact and extent of bargaining costs will be assumed to be a function of the complexity and discreteness of the transactions. Thus, the impact of transaction costs increases together with complexity and non-discreteness of transactions, making it harder to reach an agreement in the first place (*and to draft it*); and, afterward, requiring several adaptations during contract execution (for which renegotiation is needed). Nobel laureate Oliver Hart supports this claim in the following way:

> "When drawing up a contract, it is often impracticable for the parties to specify all the relevant contingencies. In particular, they may be unable to describe the states of the world in enough detail that an outsider (the courts) could later verify which state had occurred, and so the contract will be incomplete. The parties can make up for this incompleteness to some extent by building into the contract a mechanism for revising the terms of trade as they each receive information about benefits and costs" (Hart & Moore, 1988, p. 755)

2.5. Conclusions

Contracts are legal tools that are necessary to safeguard an economic exchange when the parties mutually distrust each other. Their main economic function is to suppress (or at least, counterweight) the incentives that the parties have to deceive each other. In doing that, they make wealth-maximizing transactions happen. For that, the parties to a contract try, to the best of their possibilities, to describe their mutual obligations and to encompass the potential future contingencies that could bolster compliance. They do so to provide an adaptation or a remedy (in the case of a breach).

However, the reality is complex; not even present circumstances can be completely known, and future events can only be anticipated with poor accuracy. Hence, the parties know very little about the relevant elements of a contractual relationship. Ignorance is pervasive. As a result, the parties to a contract need to invest a vast amount of resources in planning at the outset, adapting the original planning to the circumstances that unfold as the contract performance progress, and monitoring the relevant actions of the counterparties, with regard to contract performance. But no matter how much resources the parties invest, a contractual environment of full information is never achievable. Thus, the contractual process will always be imperfect and costly. These costs are herein defined as transaction costs.

It is noteworthy, however, that the amount of resources that would be required to achieve an adequate level of (imperfect) information (*sufficient to persuade the parties to transact in the first place*) depends on the circumstances of each transaction. Disparities can be found in the transactions' dimensions. Some transactions require the parties to invest in resources that cannot be easily reallocated should the exchange fail (asset specificity), some of them are recurrent, some of them are occasional; plus, they do not pose the same level of uncertainty.

As the transaction gets more complex, the contractual hazards are exacerbated. The complexity of the transaction depends on concepts that were referred to in the literature review and in this chapter. Some of these factors are the non-discreteness of the transaction, its level of uncertainty, the degree to which the initial investment of one of the parties is specific (non-re deployable) and the importance of the asymmetry of information that the parties face.

Governance of complex transactions is more costly. Transactions that differ in their attributes are not to be governed in an equal but in a discriminatory manner. So, a recurrent transaction of highly standardized goods (that can be obtained, basically, anywhere else) do not require complex governance structures as long-term, and uncertain transactions do.

As previously declared, the purpose of this thesis is to determine how smart contracts can help the parties to govern their transactions. This introductory chapter has served the purpose of setting the stage to analyze further the role of smart contracts in dealing with contractual hazards; that is to say, the role of smart contracts in the governance of transactions. Smart contracts are one of the governance mechanisms which the parties use to secure the successful completion of the economic exchange as they mutually agreed at the outset. How efficiently smart contracts perform this task (in comparison to traditional contracts) is something we will study in the following sections.

CHAPTER 3
WHAT ARE SMART CONTRACTS?

3.1. Introduction

So, we have established the importance of promises from a moral and economic perspective. We have also established that the central role of contracts is to enforce those promises. They create a powerful institutional structure and put it to the service of the parties. We have also seen that they are costly and imperfect for many reasons (*no matter how extensively the parties negotiate, all the contingencies can never be sufficiently described, and even if they are, they cannot be acceptably verified by third parties in charge of the adjudication and enforcement*). Now, at the end of the previous chapter, we introduced the idea that transactions should be governed in a discriminatory way, assigning simpler or more complex governance structures to them, according to their different attributes (dimensions). So, what the contract (as a mean to govern a transaction) should feature depends on the characteristics of the transaction.

In the end, governance boils down to creating trust between the parties. The parties need trust in order to contract (Eenmaa-Dimitreva & Schmid-Kessen, 2019, p. 33); after all, the core of trust is "placing oneself at risk to another" (Coleman, 1990, p. 105). Trust could be of different kinds: calculative, interpersonal (non-calculative) or societal (Williamson, 1996, p. 250). Contracts are a legal device to generate the trust of the calculative kind. It is the contractual safeguards what generates the required trust. But what if such trust could be created by other cheaper means? Technology, for example. That is the central feature of smart contracts. To introduce appropriate safeguards that will govern the parties' exchange so as to provide sufficient trust to make the transaction happen. In the following section, we will study what smart contracts are, and what they entail for the practice of law.

3.2. What is a smart contract?

Let us remember the example with which we started this work. A Dutch importer is trying to procure his company of dragon fruits, and he intends to procure them from an Ecuadorean exporter. They sign a contract and also require the services of banks and other costly intermediaries to secure that the exchange is successful and that no one is deceived. Those sets of contracts would be the governance structure of their transaction.

Now, consider the same story but with a slight variation. To secure the transaction, the Dutch importer proposes the Ecuadorian exporter to conclude a smart contract. If done correctly, it will allow the parties to predetermine each other's behavior in an immutable way, in order to secure contract performance. To turn a regular contract into a smart contract means to translate its clauses into computer language, compiled into a single piece of software. The software's code will be registered into the publicly distributed ledger (blockchain based) that will make it inalterable after both parties sign it. Once concluded, the software will execute its commands automatically; no one has the power to stop it (unless the whole network shuts down, which is highly unlikely). It will check if certain predetermined conditions have been met and behave exactly as the parties determined.

In the current example, the Dutch importer will deposit a certain amount of Ether or ETH (*a cryptocurrency that is used to exchange value in the Ethereum smart contracts platform*) in an electronic walled controlled by the smart contract. The smart contract will also have access to external data, namely, the information displayed by the Ecuadorean customs administration's cloud software. In that platform, the smart contract will be able to verify by itself once an export has been given clearance. On the other side of the ocean, the Dutch customs cloud software also displays once an import has been given clearance. The smart contract is, thus, programmed to invariably transfer the ETH to the Ecuadorean exporter once both conditions have been met.

In the end, the agreement translated into computer code written on a blockchain (in short, the smart contract), transferred the money to the Ecuadorean exporter as soon as it checked that the Dutch importer obtained the customs clearance. Both parties obtained what they bargained for and, most importantly, they did not rely on costly financial intermediation to achieve it.

In plain words, a smart contract is a mean of automatizing the performance of the contractual obligations, similar to a piece of software that is programmed to make recurrent monthly payments to a service provider from our bank account. We find this feature incorporated, for example, in the business model of several providers like Netflix, Spotify, and many other online subscription-based services. The difference with a smart contract is that the software could be, hypothetically, altered by the service providers (even if it would constitute a breach of the terms of the contract); also, the user could revoke the authorization provided for the automatic payment and exit the contract unilaterally. Automatic contracts are (somewhat) flexible and open to opportunistic behavior or contractual breaches from the parties. Smart contracts are not. For reasons that we will soon explain, once they are concluded, their text (code) is registered on a blockchain and becomes independent for it gets out of the reach of the parties.

The following is an example of what an actual (very simple) smart contract (written in solidity) looks like, as shown by (Savelyev, 2017, p. 125):

```
contract token {
    mapping (address => uint) public coinBalanceOf;
    event CoinTransfer(address sender, address receiver, uint amount);

  /* Initializes contract with initial supply tokens to the creator of the contract */
  function token(uint supply) {
        if (supply == 0) supply = 10000;
        coinBalanceOf[msg.sender] = supply;
    }

  /* Very simple trade function */
    function sendCoin(address receiver, uint amount) returns(bool sufficient) {
        if (coinBalanceOf[msg.sender] < amount) return false;
        coinBalanceOf[msg.sender] -= amount;
        coinBalanceOf[receiver] += amount;
        CoinTransfer(msg.sender, receiver, amount);
        return true;
    }
}
```

Figure I: smart contract written in solidity by (Savelyev, 2017, p. 125)

As can be readily seen, it is written in computer code. The parties code the contractual obligations into digital instructions using a computer language (code). There are many coding languages available, one of them is solidity (the one displayed in the example), used by the platform Ethereum. The role of platforms like Ethereum is to provide the parties a digital environment in which the contract-software can be registered and then executed, like in a regular piece of software run on Windows 10, for instance. The fundamental difference is that Ethereum registers the code of the software using blockchain technology, which makes the registry immutable (more on the virtues of blockchain technology will follow below).

So, once the smart contract is signed by the parties and registered on the blockchain, the code with the instructions is absolutely irreversible (unchangeable). One cannot change what has been registered in a blockchain. It is possible, however, to code and to register a completely new and independent smart contract with the purpose of "replacing" the previous one. The previous one, however, will forever remain registered in the past blocks of the chain. And that is a game-changing feature that enables the parties to contract without the trust of any previously known kind – calculative, societal or interpersonal, as studied by (Williamson, 1996, p. 250). If there was even the slightest possibility that the smart contract could be fraudulently changed by one of the parties after its conclusion, then its function as guarantors of trust between the parties would be completely undermined. Like a vessel with a hole on its hull (no matter how small the hole is), the technology would be rendered useless.

Immutability, together with the automatization of contractual performance is what makes the technology an effective "trust builder." As shown by the previous examples, the parties need to trust each other in order to undertake the risks associated with being the first one to perform an obligation. Contracts are, certainly, a mean through which the parties can secure contractual performance. However, enforcing a contract is quite costly or, sometimes, plainly impossible due to practical obstacles such as the location in which the trial would take place, or knowledge of the applicable law and language.

Smart contracts, on the other hand, offer an automatic performance of the contractual obligations in a transparent way. The risk of contractual breaching is taken out of the equation. If the code is programmed correctly, there should be no doubt that the smart contract will execute the payment (or any other conceivable digital transfer or action), upon the occurrence of the (verifiable) condition. The risk of the manipulation (hacking) of the code is also taken out of the picture by virtue of the security offered by the blockchain technology. In short, what the parties see in the code is exactly what they will get.

3.3. Blockchain technology

But what exactly makes this technology secure beyond a reasonable doubt? The answer lies in the blockchain technology in which the coded instructions are permanently and irreversibly registered. Indeed, we consider that a crucial feature of a smart contract is that they are written on the blockchain, which entails that once they are concluded, they cannot be modified, not even by consensus of the parties (Savelyev, 2017). Blockchain will be defined as: "a decentralized distributed database of all verified transactions that take place across a P2P-network system operating on cryptographic algorithms" (Savelyev, 2017, p. 119). In practice, blockchain works like a public ledger that is controlled simultaneously by all the computers of a network (also called nodes).

The integrity of the ledger is secured because the blockchain technology has several layers of security. As a mean of example, we will explain just the basics of the security protocol used in bitcoin:

3.3.1. Authentication: encryption using public and private keys

To start with, the parties who wish to conduct a transaction must, first, authenticate their identity. This authentication is usually performed through an asymmetric encryption system, in which each party is provided with two "keys" (a key is a unique sequence of characters) which are interconnected with one another: one private (only known by that sole person) and one public (publicly available for anyone to know). One party will encrypt a message (data) using the other party's public key. Now, this message can only be decrypted using the other party's private key. So, the idea is that if the message is successfully decrypted, it is an unequivocal sign that the person receiving the message is (can only be) the owner of the private key. Therefore, by using the private key assigned to person A, the user X can prove to the user Y (who sent a message using person A's public key) that he is the person A with which he intended to communicate; and vice versa, by using the private key assigned to the person B, the user Y will prove to the user X that he actually is the user B, with which he intended to communicate (de Filippi & Wright, 2018, p. 15).

3.3.2. Hashing and Merkle trees

Once the parties have concluded a transaction on the blockchain, it is registered on a temporal ledger, waiting to be added to the definitive one. The data contained in every transaction is hashed, that is, transformed into a string of characters (the hash) that represents that original data. To an uneducated user, that string of characters would seem to be randomly generated, but in reality, they are not. They are derived using a hashing function. A hashing function (*in bitcoin, the hashing function used is named the SAH-256, which was invented by the National Security Agency of the USA*) will always derive the same string of characters from the same input of data; and the same number of characters no matter how long or short the input data is. If we introduce even the slightest modification in the original input of data, the string of characters (the hash) would be completely different. That is why it is impossible to tamper with the original data without being noticed or leaving a trace. (de Filippi & Wright, 2018, p. 22). As an example, the result of applying the hash function SAH-256 to the phrases: "Help me!" and "Help me" (without an exclamation mark).

Help me! = 979E3AC5DE4822AE0DC2B03338CCBE86D5D8E4C8861D5C2F920013D8AF0C6009
Help me = 90EC641CDAD5500CE22DA36D2961602B19E33641C4AC016E7997A6392B22BB97

It is virtually impossible to figure out the original message from the hash because, even though the same input will always get the same hash, the possibilities of deducing the data from the hash are astronomically low. Thus, it is computationally infeasible to derive that "Help me" was the message behind the aforementioned hash.

Now, what makes blockchain technology so uniquely secure is that not only each transaction is hashed to avoid manipulation, but also, using a method called "Merkle tree hashing", the previously hashed transactions are hashed again in pairs (level 1), and then the resulting node is hashed again in pair with another resulting node (level 2); the process is repeated until there is only one resulting hash (which is called the Merkle root). The resulting hash (*which always contains 64 characters, as all the hashes derived from the SAH-256 hashing function*) represents the whole transaction. So, now a group of hashed transactions can be represented with as little as 64 characters, the Merkle Root. If any single transaction of the Merkle tree receives even the slightest modification, its hash value will change, thereby changing the hash value of the node in level 1, which in turn would alter the hash value of the node in level 2 and so on, up until the Merkle root. The following figure by (Narayanan et al., 2016, p. 35) illustrates the abovesaid:

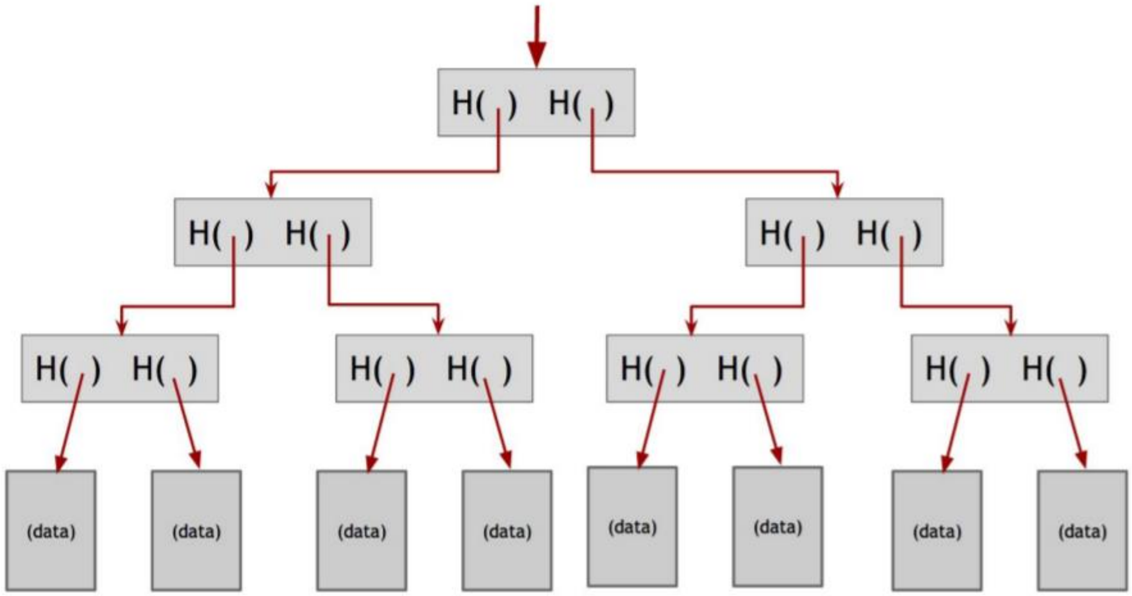

Figure II: Merkle root by (Narayanan et al., 2016, p. 35)

3.3.3. Hashing blocks after blocks

An additional level of cryptographic security is added by hashing the information contained in the header of each block. In the case of bitcoin, the header of each block contains the Merkle root, the timestamp and the hash of the previous block among other information. A hash value is derived from this information in which we remark the Merkle root and the hash of the previous block. This protocol entails that if a transaction is illegitimately altered, the hash value of the Merkle root in which it is embedded will change completely, and since the hash value of the block is tied to the hash value of the Merkle root, the hash value of the block would also change; and since the hash value of the block is also present in the header of the subsequent block, the hash of the next block would also be altered and so on (de Filippi & Wright, 2018, p. 22). Therefore, it is simply not possible to fraudulently change the value in a transaction and go undetected, because all the users (nodes) of the network check and vote about the integrity of a block before adding it to the end of the chain. If the information has been tampered with, their hash value would be inconsistent with those known to the members of the network. One block is added if, and only if, the *majority* (>50%) of the nodes of the network agree on the integrity of the block (de Filippi & Wright, 2018, p. 24). The frequency in which a new block is added to the chain also depends on the rules of the network.

The most important part of the process is that because each block is logically tied to the hash value of the previous block, it is impossible to alter the content of one of those blocks alone. To be successful, the hacker would have to break the encryption of each one of the thousands of blocks in the chain, since the beginning of time. Doing so would require an impractical amount of computing power, so vast that the costs would surely outweigh the potential benefits.

Another way to hack the system would be to acquire as many computers (nodes) as to take over the majority of the network (something similar to a hostile takeover in corporate law); in that way, the nodes that the hacker controls could "agree" on the integrity of a fraudulent block, and it could be illegitimately added to the blockchain. Again, implementing such a plan would demand an incredibly high amount of resources that costs would outweigh the benefits, by far. And, even if it is done, the honest remainder of the community would instantly lose *trust* in the network, which is the single most valuable asset in systems like those. It is the perfect example of a *pyrrhic victory*.

3.3.4. Public and Private Blockchains

There are two types of blockchains: the public and the private. The public blockchain has no central administrator, which means that anyone with a terminal may enter the network; whilst the private blockchain has a central administrator that decides who can enter the network and how it functions (Eenmaa-Dimitreva & Schmid-Kessen, 2017). It is the public blockchain the most disruptive one in regulatory terms because it allows people to make transactions under complete anonymity (using pseudonyms or public keys); furthermore, the network does not have a central and liable administrator; all the decisions are taken by the network as a whole. The network is an ethereal entity with no legal personality of its own, where people who do not know their identities can make secure and self-enforceable transactions.

3.4. What makes smart contracts qualitatively different?

The main features of smart contracts are that: a) They are written in software code; b) The code makes the contract to be self-executable (automatic, without human intervention); c) Once registered in the blockchain, they are immutable, d) It is not necessary to know the real identity of the parties to conclude an effective smart contract. In the next lines, we will focus on their automation and immutability, which makes them effective instruments to create trust, the fuel of economic relationships.

Once those risks are taken out of the equation, parties are free to enter into transactions with just about anyone who is able to participate in the network. To participate, all that a person needs is an electronic wallet which acts as the *public key* to allow others to single him or her out. A public key that represents a person looks like this: 0x5baeac0a0417a05733884852aa068b706967e790. The technology is groundbreaking in the sense that the parties do not even need to know each other's identities; it is possible to find a trading partner on online platforms and conclude surplus-creating smart contracts, all we need to know is his or her identification key, and the software will do the rest.

Indeed, smart contracts represent a qualitative improvement in terms of trust. They perform much better than contract law and courts at ensuring the parties a fallback mechanism to enforce their agreements — a mechanism that is, so to say, bulletproof. The (virtually) absolute certainty that smart contracts create with regard to contractual performance has motivated some scholars to argue that they are not really "contracts" as such, in the theoretical sense (Savelyev, 2017).

A contract, as the argument goes, consists, mainly, of a promise whose compliance is mandatory by law. A promise, as previously stated, is the invitation to trust that the promisor is going to behave in a certain way. It is noteworthy, however, that it involves a future uncertain behavior under control of the promisor. In the case of smart contracts, there is no uncertainty about a future event. All uncertainty vanishes the moment that the parties sign the smart contract, which also marks the initialization and the execution of its code. Therefore, a smart contract contains no promises, and there are no obligations without promises. An obligation is just the legal assignation of the deontic moderator ‘mandatory’ (OB) to an action ‘p’ (whatever action was promised), so, basically **OB**p. As a conclusion, a smart contract creates no obligations; and since, by definition, contracts create obligations, then smart contracts are not really contracts; at least, not in the traditional sense.

The argument is compelling. If smart contracts do not create obligations, then they are not really contracts. It would be more accurate to say that they are merely means of performance of a contractual obligation. Under this view, the parties would reach an agreement (through the *bargaining* process) and conclude a contract before adding their signature to the software. The act of signing the software, thereby initiating its execution, represents the irreversible start of the contract performance, not the conclusion of the contract.

The analysis is different with regard to standard form contracts. In such contracts, there is no bargaining process, and the only opportunity that the party has to accept the contract that is put before him is through the signature of the smart contract. In such a situation, we can say that the stage of contractual performance collapses into its conclusion. In other words, the conclusion of the contract entails its performance. So, even when no obligations are going to be created, the other elements of the contract are present: it is still a voluntary act of the parties that involves an offer, an acceptance, and consideration. Therefore, we must not be so quick to dismiss the contractual nature of smart contracts. In such cases, the smart contract is both, the mean through which the agreement is reached and its content (the content of the agreement).

Savelyev identifies six key features of smart contracts, which are: 1) solely electronic nature; 2) software implementation; 3) conditional nature 4); increased certainty; 5) self-performance; 6) self-sufficiency (Savelyev, 2017).

For the author, that a contract has a *solely electronic nature* means that it cannot exist in any other mean. Indeed, an ordinary contract (usually) can be concluded orally or in writing; however, a smart contract can only be concluded in electronic form. The whole point of a smart contract is that it is able to manipulate (administer) digital assets in a direct way, according to the instructions (algorithm) coded in the software. It is not possible to produce a printed copy of the contract or to materialize it in any way (not even with the intervention of a notary). Even if we could, it would serve only as indirect evidence of the existence of the contract, but, for obvious reasons, a printed copy of the code of a smart contract is not apt to produce any of the electronic changes that a smart contract is supposed to produce.

A smart contract is *implemented through software*, which poses limitations on what can be included in a smart contract. The language that is used in coding is strictly logical. Only formal languages can be used in software, which eradicates from smart contracts two of the defining features of natural languages, namely, vagueness and ambiguity. Furthermore, the software of a smart contract can only recognize the occurrence of events that can be singled out with absolute certainty. For an event to be taken into account it must be reduceable to an absolute YES (1) or NO (0); a single TRUE or FALSE.

The latter is connected to the *conditional nature* of the smart contract. The software of a smart contract is equipped, basically, with a set of instructions that are executed IF and ONLY IF a certain event occurs. Like the increase of the value of the Euro in relation to the US Dollar in a certain percentage, the late arrival of a flight, the fact that a package is marked as delivered in the system of the postal office, the fact that a person is registered as deceased in the national civil registry, or the fact that a car is registered as robbed in the national police database. As it can be noted, some of these events are physical in nature (they occur in the real world); nonetheless, it is possible to incorporate a registry of those events in the digital world through trusted third parties that act as oracles. Oracles are trusted with the function of determining when an event has taken place (Buterin, 2014). The smart contract is programmed to take their inputs into account to determine when a condition has been met.

All this generates an *increased certainty* among the parties, not only because they can be absolutely certain that the valuables are going to be exchanged exactly as agreed, but also because smart contracts are designed to take away the uncertainty that comes with judicial enforcement. When the parties to an ordinary contract have a dispute, they can settle it on the court. However, if the dispute goes to court, it is, precisely, because each party considers that there is a reasonable chance that they will win the trial. Thus, judicial enforcement is intrinsically uncertain. Smart contracts are designed to be self-executable without relying on any trusted authority (Bartoletti & Pompianu, 2017), to the point that, if programmed correctly, the obligations would be performed automatically (*self-performance*) exactly as predetermined, leaving no leeway for different interpretations as to what constitutes the satisfactory performance of the obligation.

Finally, smart contracts are self-sufficient. This is the case because they do not rely on any person, institution or legal system to be effective. Smart contracts can exist even without a legal system or institutional framework, precisely because the performance of what the parties agree and code is not a matter of law, but a matter of logic. The only external circumstance that can stop a well programmed smart contract from executing itself is a massive and absolute shutdown of the blockchain network under which it is functioning (which, given the size of the current blockchain networks is highly unlikely). This feature, however, might be one of its weakest points, for it is possible to use them to circumvent the current mandatory contract rules that exist to protect consumers or pursue other important public policy goals in a wide array of fields such as competition law, intellectual property, financial regulation, and many others.

3.5. Conclusions

We have defined what a smart contract is and how they perform the enforcement of promises (made between the parties with the purpose of carrying out the exchange of things with legal value). We highlight the fact that they are irreversible; and that they provide absolute certainty to the parties that their instructions are going to be executed exactly as programmed, although their binary drafting forces the parties to be exact in their commands (which can be counterproductive).

A key assumption of this research is that transactions need governance structures. In the introductory chapters we anticipated that smart contracts could play an important role in the governance of the transactions. To determine what that role could be, we need now to proceed to explain how the characteristics of smart contracts, that we have explained here, interrelate with the need to infuse order, avoid conflict and realize mutual gains (Williamson, 2005, p. 5). In other words, how well do smart contracts perform as a governance structure, in comparison to traditional contracts. That is the topic of our next chapter.

CHAPTER 4
THE COSTS OF GOVERNING USING SMART CONTRACTS

4.1. Introduction

We have mentioned that transactions need governance. Without governance, conflict is prone to escalate without order and end up derailing the whole economic exchange, preventing mutual gains from happening. The governance structure under which the transaction operates needs to be tailored (designed) to the characteristics of the transaction, and this could be a costly process. The cost of designing appropriate safeguards to infuse order and mitigate conflicts during the economic exchange is what we mean by the costs of governance. Therefore, the design of an adequate governance structure is a pervasive (ex ante and ex post) transaction cost.

An important insight of this work is that smart contracts are governance mechanisms which could be used as building blocks of particular governance structures. They come at a cost, though. In this section, we will perform a comparative costs analysis of smart contracts and traditional contracts with the aim of establishing what do we gain and lose (in terms of transaction costs) when using smart contracts instead of traditional contracts?

So, having defined what a smart contract is and having studied in depth the origins and effects of the different types of transaction costs we are now in a good position to determine how the smart contracts help to reduce transaction costs (i.e., help to overcome *contractual hazards*) or if they might increase them. This is a necessary step in order to clarify when it is more efficient to use smart contracts. We will start by exploring how smart contracts help the parties to deal with the sources of governance issues, we will see that even when their use might not help to reduce the source, they do help to diminish significantly (or to suppress altogether) the impact of their effect on the transaction; although, they do so at some costs. But first, we need to support the premise that smart contracts are governance mechanisms, for which we will explore the notions of structures and mechanisms of governance briefly.

4.2. Smart contracts, governance structures and mechanisms

The transaction is taken to be the central unit of economic analysis; they need to be governed to "infuse order, thereby to mitigate conflict and realize mutual gains" (Williamson, 2005, p. 3). Indeed, inherent to every transaction is conflict (Commons, 1932, p. 4). Conflict without order is prone to (potentially) upset the opportunities to realize mutual gains among the parties. That is, indeed, the central point of devising governance structures for transactions, to provide workable arrangements that, taken as a whole, prevent the conflict from escalating and drifting mutual gains away.

Now, the transaction costs economics has identified three main governance structures, which are: a) the market, b) hybrid structures, c) hierarchy. The market, as a governance structure, works as an external force that allows the parties to adapt autonomously, given the unsatisfactory performance of a contractual obligation. This "autonomous adaptation" materializes when the unsatisfied party simply walks away from the other to find another suitable trading partner in the market. The prices on the market signal the direction that this adaption is likely to take since the parties are rewarded directly for their efficient investment choices (Bijman, Cechin, & Pascucci, 2013, p. 8). On the other hand, hierarchy as a governance structure refers to the vertical integration that takes place when two firms join their respective stream of capital into one single entity; what previously was an independent firm, now is a department within another firm. Afterward, the controversies between the former firm (now a department) and its acquirer are solved by means of authority. Furthermore, since their respective stream of capital is now joined as one, the incentives are realigned, so that now their gain does not come from competing one against the other but from cooperating (Williamson, 2005, p. 5). The essence of hierarchy as a governance structure is the consolidation of property and decision-making rights (Bijman et al., 2013, p. 9).

A third and intermediate type of governance structure is referred to in the literature as "hybrid." Hybrid governance structures are conceived as intermediate forms of governance that gather features of both markets and hierarchies. They comprise: "a great diversity of agreements among legally autonomous entities doing business together, mutually adjusting with little help from the price system, and sharing or exchanging technologies, capital, products, and services, but without unified ownership" (Menard, 2004, p. 348). We can readily see that smart contracts fit within this category, for they are means through which two independent entities (without unified ownership) carry out an exchange of legal value.

Hybrid governance structures can take many particular forms. Some examples include subcontracting, alliances, joint-ventures, selective intervention, profit centers, quasi-integration, buyer-supplier relation, consortia, partnerships, franchising and inter-organizational networks (Ebers & Oerlemans, 2013, p. 8). Of course, this list is not exhaustive. These are examples that show the wide array of intermediate hybrids governance structures, which the literature has not been able to systematize yet (Ebers & Oerlemans, 2013, p. 2).

Now, these governance structures consist of a group of governance mechanisms which are ordered consistent and coherently around the goal of minorating conflict and realizing mutual gains between the parties. A governance mechanism can be defined as any constraint that affects the behavior of an actor of economic exchange or attempts to control it in any way (Ebers & Oerlemans, 2013, p. 7). Dekker proposed a classification of governance mechanism, which he divided into two broad categories, namely, formal and informal, each one with ex ante and ex post ramifications. Formal control mechanisms include rules, regulations, standard operating procedures, behavior monitoring and reward, while informal include trust, reputation, social networks, joint decision-making, risk-taking and partner development (Dekker, 2004, p. 32).

We would argue that *smart contracts are and should be treated like governance mechanism*, *within any given hybrid governance structure*. They do not set (nor they help to set) a structure of governance by themselves; they serve the specific purpose of enforcing a preestablished obligation within a governance structure. *The structure of governance should be devised by the parties according to the different attributes of the transactions in a discriminating way* so as to minimize the transaction costs.

But smart contracts, are not a simple a governance mechanism for its use has the potential to change the tone of the whole process of exchange. As we will see in the following sections, incorporating smart contracts within a given governance structure has paramount implications in the enterprise of economizing in transaction costs while facilitating the allocation of resources from less to more valuable uses. So, what are the costs associated with using smart contracts? And how well they perform (at overcoming contractual hazards) in relation to traditional contracts?

4.3. What can smart contracts do to help?

This work relies on a useful distinction between contractual hazards and transaction costs as such. Transaction costs, in general, are the costs associated with using the market (Arrow, 1969, p. 59). These costs take place ex ante (searching, negotiating) and ex post (monitoring and supervising), although, negotiation costs, as previously explained, are pervasive through the whole contracting process (ex ante and ex post). These costs can be influenced by many factors. Part of those factors is grouped in what we called contractual hazards, in which we find informational problems (observability, verifiability, information asymmetries), opportunism, uncertainty, and asset specificity. As we previously declared, contractual hazards are sources of transaction costs in the sense that they affect the complexity of the governance structure that is needed. We assume that the bigger the hazards, the bigger the costs associated with the transaction. But what the costs of using the market are, is also influenced by the choice of governance mechanism; in this case, smart contracts.

In what follows, we will analyze the fields in which smart contracts offer opportunities to reduce the costs of contracting and those in which the costs are increased. That is crucial information to help the parties to determine if it is economically viable to use smart contract in their transactions. To determine this, the first obvious step is to estimate the expected value of the transaction (or group of transactions) and weight it against the expected drafting costs of a smart contract, which is most salient transaction cost associated with the smart contracts. If from this simple operation we can infer that the transaction is not significant enough (from the economic standpoint), then we can conclude that the use of smart contracts is not justified.

If this first hurdle is passed, then we may proceed with a more nuanced comparative analysis between the transaction costs associated with smart contracts and those associated with traditional contracts. We call this a *nuanced* analysis because it involves tradeoffs: by using smart contracts, we gain in one area, but we lose in another. The value assigned to what we lose and what we gain is a judgment exercise that depends upon the risk preferences of the parties. The decision-making process involves, therefore, a balancing exercise for which we can only provide some guidelines to make the process as rational as possible.

To simplify this *prima facie* assessment of the costs of using smart contracts, we will divide the transaction costs into three categories: searching, negotiation and enforcement costs.

4.3.1. Searching costs

In principle, smart contracts offer the possibility to engage in a contract with unknown people without the risk that they will engage in opportunistic behavior. This reduces the costs of the previous research that any diligent merchant must conduct on their customers before engaging in risky transactions. Also, the elimination of opportunistic behavior may act as a catalyzer for transactions that would not have been otherwise done due to the lack of trust and high costs and uncertainty of litigation (judicial enforcement).

4.3.2. Negotiation costs

a) Completeness and the use of standards in contracting

Some smart contracts proponents predict that this disruptive technology will allow the parties to "code" most of the aspects of an agreement into a (self-enforceable) smart contract (Szabo, 1997). As a result, part of the legal community is concerned that the increasing technification of the contractual making process and its enforcement is going to affect the role of lawyers substantially (Tjong Tjin Tai, 2017).

This optimistic view lays on one under-researched assumption, namely, that it is possible and desirable to "code" most of the aspects of a contractual relationship. The first issue, whether it is possible, is an issue that has been studied for a long time by legal philosophers under the label of the "completeness" of any given legal system. Leibniz, for instance, thought it was possible to do so through "classification" and "combination" because the number of cases may be infinite, but the classes are not (von Leibniz, 1960). Other philosophers though otherwise and resorted to "principles" to cover what could not be explicitly covered by legislation (Dworkin, 2013).

A very similar discussion has taken place in the field of contract law, where the dominant theory is that every contract is – necessarily – incomplete. There is no such thing as *the perfect contract* (Shavell, 2009). This assertion has also been explored in the field of economics by Nobel laureates (2016) Oliver Hart and Bengt Holmström (Hart & Holmström, 1987), whose insights have galvanized numerous contributions in the field of contract law and economics (Schmidt, 2017).

Now, even when we accept that all contracts are incomplete, contracts can still be "more complete" than others. Indeed, the complexity of contracts is a continuum; it can go from a very simple contract that covers just the most basic elements of the transaction, to an extremely complex contract that includes a detailed description of what is taken by the parties to be a "satisfactory performance of contract obligations." However, it is important to keep in mind that not even the most complex contract that has ever been drafted, can be deemed to be "complete" (with regard to its ability to encompass all the present and future circumstances that the parties face and/or might face) (Shavell, 2009).

If the complexity of contracts is a continuum, the smart contracts would be positioned at the lowest scale of complexity. By their very nature, they cannot encompass any relational aspect existing among the parties. The code in which the smart contract is written is strictly binary. The code consists of a set of IFTTT (If this, then that) instructions that have to be logically perfect for them to be "readable" by the computer. Computer code cannot hold open-texture concepts that are meaningful for the human mind, like a "reasonable effort" or "good faith." Hence, the drafting of a smart contract can only refer to concepts that can be defined in terms of a "1" or "0".

Some proponents of the technology argue that the fact that smart contracts only contain "smart obligations" (hereby understood as obligations defined in binary machine-readable terms) is an absolute gain for the parties. On the other hand, other legal scholars of traditional contract law argue that the use of general terms (standards) accomplish an important task during the negotiation process and that depriving the contract of such semantic richness is detrimental.

Certainly, vague terms raise the possibility of judicial misinterpretation, thereby making the outcome less predictable, diminishing the ability of the parties to govern the contractual relationship with sufficient certainty, and increasing the odds that the parties will have a dispute over their understanding of "adequate performance." A complex contract that describes the parties' obligations with great detail offers fewer incentives for the parties to litigate over its meaning and compliance; while a contract that describes the parties' obligations under looser terms (standards), offers the parties a broader array of possibilities for litigation (Gilson, Sabel, & Scott, 2014).

Nevertheless, the importance of standards during contract formation (negotiation and drafting) is not to be neglected. Using standards offers the parties substantial benefits such as 1) A more efficient negotiation process; 2) Dynamic interpretation during the execution of the contract; 3) Strengthening of social bonds between the parties.

1. **Efficient negotiation**: Standards are an important negotiation tool. Under some circumstances, reaching a sufficiently detailed description of the "adequate performance" of a contractual obligation is virtually impossible (or way too expensive). This is the case, particularly with regard to contracts for services; and any other where the risk for moral hazard is high because the circumstances under which the obligation is going to be performed lack transparency (Hart & Holmström, 1987).

2. **Dynamic interpretation**: When the environment in which the obligations are going to be executed is subject to continuous changes (for example, because of innovation or changes in the market conditions), it is more efficient for the parties to use standards than it is to use specifically defined obligations (Sklaroff, 2017). Open standards allow the parties to adapt themselves to contingencies that arise during the execution of the contract. Absent standards, parties would be forced to renegotiate the original contract; this is true, particularly with regard to smart contracts. However, one definitional aspect of smart contracts is that they are immutable. Once signed by the parties and registered on the blockchain, they cannot be changed by the parties; therefore, renegotiation and sequential adaptations are not even a possibility.

3. **Strengthening of social bonds**: Besides the purely economic benefits of the use of standards in the contract formation, they also accomplish important social goals. These terms help the parties to signal goodwill, and they invite them to rely on each other to provide meaning to the text. Contracts with obligations defined in exhaustive detail, on the contrary, signal lack of trust between the parties. Smart contracts, in principle, contain clear-cut obligations that can be defined in terms of 1 or 0, such that can be read and processed by a computer. It is true that the software can be coded to include the judgment of an impartial third party (an arbitrator) whose authorization is needed to execute a software instruction (for example, was the delay justified? If so, do not transfer the funds – compensation – or else, transfer the funds), as smart contracts with multi-sign feature. However, such application is still rigid, for the arbitrator has the possibility to enter only a yes/no answer, exclusively with regard to the matter that has been programmed by the parties. No leeway is allowed.

b) **Drafting a smart contract:**

Drafting a smart contract is a radically different process than drafting an ordinary semantic contract. As said before, a smart contract needs to be written into a machine-readable code. Writing a smart contract is, basically, developing software. Of course, this brings an important consideration into play. Lawyers, generally, do not know how to write code; and coders, generally, do not know about contract law. Therefore, there is a high risk of ending up with a significant gap between the actual intention of the parties and what was finally coded. Because computer code (dry code) lacks the capacity to hold semantic richness, a smart contract would hold no trace of the intention of the parties. Any evidence about that will have to be reconstructed by the parties from scratch. This unavoidable risk is relevant if an eventual judicial interpretation of the contract is to take place, which is still possible since one of the parties can sue the other to recover what the smart contract *unduly* transferred.

4.3.3. Enforcement costs and relational aspects

a) Relational aspects

A meaningful, strong commercial relationship cannot be built if the parties are governed by closely-monitored detailed contractual provisions, that are enforced on a constant basis. In that sense, a semantic contract, presumably, offers the parties the possibility to build trust between them without the significant constraints that are imposed upon them by an inflexible smart contract. Indeed, deciding when to enforce a contract and to forego that possibility for the (forward-looking) purpose of sowing future transactions is a strategic decision that, in principle, should be left to the (human) discretion.

In that sense, the effect that the ordinary use of smart contracts in a long-term commercial relation could have on the relationship of the parties needs to be further researched. The current literature signals the importance of allowing the parties to be flexible with regard to enforcement. Looser contractual terms allow the parties to build their own history of transactions, which, in turn, is going to drive them to consistently reduce transaction costs by deploying increasingly informal agreements, instead of the detailed contractual provisions that used to govern their relationship in the beginning.

It is not to be neglected that, most of the transactions, in practice, take place without regard to what the contract specifies (Macaulay, 1963). There is a vast hemisphere of transactions that take place "in the shadow of the law" (Brownsword, van Gestel, & Micklitz, 2017). In the end, the threat to break a long, fruitful commercial relationship could be a more effective deterrent than any contractual sanction (Bernstein, 1992). Then, the question that lingers is: Are smart contracts able to build a meaningful contractual relation to the same extent than flexible semantic contracts?

b) Enforcement

One of the main features of smart contracts is that parties "pre-commit" to fulfill their obligations. Hence, the automatic execution is immutably predetermined at the moment of the conclusion of the contract. In theory, this eliminates all the costs associated with the enforcement of the contract (Werbach & Cornell, 2017). However, even though smart contracts are self-enforceable, we cannot assert the costs of enforcement are going to be completely eradicated. As previously stated, the parties still have the constitutional right to request a court to review the actions taken by the smart contract and seek compensation for any damage caused.

Moreover, if the smart contract violated one of the mandatory contract law rules (consumer protection, competition law, intellectual property), the contract is void, and the effects of its automatic execution could be reversed by a court of law.

c) Monitoring costs

Smart contracts exist in a purely electronic environment. The software can only receive inputs that are readily available in an electronic format (although the Internet of Things is closing that gap, bringing smart contracts one step closer to the material world); the same is the case with respect to outputs. They can only be effective with regard to electronic assets (or even physical assets that are connected to the internet).

This, of course, limits the situations in which one can use smart contracts; however, it also makes contract performance fully transparent. The risk of moral hazard and opportunistic behavior is eradicated. Since every aspect of the relationship has to exist (and be registered) in the blockchain (be it public or permissioned), audits are always possible at reduced costs.

An additional benefit of this enhanced transparency is that the parties do not need costly intermediaries. The platform of a smart contract allows the payment to be made directly, through the transfer of some cryptocurrency or crypto assets (such as a trademark registered on the blockchain; or any other registry that constitutes property rights on a physical asset such as vehicles, real state, vessels), for instance.

4.4. Contractual hazards

Contractual hazards are a source of transaction costs, for they force the parties to invest in searching a trustworthy trading partner, devise contractual safeguards against opportunism, and they increase the likelihood of a long and costly negotiation and renegotiation. These contractual hazards include asymmetries or insufficient information (as in the case of unobservable and unverifiable behavior), opportunism, asset specificity, and uncertainty. To engage in a safe economic exchange and realize mutual gains, the parties need to overcome them through the use of governance structures. Devising these governance structures is costly; devising a hand-tailored governance structure for a particular set of transactions is even more costly. In this section we are going to analyze how can smart contracts help to reduce these contractual hazards.

Let us start with an example. Let us suppose that subject A wants to buy insurance that is being offered by an online company. The insurer will pay compensation equal to 50% of the price of the plane ticket if the flight is canceled or delayed more than 3 hours. In this instance, the subject A does not know whether or not the online insurer is trustworthy. There are many pieces of information that remain unobservable to subject A. The online insurer might as well behave opportunistically: the company could take the money and not pay any compensation, even if the covered event takes place.

Using a smart contract does help to reduce some informational problems in the example. Let us start with the hazard of non-observable information, that is when one party keeps some information private, thereby creating an information asymmetry problem. With smart contracts, there is no possible way to keep relevant information private because, by definition, keeping it private means not including it in the code of the smart contract, to begin with. The parties will be ruled *only* by what is coded. If it is not in the code, then it does not exist as a variable; and, on the contrary, if it is in the code, then the information is public. This mere fact forces the parties to reveal possible contingencies that the other party may not know if they want to benefit from them. All the information with which the smart contract is coded is *symmetrical*.

On the same grounds, all the information with which the smart contract is coded and that is input into the software is readily *verifiable* by anyone who has access to the transaction. Given their transparency, their unequivocal reliability and their purely electronic nature, a third party (a court of law, for instance) could have immediate and unrestrained access to what the parties agreed and be able to reconstruct the instructions followed by the software that led it to execute contingent result A or B (if it was necessary to have the operation reviewed by a court of law with regard to its legality).

With regard to uncertainty, smart contracts cannot reduce it in any way (with the exception of behavioral uncertainty, which is defined here as a synonym for opportunism). The same reasons that difficult the governance of transactions with a high degree of uncertainty by means of a traditional contract apply with smart contracts. As previously seen, by its very definition, uncertainty refers to the *unknown*; and if future contingencies remain unknown, then the parties cannot encompass them in the code of a smart contract. The traditional contract has an advantage here, though, since it can be *adapted* subsequently as the unforeseen contingency unfolds; a smart contract cannot be adapted. Evidently, the risk of *maladaptation* disappears; however, the risk of an inefficient (automatic) specific performance arises in its place. Specific performance is always inefficient, save the utopian case of completely specified contracts (Shavell, 2004, p. 252).

Asset specificity cannot be reduced by the use of smart contracts neither. That is because it refers to the circumstances of the investment as such. The type of contract that is used by the parties would make no difference whatsoever with regard to the nature of the initial investment. However, what the smart contracts can do in such situations is to eliminate altogether the possibility of opportunistic behavior that stems from such specificity. Think for example of a transaction with a high degree of asset-specificity where the vulnerable party request an electronic deposit through a smart contract (the deposit is large enough to cover the salvage costs of redeploying the specific assets to a second-best alternative use) whose execution is linked to any such actions that reflect opportunism from the counterparty, as judged by a community of jurors (like the one that already exists at https://kleros.io/). Then, the behavioral uncertainty to which Williamson referred (Williamson, 1985, p. 58) is taken out of the equation. After signing the smart contract, compliance is the only choice. As a consequence, the parties have no incentive even to try to behave opportunistically. The moral hazard is simply enervated at the outset with the mere existence of the smart contract, which, certainly, cannot be subject to opportunistic ex post renegotiation. That is the main strength of smart contracts: their ability to eliminate the incentives to behave opportunistically.

4.5. A balancing exercise

The greatest strength of smart contracts, in terms of transaction costs, lies in their ability to suppress the costs of enforcement and supervision altogether. With this, comes an additional benefit, namely that the searching costs are substantially reduced, particularly the ones that would have been invested on to screen the counterparty to assess his trustworthiness.

Trust between the parties is a necessary element of a contract, particularly a non-discrete one. Without trust, contracts would not be formed in the first place. But it is important to remark that interpersonal trust is not the only type of trust that can stimulate the conclusion of a contract. When the parties do not trust each other, the center of the trust is shifted from the persons to the institutions of law (courts, government agencies, arbitration tribunals) into what we can call institutional trust (Werbach, 2018, p. 495). However, even if the parties share strong confidence in the institutions, access to their enforcement services is costly and uncertain. Therefore, it can be anticipated that parties might want to invest in ex ante screening, in order to reduce the probability of having to resort to institutions (Werbach, 2018). In contrast, Smart contracts offer the ability to contract without trust in the persons or the institutions. Its automatic and irreversible enforcement allows the parties to suppress the need for ex ante screening for trustworthiness altogether, as the ex post opportunism is technically blocked at the outset (Eenmaa-Dimitreva & Schmid-Kessen, 2019). When the enforcement is secured at the outset through an immutable software, the center of trust shifts from the persons to the technology (bypassing the institutions), resulting in a significant reduction in searching costs.

Now, even if searching costs are substantially reduced, and enforcement costs become almost irrelevant (*except if one of the parties wanted to seek redress from the actions taken by the smart contract itself, as would happen, for example, if the execution was against a mandatory rule of contract law*), we have to consider that drafting a smart contract is substantially higher than drafting a traditional one. For starters, it is an inherently interdisciplinary enterprise that requires experts both in contract law and professional software developers. Besides the drafting process has the additional complication of translating into binary language the intentions of the parties. This process requires extra commitment from the parties, as it is easier to agree on general principles, but as these principles are translated into more specific obligations, the disagreements emerge to the surface. In the end, much is *lost in translation*; the binary obligation is stripped of its (semantic) meaning.

In that line, the parties who use smart contracts have to forego the possibilities offered by open standards, which, as we have seen, allow for flexible enforcement. When the parties use open standards, they are signaling trust towards the other party, as they agree to provide specific meaning to the term as the contract execution unfolds and a relationship develops. The standard, thus, acquires meaning in the specific context of the relationship.

But the disadvantage is not only with regard to the relational aspects of the contract; it is also in the scope covered by the contract. Since the smart contract is composed of instructions of binary nature, it cannot encompass the complexity of the contractual exchange. A smart contract is nothing more than a set of instruction. Each instruction is meant to address one single issue. But given the costs of the coding (drafting) process, not all the issues can be included in a smart contract. A careful selection must be made at the outset and during the negotiation process. Indeed, a reasonable implementation of a smart contract demands a careful selection of the issues that will be addressed through software code; other issues (as important as they may be to the parties) simply must be left out.

On the other hand, semantic rules can encompass a wide array of topics, as when the parties agree to incorporate the foundational principles of privacy by design in their IT contract. And, since a traditional contract transcends the four corners of the written contract, it is not necessary to think ahead of all the possible contingencies (as would be strictly necessary for a smart contract). Some situations can be safely unregulated or be left to the law to decide (*which contains a wide array of default rules*) which acts as a fallback system for everything that the parties have not stipulated expressly. Therefore, even the shortest written traditional contract has an immensely wide scope, which is given (in complement) by all the applicable law and jurisprudence. The legal system, which complements the scope of contractual provisions is, by no means, present in smart contracts. Given its purely electronic and autonomous nature, the scope of a smart contract is reduced to what the parties have expressly coded, nothing less, nothing more.

Having said that, a trade-off becomes visible (apparently), one between scope and costs. To encompass a wide scope with smart contracts is extremely costly; whilst it is extremely cheap to do it with traditional (semantic) contracts. But we contend that it is possible to integrate smart contracts for specific elements of the contractual relationship that can be readily translated into binary language while leaving some other aspects of it uncovered by the software. Then the obvious question that arises is: when is it efficient to base the exchange solely on smart contracts? Alternatively, when should the parties mix both elements? And finally, when should they discard the use of smart contracts altogether? The answers to those questions depend on the nature of the specific transaction within the contractual relationship; and on the contractual relationship as such.

4.6. Smart contracts, applications

Information is at the core of contracts and their problems. If a single person had all the relevant information available in the world (past, present, and future), if a system of preferences is assumed, and he knew all of the available means, then allocating economic resources to the most valuable uses would not be an economic or contractual problem, but one of logic (von Hayek, 1945, p. 519). Of course, no one does have that information. Information is scarce (and therefore, expensive) and asymmetrical (which means that everybody has information in different quantity and quality). This is precisely what motivates people to contract in the first place (Bag, 2018, p. 8). The function of elaborated contracts (and contract law) is to mitigate contractual hazards while infusing order and reducing conflict at the same time. With this in mind, we can start to analyze several use cases under the lens of those three fundamental concepts in the law and economics of contracts, namely, observability, verifiability, and enforcement.

According to a study done by Bartoletti and Pompianu by the first trimester of the year 2017, there were over 2715 smart contracts (software) projects available on the platform Github. They explored 6 different online platforms that host smart contracts from which they took a sample of 834 smart contracts that were already running and available to the public (2017). The platforms surveyed were: Bitcoin, Ethereum, Counterparty, Stellar, Monax, and Lisk. They analyzed the usage of smart contracts and came up with a taxonomy of smart contracts:

1. Financial: In this category, they grouped smart contracts that were used to gather, manage and distribute money. The most frequent types of smart contracts that they found include:

a) Crowdfunding (where users come up with a commercial project and request money from the public, which is transferred to the entrepreneurs once a specific goal has been reached*)*. Crowdfunding is a contractual scheme that, in principle, could benefit greatly from the use of smart contracts. In a crowdfunding operation, an entrepreneur asks funds from the public to finance a project. It is the innovative character of the idea what drive the people to invest in the project. The main issue with this contract, however, is that the micro-investors put themselves in a vulnerable position, since the entrepreneur may easily get away with the money and cancel the project altogether (or the project may have not even existed in the first place). The incentives for an opportunistic behavior are vast since the micro investors are unlikely to enforce the crowdfunding contract because the enforcement costs outweigh the money invested. Given that the investment is usually performed online, it is extremely difficult for the investors to join together and coordinate a collective lawsuit to cut the enforcement costs. Put differently, the actions of the entrepreneur are *not observable* to the hundreds (perhaps thousands) of investors who are not able to track to what extent the entrepreneur really intended to develop the project, or to what extent he deployed his best efforts to implement it. Also, investors do not know if the required funds have been raised yet.

Usually, this informational problem is solved through a trusted (online) intermediary who compromises his patrimony and reputation to assure the community of the seriousness and profitability of the project (such as kickstarter.com). The intermediary, of course, charges a fee for using his platform and reputation. The costs of these intermediaries could be cut altogether by using a smart contract. In this use case, the community could create an open source platform where everybody can monitor the amount of money that has been raised. The software would have the instructions (also publicly available) to transfer the funds to the entrepreneur once the goal has been reached; or else, to transfer them back to each one of the micro-investors. But that would be the limit of the smart contract. Once the goal has been reached, and the smart contract has transferred the funds to the entrepreneur, there is no possible way for the smart contract to monitor what he does with the money (unless more complex governance structures are devised afterward).

So, the ability of the smart contracts to undercut the information asymmetry and mitigate the risks associated with the entrepreneur's opportunisms are, somewhat, limited. Smart contracts, of course, could be bolstered by using reputation mechanisms (also tied to blockchain technology) with which the community could make some private information (related to moral hazards) *verifiable*, in a way. These reputational mechanisms also accomplish an enforcement role, since the users could communicate to the community the bad (and good) experiences that they have had with a particular entrepreneur, in the form of a review. The threat of bad reviews acts as a deterrent for misbehaviors, for they foreclose the prospect of future businesses.

b) Ponzi schemes**:** The U.S Securities and Exchange Commission defines Ponzi Schemes as: "an investment fraud that involves the payment of purported returns to existing investors from funds contributed by new investors." Since they are, most of the times, associated with fraudulent businesses, they are illegal in most jurisdictions. They could be sustainable, though, as many social security systems around the world. Here, the sustainability of this scheme in time depends, among other conditions, on the entrance of new investors (Artzrouni, 2009, p. 200). Even if they were legal, like, for example, in the case of privatized social security systems, the "investors" face an informational problem because they do not have full access to the organization's accounting; their actions are not observable to the investors. This is the source of critical behavioral uncertainty, for which we can refer to (Williamson, 1985, p. 57).

Both sides (the organization and the investors) could benefit from the use of fully transparent trustworthy public blockchain registries. From one side, the investors would have strong reasons to trust the good management of the fund if the information is made public and its books are tamper-proof. On the other side, the organization would benefit from a greater number of investors. However, the use of smart contracts for this purpose would be relatively limited. It could contain detailed instructions with regard to the payment of the investors' benefits and some other specific conditional instruction; but it would be unfeasible to try to regulate exactly what the organization can do with the investors' funds, which is a critical issue (usually the funds are invested somewhere else with a fairly high-profit rate). Besides, since the contract is destined to be a long-term one, the scheme would need a fair amount of flexibility to handle unforeseen circumstances; and that is something that goes against the very nature of a smart contract.

c) Insurance: In a regular insurance contract, the promoter pays the user a predetermined amount if a certain event happens. These contracts are particularly vulnerable to the opportunism of both parties: the insurer and the policyholder. The insurer may illegally refuse to pay the compensation for a covered loss, or the insured may illegally claim compensation for a non-existent or an uncovered loss. Furthermore, after the insurance policy has been issued, the insured may incur in moral hazard, which can be defined as: "the tendency of a person who is imperfectly monitored to engage in dishonest or otherwise undesirable behavior" (Mankiw, 2015, p. 462) so as to abuse his right conferred by the insurance policy.

Smart contracts can do a great job at reducing the opportunities to act opportunistically. To start with, the reputation of both the insurer and the insured can be tracked through reputation mechanisms registered with blockchain technology, which can convey relevant information about the moral attributes of the parties before they enter the insurance contract and histories of past breaches or abuses. This information would otherwise remain private and, thus, *unobservable* to the parties. Also, a set of instructions coded in a smart contract could be used to automatize the execution of the insurance policy in the event that a covered loss occurs. For this, the parties could rely on an external and impartial source of information, for example, if the insurance covers delays of cancelation of flights, the website of the airline could be used by a smart contract to verify if the condition has been met. If it has, it would automatically transfer a certain amount of funds to the insured.

If the event that generates the loss is more complex (cannot be reduced to a binary check), then the parties could rely on a crowdsourced online dispute resolution mechanism. In this case, the signature of a third party (or a group of persons acting as community jurors) would be needed to execute a transaction contained on a smart contract, if the legitimacy of the transaction is questioned by one of the parties. Based on the evidence submitted by the parties, the community of users (acting as anonymous jurors or arbitrators) would determine whether or not the event took place and whether or not it was covered by the policy (Darcy Allen, Lane, & Poblet, 2019, p. 11). Such dispute resolution mechanism has been put in place by Kleros, a startup from 2017 who claims to provide fast, secure and affordable blockchain-based arbitration.

2. Notary: In this category, they grouped smart contracts whose main object was to store data persistently, in exchange for money. This functionality is useful, for example, to *register the ownership* of an immaterial asset (like a patent) or a physical one whose ownership can be proved by means of a public register (like the property of land). Users also deploy this type of contracts to *prove the existence* of a document (in a given time) and prove its integrity. Besides private law purposes, they can also be used to claim *copyrights*. Their main social and economic function is to make information public, accessible in an easy and cheap manner, and reliable (in many respects, more reliable than a human notary).

3. Game: Gaming is a multi-billion industry. This category encompasses online games based on skills and the ones based on chance. In the first case, the user pays to play the game and is compensated with immaterial rewards, some of which are transferrable and may have economic value outside the boundaries of the game. The latter is a use case where smart contracts could be used to secure the integrity of the virtual property earned by the users of the game. Back in 2006 Meehan pioneered the construction of the concept of virtual property, showing that in the game Project Entropia, a virtual island sold for over $26,000 and a virtual space station sold for $100,000 (Meehan, 2006, p. 3). It seems clear that virtual property has real economic value nowadays and blockchain-based smart contracts could protect it in a very effective way.

With regard to online games based on chance like lotteries, dices, rock-paper-scissors, roulettes (despite their legality) the users face a severe information asymmetry problem reflected in the unobservability of the actions of the organizer of the game. In essence, the users do not know if the organization sponsoring the lottery is trustworthy or if it is only an online scam. Should the rules of the game be coded in a publicly available and transparent smart contract, that information asymmetry would vanish entirely. The users would know for sure and in advance the true probability of winning and would have absolute certainty that if they do win, they will get promised prize. In essence, the contract would be performed in a completely symmetrical information environment.

4. Wallet: By this mean, the provider secures its user an inviolable public key together with an associated private key that accomplishes a double function. First, it identifies a person in the network, and second, it allows that person to receive and store money in a secure way. It is noteworthy that these crypto wallets are the only way to identify a user in anonymous blockchain networks. The real identity of the human being behind the wallet is never revealed. In principle, this would create a unique situation of information asymmetry where the anonymous party could take advantage of his counterparty; however, as we saw earlier, the technology itself suppress all the potential opportunism, for it is not possible to behave against the rules already coded in the smart contract.

5. Library: Contracts of this kind provide general functionality (like picking random numbers from a range, mathematical operations, or other general processes). They are used by other contracts; so, for example, a lottery game calls a library-smart-contract that contains software that offers random number picking (Bartoletti & Pompianu, 2017).

There are, of course, many different unclassifiable contracts that are tailor-made to fit the specific need of the parties. Those contracts could not be categorized by the authors of the aforementioned study.

6. Generic smart contracts using external sources (oracles): We could name, for example, the case of the smart contract devised together by ABN Amro Bank, Samsung DDS (the division of logistics and IT of the company of the same name) and the authority of the Port of Rotterdam. The smart contract is programmed to track the logistic operations involved in importing or exporting merchandise from and to the Netherlands. It already executed a successful operation to Asia. The smart contract received reliable information from external sources like the authorities of the different ports and customs offices around the world. In that way, the smart contract knew when the container left the country, when it arrived at its destination and when it received customs clearance. The payment for the goods was tied to certain events so that the seller received part of the money when the container was registered to have left the country; and the rest, when the container received customs clearance.

The aforesaid is a way in which the smart contract could mitigate the effects of information asymmetry without trusting on costly intermediaries. Of course, this project was performed by traditional intermediaries and was executed on proprietary software. But the really exciting use case would be to see one similar operation carried out through an open-source community-based software executed on a blockchain-based platform (like Ethereum or EOSio).

7. Smart contracts using the internet of things: Some other exciting use case rise when we combine this technology with the internet of things. Some vehicle retailers in the United States of America already include starter interrupt devices (also known as kill switches) that are connected to the internet and can be activated or deactivated remotely. If the customer does not pay the credit on time, then the retailer can activate the device and prevent the car's engine from being started. This technology, together with a GPS device could be used in a smart contract setting to automatize the enforcement of the contract, as a form of self-help, to block the starter of the car if and only if the car is located at the customer registered home address (Werbach & Cornell, 2017).

It is also conceivable that this technology could be combined with smart keys, like the ones used in hotels (or maybe in rooms available in private households, like the ones offered in AirBnB), in order to activate and deactivate them automatically once the smart contract verifies whether or not the room or apartment has been paid. This could, however, raise concerns with regard to the legality of this instrument as a valid self-help mechanism in private law (Raskin, 2017).

This use of smart contracts might not mean much in terms of observability or verifiability; however, they could undercut the opportunism that might arise because of the (usually excessive) costs of litigation. Indeed, sometimes the costs of enforcing a contract are so high that they disproportionately outweigh the benefits of having the contract enforced. As a result, knowing this in advance, the advantaged party breaches the contract with impunity, displaying strategic opportunism. This opportunism could be suppressed by using smart contracts as a mean for private enforcement (Koulu, 2016, p. 46).

4.7. Conclusions

So, smart contracts provide automatic and inviolable self-enforceability. At first glance, the removal of the enforcement costs of the equation seemed like an unsurmountable advantage in favor of smart contracts. However, during this chapter we explored the idea that an adequate contractual governance is a complex enterprise that must be performed strategically, considering all the potential tradeoffs involved in the choice of the governance mechanisms.

Hence, the effectiveness of smart contracts as governance mechanisms depends, partially, on its ability to manage contractual hazards, which are sources of potential conflict which might prevent the realization of mutual gains. So, after studying the characteristics of smart contracts, in this chapter, we studied how they can help the parties to handle informational problems (asymmetries, observability and verifiability issues), uncertainty, asset-specificity, and opportunism.

But, even if smart contracts might seem, prima facie a good choice, we still need to take its costs into consideration. Not only material (such as the costs of negotiating and drafting a smart contract) but also immaterial costs (such as the potentially negative impact of smart contracts on the long-term interpersonal relationship of the parties). Indeed, while smart contracts reduce drastically the costs of screening the potential counterparty to look for signals of trustworthiness; and while they cut out completely the enforcement costs, they have very high set-up (drafting) costs.

So, the decision must be carefully studied taking these considerations into account. But we are not ready yet to make a decision. As we have repeated, transactions are not uniform; they differ in their attributes (frequency, uncertainty and asset-specificity). While smart contracts could be a good choice for one type of transactions, they might perform poorly at another. In the next chapter, we will further explore the last element (types of transactions) that needs to be assessed to answer the question: under which conditions are smart contracts a better governance mechanism than traditional contract provisions?

CHAPTER 5
A TYPOLOGY OF TRANSACTIONS AND SMART CONTRACTS

5.1. INTRODUCTION

Up to now we have explored how smart contracts help the parties to manage contractual hazards. We concluded that they promote the disclosure of private information and, thus, foster transparency among the parties. Beyond that, they do not help to overcome bounded rationality in any significant way. We have seen that their self-enforceability creates great opportunities to suppress opportunism but, as a tradeoff, it makes them inflexible. This feature, in turn, makes them poorly suited to build a significant relationship over the time, for which selective (not automatic) enforcement would be preferred. We posited that the fact that they are written in computer code makes them purely electronic and binary in nature (*save the case when the parties use external oracles to provide digital inputs to the contract software*) and, thereby, limited in scope.

But to this point, the object of our inquiry has been smart contracts, as governance mechanism. We still need to analyze transactions as such, to provide an answer to the question with which we started this research: when is it efficient to use smart contracts? The first step is to acknowledge that transactions are not uniform; they have different characteristics or *attributes*. We need to study the ways in which transactions differ if we want to know in which ones to use smart contracts.

But how exactly do they differ? They vary in the extent to which contractual hazards affect them. However, trying to elaborate a typology of transactions considering all the potential contractual hazards would be unnecessarily complicated. Williamson simplified the analysis by selecting three critical attributes of the transactions, which he called the *dimensions*. The dimensions are *uncertainty*, *frequency,* and *idiosyncrasy* (1979, p. 239). We explained this framework previously in the introductory chapter, where we also described the 2x3 matrix of transactions, considering uncertainty, investment specificity (idiosyncrasy), and recurrence of transactions (frequency).

		Investment characteristics		
		Non-specific	Mixed	Idiosyncratic
Frequency	Occasional	Purchasing standard equipment	Purchasing customized equipment	Constructing a plant
	Recurrent	Purchasing standard material	Purchasing customized material	Site-specific transfer of intermediate product across successive stages

Table I: A typology of transactions (Williamson, 1979, p. 247)

Williamson's intention when developing this typology was to produce a discriminating match between each type of transaction and a mode of governance (previously studied in 4.2.). His contention was that: "transactions, which differ in their attributes, are aligned with governance structures, which differ in their costs and competencies, so as to effect a (mainly) transaction-cost-economizing result" (Williamson, 2005, p. 5). This was called the "discriminating alignment hypothesis" and entails the following analytical steps:

1. "To name and explicate the principal dimensions with respect to which transactions differ (thereby to uncover differential adaptive needs);
2. To name and explicate the principal attributes for describing governance structures [⋯];
3. To effect a discriminating match, according to which transactions are aligned with governance structures so as to promote adaptation of autonomous and cooperative kinds; and
4. To ascertain whether the predicted alignments are corroborated by the data" (Thiel et al., 2016, p. 160)

This hypothesis assumes that some modes of governance are well-suited for some purposes, but poorly suited for others. Hence, transaction costs economics is understood as an enterprise that purports to ascertain the attributes of transactions to which a given mode of governance affords a (comparatively) efficacious governance response (Williamson, 1999, p. 307). For that purpose, it would be necessary to assess comparatively the attributes of modes of governance, whose critical dimensions include incentive intensity, administrative control, and contract law regime (Williamson, 2005, p. 6).

But we do not intend to use the discriminating alignment hypothesis as is, because it is originally designed to match *governance structures* with types of transactions (for which the attributes and competencies of different governance structures need to be explored analytically). We intend to follow its approach to apply it to smart contracts, which we previously defined as a type of *governance mechanism* (not a governance structure by its own merit). Therefore, instead of naming and explicating the principal attributes of a specific governance structures, we did it with smart contracts as governance mechanisms (chapters 3 and 4). Thus, we explained how smart contracts deal with contractual hazards. In this chapter we will "effect a discriminating match according to which transactions are aligned with" (Thiel et al., 2016, p. 160) smart contracts; in other words, we will determine for which transactions are smart contracts well-suited and why?

5.2. THE FRAMEWORK

As we have established, smart contracts are qualitatively different from traditional contracts; they differ in their costs and competencies. Furthermore, smart contracts are new governance mechanisms whose position in the literature needs to be established. We already know the costs and competencies of smart contracts and know that they operate in hybrid governance structures. Therefore, what we are going to do is to take the analysis one step further. We are going to align transactions, which differ in their attributes, with a specific governance mechanism (smart contracts) within a specific generic type of governance structure (hybrid structure).

Now, by the time Williamson developed this typology of transactions, the technology landscape was dramatically different. The internet had not even been invented yet, and blockchain technology goes without saying. These innovations open new possibilities that make one-time transactions relevant, which will be added to the analysis as a derivation of the discrete contracting that is taken as the basis for classical contracting.

Plus, given that uncertainty is a feature that affects critically the usage of smart contracts as governance mechanisms (*since it is the reason why the parties encounter unforeseen circumstances in the face of which they need to renegotiate and adapt the original agreement*), our analysis will consider the impact of the degree of uncertainty in each one of the categories displayed above.

In what follows, we will match the attributes of smart contracts as governance mechanisms of hybrid governance structures to each one of the categories of transactions advanced by Williamson, which will be complemented as explained in the previous paragraph. The result will be a prediction of how well a smart contract would govern a contractual relationship with the features corresponding to each category.

1) Discrete contracting
2) Occasional – non-specific
3) Occasional – mixed
   a. High uncertainty
   b. Low uncertainty
4) Occasional – Idiosyncratic
5) Recurrent – non-specific
6) Recurrent – mixed
   a. High uncertainty
   b. Low uncertainty
7) Recurrent – Idiosyncratic

5.3. Discriminating Alignment

Knowing what we know about smart contracts costs and competencies, we are now in a position to provide the following analysis (with regard to transaction-costs-economizing features and competencies) for each of the following type of transactions:

5.3.1. Discrete contracting:

Williamson excluded the types of transactions where the parties can safely expect never to see each other again because he considered them to be extremely rare. In reality, he argued: “few transactions have this totally isolated character” (1979, p. 247). However, the current state of technology allows the parties to perform transactions under conditions of anonymity, where what truly matters is the object being exchanged (which must be highly standardized) and the identity of the parties (including their past, present, and future behavior) is absolutely irrelevant (as long as the technology assumes away the possibility of opportunism). We see this pattern of contracting in fintech smart contracts (Bartoletti & Pompianu, 2017), automated shopping bots or crypto assets trading bots, for instance.

Given the characteristics of smart contracts, we posit that they are the ideal governance mechanisms for these types of transactions. Since the assets are highly standardized and the price is given by the market conditions, the uncertainty that is usually inherent to any form of contracting becomes immaterial, in practice. In this scenario, the parties are after financial operations that could be concluded with, basically, anyone with enough capital; therefore, conducting the transaction under pre-established and invariable instructions written on blockchain secures the self-enforceability of the exchange in a fully digital environment. Smart contracts are, therefore, a decidedly efficient device to manage the exchange in a highly discrete transaction for their ability to create trust in no-trust environments (Eenmaa-Dimitreva & Schmid-Kessen, 2019).

5.3.2. Occasional, non-specific:

Occasional transactions are ones where the parties have reasonable expectations to engage in future transactions, whereby the good or service being exchanged is of a durable nature (meaning that the need for future exchanges of the same good or service will not arise again in the short-run). In this case, the prospect of future business acts as a deterrent for wrongdoing during contract execution, although this incentive is relatively weak since the long interval between transactions makes future exchanges uncertain.

On the other side, following Williamson, we will accept that given the non-specific nature of the investment, the market will act as an appropriate and sufficient governance mechanism (assuming that competitors are numerous). If we assume a functioning level of competition, the parties can readily switch supplier (or purchaser) if the contract performance is not satisfactory. This sole threat on the parties suffices to govern the contractual relationship in an adequate manner. Any additional investment will make the set-up costs of the contractual governance mechanism non-recoverable (given the occasional nature of the exchange).

With regard to uncertainty, we consider that it is safe to assume that, given the standardized (non-specific) nature of the object of the transaction, it will be (necessarily) unimportant. Even if unforeseen circumstances arise (for which the parties or the law have not established a specific remedy), the parties can still resort to the market, reputational and legal mechanisms to provide sufficient motivation for them to reach a mutually satisfactory adaptation. The fact that they have that relatively strong BATNA (Best Alternative to a Negotiated Agreement) diminishes the expected value of smart contracts as governance mechanisms for this type of transactions. Again, the set-up costs of a smart contract make it inviable in relation to alternative governance mechanisms (traditional contracts), because of the occasional nature of this transaction.

A relatively weak reason to use smart contracts in occasional transactions (non-specific, mixed and idiosyncratic) stem from the fact that the prospect of future business is uncertain. Therefore, the parties could act opportunistically as if the current transaction were the end-game. The use of smart contracts in specific crucial obligations could do away with this risk and compel the parties to honor their agreement at all times, even when the probability of future business is extremely low.

5.3.3. Occasional, mixed:

In this kind of transactions, the degree of asset specificity is higher; therefore, the potential payoff of opportunistic behavior is also higher. In occasional transactions with a medium degree of asset specificity, one of the parties is in a vulnerable position and can be exploited by the other one, unless he takes appropriate contractual safeguards. In the example used in the chart (cited in the introductory chapter), the one that started to work on the custom-made equipment for his customer is the vulnerable party. Note that the market mechanism is obstructed by the higher degree of asset-specificity; this is because the resources of the initial investment cannot be allocated to an alternative customer without sacrificing significant value. This investment is a sunk-cost that forces the manufacturer to maintain the relationship with his customer in order to realize profits (otherwise not only that he will not make any profit, but he will lose the initial investment).

So, the incentives to behave opportunistically are higher, and the threat to turn to the market to find alternative customers is not as credible as would be with non-specific transactions. As a result, the parties need to resort to stronger governance mechanisms to carry out their exchange in a fruitful manner. Williamson suggests turning to trilateral governance, which entails including third party assistance (like arbitrators) to resolve disputes and evaluate contractual performance (1979, p. 250). We agree. However, we would suggest to go a bit further and create contractual safeguards through smart contracts that include third-party assistance.

The aforesaid could be done by creating a smart contract with a multi-sig feature whereby independent third parties (oracles) can help the disputants to determine the facts and or assess them (as in the question: Is the increase in price requested by party A justified?). Such use of a smart contract (that resort to third-party assistance) can only be recommended if the level of uncertainty (surrounding that specific obligation) is fairly low. Otherwise, the use of traditional trilateral governance and mechanisms (a semantic contract with arbitrators or fact-finding panels) is still suggested. In this point, a correct assessment of the level of uncertainty is important, since the expected utility of the usage of smart contracts diminishes as the level of uncertainty grows. Contractual environments with high levels of uncertainty need rather flexible governance structures and mechanisms, something that the rigidness of smart contracts cannot offer.

Now, as we previously stated, the use of smart contracts has detrimental effects on the relationship of the parties; however, given that in this type of transactions maintaining the relationship is not as crucial as it is in idiosyncratic transactions (*because of its merely occasional character and due to the fact that the parties have not committed a significant percentage of their resources on one another*) the benefits seem to outweigh the losses. A caveat needs to be remarked; however, the high set-up costs of such smart contract need to be weighed against the economic value of the current transaction and its expected (future) frequency. The alternative would be to devise traditional contracts, whose set-up costs, in general, tend to be much lower.

5.3.4. Occasional, idiosyncratic:

In general terms, we can anticipate that smart contracts are not a viable governance choice for this type of transactions. In fact, we would go as far as to say that they offer the least favorable conditions for their use. In idiosyncratic transactions (both occasional and recurrent) the relationship matters to the parties. It is in the interest of both parties to maintain a good relationship (at the personal and commercial sphere). Since both the manufacturer and the beneficiary have compromised a significant amount of resources on one another, breaking the relationship means losing the initial investment (which works as a sunk-cost) and diluting the prospective profit. We must stress, once again, that using smart contracts has detrimental effects on the relationship of the parties; therefore, its usage in idiosyncratic transactions (even with the multi-sig feature) must be strongly discouraged.

Besides, idiosyncratic transactions (*transactions where the asset-specificity is high enough to compromise the walk-away threat on both parties*) can be said to be hand-tailored to the needs and capabilities of the parties, plus they are executed through long periods of times (for example, the construction of a plant). Both attributes increase the uncertainty exponentially, which creates constant opportunities for the parties to renegotiate the initial agreement. Since smart contracts are inflexible by design, they perform poorly as a governance mechanism for this kind of transactions. More specific and flexible governance mechanisms of the traditional kind must be devised to encompass the unique features that the dynamics of the particular relationship have generated throughout the time.

5.3.5. Recurrent, non-specific:

In general terms, transactions of a recurrent kind incorporate an incentive on both parties to maintain the relationship in the long-run. However, this incentive is weak when it comes to non-specific (highly standardized) goods or services. This is the case because in non-specific transactions the existence of a competitive market makes it easy for unsatisfied parties to walk away from each other and find a new trading partner among the numerous alternative suppliers or purchasers; all this without significant switching costs.

Nevertheless, in contrast with occasional – non-specific transactions, the recurrent nature of this type of transaction makes the use of smart contracts an appealing alternative. The main drawback of using smart contracts in occasional – non-specific transactions is that the set-up costs of using a smart contract are not easily recoverable. This assertion is not applicable to recurrent transactions where the initial costs can be redeemed across the numerous future transactions.

Since we are discussing non-specific transactions, we will assume the impact of uncertainty to be negligible. Therefore, considering that the high drafting costs can be redeemed in the long-run; and that the continuance of the relationship is not particularly important to the parties of this kind of transactions, we will conclude that smart contracts are, in this case, particularly a useful governance mechanism.

5.3.6. Recurrent, mixed:

As previously analyzed with the occasional-mixed transaction, one of the parties is in a vulnerable position, facing a latent risk of opportunistic behavior from the counterparty, against which he would wish to be safeguarded. Smart contracts were recommended as a viable alternative governance mechanism for occasional transactions of the mixed type (*as long as the set-up costs of using a smart contract are weighted against the prospects of future transactions*); all the more are they a more attractive alternative for recurrent-mixed transactions. The recurrent nature of these types of transactions makes the high drafting costs of a smart contract recoverable in the long-run.

Again, as previously stated, the extent to which it is convenient to use smart contracts in these types of transactions depends upon the degree of uncertainty. Therefore, a thorough assessment of the conditions of the maturity of the market and the particular circumstances of the transactions is recommended to identify the potential issues that might arise during contract execution. The higher the uncertainty, the less convenient it is to use smart contracts.

5.3.7. Recurrent, idiosyncratic:

These types of transactions offer one of the least favorable conditions for the use of smart contracts, given that idiosyncratic transactions tend to have a high degree of uncertainty, with which the smart contracts cannot cope. In this particular case, the fact that the transaction is recurrent only reinforces the previous assertion.

Indeed, the relationship between the parties matters in regular idiosyncratic transactions, all the more it matters if the transaction is of the recurrent type. Smart contracts would only tend to obstruct the dynamics of the relationship, which is supposed to grow stronger as the contractual performance unfolds. The parties cannot create a history of their own if they are not allowed sufficient leeway to enforce the contractual obligations (or turn a blind eye) as they judge fit.

5.4. CONCLUSIONS

Following the *discriminating alignment hypothesis*, in this chapter, we analyzed whether or not smart contacts would be convenient governance mechanisms, depending on each type of transaction. As a general conclusion, we contend that the use of smart contracts is highly recommended in contractual environments where the incentives to behave opportunistically are high and are not diminished by external forces with economic significance, such as reputation and the prospect of future business. This is the case, for example in discrete and occasional (mixed) transactions.

On the other hand, the use of smart contracts must be discouraged in transactions where the level of uncertainty is high and in transactions of an idiosyncratic type. With regard to uncertainty, because smart contracts do not offer the flexibility for the parties to adapt to unforeseen circumstances; and with regard to idiosyncratic transactions because in those circumstances it is essential for the parties to be able to build a relationship based on interpersonal trust, something that cannot be achieved through the use of smart contracts, given their autonomous and electronic nature.

In deciding whether or not smart contracts are a good alternative, we must also consider that the market is, in many instances, a self-sufficient governance mechanism that allows dissatisfied parties to find another trading partner. This, by itself, puts a strong pressure on the side of the supplier to provide a competitive good or service and forces him to try to "work things out" with the buyer. Finally, the high set-up costs of smart contracts must be considered because they might not be recoverable unless the transaction is of huge economic magnitude; or the parties envisage to redeploy the smart contract in a set of future (recurrent) transactions.

CONCLUSIONS

We started this research with the purpose of shedding some light in the unexplored territory of the transaction costs economics of smart contracts. The question that we addressed was, basically, when should smart contracts be preferred over traditional contracts as a governance mechanism? To answer that question, we started by reviewing the economic literature on the functions of contracts. We determined that they are economic and legal devices that build the trust of a calculative kind, which safeguard the parties against each other's opportunism. This is essential because, otherwise, the economic exchange would not take place in the first place; the mutual gains that are generated through the exchange (the cooperative surplus) would not be generated.

Furthermore, we related contracts to the notion of governance. Indeed, we asserted that the transactions need to be governed to avoid the self-interest seeking attitude of the parties to generate conflict and derail the exchange. Contracts, in the traditional sense, are legal tools to construct this governance structure that is required to bring order into the exchange. But smart contracts can also be used as governance mechanisms to achieve the same goal. With this research, we evaluated to what extent they are able to do that efficiently.

The transaction in its complexity needs to be assessed to determine whether to use traditional contracts or to take advantage of the automatic and inviolable self-enforceability provided by smart contracts. Many elements are vital for this analysis. We tried to disentangle the complexity of the transaction by focusing on what Williamson called the "*contractual hazards*" (Williamson, 1996, p. 3), which comprise informational problems (asymmetries, observability and verifiability issues), uncertainty, asset-specificity, and opportunism. We determined that while smart contracts are effective to suppress *opportunism*, they perform poorly under conditions of *uncertainty* (for which the flexibility of the governance structure is highly valuable) due to its immutability. In the same line, we determined that they contribute to diminish the payoff of keeping information private (which create *information asymmetries*) because if one of the parties is seeking to expropriate rent from the other by exploiting his informational advantage, he needs to code that contingency on the smart contract. Including the information on the code of the smart contracts makes that information instantly observable to the other party. Thus, smart contracts force the parties to reveal all the private information; or else, relinquish any potential benefit that might be derived from it. We also saw that smart contracts do not reduce *asset-specificity* in and on themselves; however, if deployed correctly, they could block the opportunity to exploit the vulnerable party.

A different element to take into consideration to determine the convenience of using smart contracts as governance mechanisms is their costs, from the transaction costs perspective. We established that *searching costs* could be dramatically reduced, in the sense that it is no longer necessary to screen the counterparty to look for signals of trustworthiness (reputation, history of past transactions and so on). When using smart contracts, trust is shifted from the person to the technology. The technology allows the parties to conduct mutually rewarding economic exchanges without revealing their identities. Drafting costs (set-up costs) are extremely high, compared to traditional contracts, because a good smart contract requires, not only a lawyer but also a software developer who is able to code the instructions agreed to by the parties. The high set-up costs diminish the cooperative surplus that the parties may obtain from the transaction; in contrast, these costs could be recovered (totally or partially) with the sharp reduction in enforcement costs (since smart contracts are self-enforceable) that smart contracts bring to the equation. Indeed, since the remedies for "breach" are incorporated in the code, the software will provide the remedy in an automatic and autonomous manner; therefore, enforcement costs are removed altogether.

Negotiation and renegotiation costs, we saw, require special attention. Negotiation costs are expected to be bigger when using smart contracts because they do not allow the use of open standards (which are a way for the parties to economize on bargaining costs) for which the parties are going to provide a meaning later during contract execution. The parties need to agree on specific results to specific contingencies, which, we argued, is much harder than agreeing on general principles. Besides, since smart contracts preclude renegotiation and the practice of selective enforcement (forego minor breaches to avoid damaging the interpersonal relationship), the relationship of the parties cannot flourish as it would with a traditional open contract.

To evaluate the convenience of the use of smart contracts as governance mechanisms, it is also necessary to evaluate the characteristics of the transaction to which they are intended to be applied. For that purpose, we relied on the typology of transactions devised by Williamson, who classified them considering their frequency (occasional or recurrent) and their level of asset specificity (non-specific, mixed or idiosyncratic), creating a 2x3 matrix (in which we included also one-time – discrete – transactions). We analyzed each type of transaction to suggest in which of them it was efficient to use smart contracts. In general, we contend that the use of smart contracts is highly recommended in contractual environments where the incentives to behave opportunistically are high (like in discrete and occasional-mixed transactions); and we discourage their use in highly uncertain transactions and in situations where the parties make mutually specific investments (idiosyncratic). The latter because smart contracts are inherently inflexible and they prevent the parties from reaching necessary and mutually rewarding ex post adaptations.

At this point we can assert that smart contracts are not well-suited to manage idiosyncratic contractual relationships. Traditional contracts that use open-ended terms and conditions (to which the parties can endow their own meaning that derives from their personal history as trading partners) are still and might continue to be, a far superior governance option for those transactions. Although, computer science advances quickly, and there are current attempts to make smart contracts successively adaptative (Marino & Juels, 2016). Perhaps, sooner than later, they will evolve to the point where they offer more flexibility to deal with idiosyncratic relationships or a high degree of uncertainty, without compromising their ability to suppress opportunistic behavior.

Smart contracts need to evolve in the direction pointed in this research, namely, their inability to cope with uncertainty and their poor performance at helping the parties develop a significant relationship both at the commercial and personal level. It is crucial, therefore, that the technical development of smart contracts is accompanied by a parallel development in the economic and legal theories regarding the use of smart contracts in the governance of contractual relationships.

So, the question: when should we prefer smart contracts over traditional contracts as a governance mechanism? Does not have a definitive clear-cut answer. Instead, it demands a three-fold test: **1)** Can the *costs* of the smart contract be justified, given the economic importance of the envisaged transaction or group of transactions? **2)** Can a smart contract tackle the *contractual hazards* involved in the transaction better than a traditional contract? **3)** Is a smart contract an adequate governance mechanism for the specific *type of transaction*?

In the end, the decision depends on a balancing exercise. What we have done here is simply to disentangle the weaknesses and strengths of the technological device, and to use the existing literature on transaction costs economics to sketch a framework to make the decision-making process as systematic as possible. Hopefully, this work will open the door for fruitful empirical research on the broader topic of smart contracts and governance.

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