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Faculteit Bedrijfseconomische Wetenschappen

master in de toegepaste economische wetenschappen: handelsingenieur in de beleidsinformatica

Masterthesis

The Business Value of Blockchain

Dimitri Schepers

Scriptie ingediend tot het behalen van de graad van master in de toegepaste economische wetenschappen: handelsingenieur in de beleidsinformatica

PROMOTOR :
Prof. dr. Benoit DEPAIRE

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Preface

If I have seen further, it is by standing on the shoulders of Giants.
—Isaac Newton, British physicist

There are quite a few giants who I have to thank, and without whom this thesis would not have been possible.

First and foremost comes the giant of giants, my supervisor, prof. dr. Depaire. In the first place, I would like to thank him for allowing me to choose my own topic for my master thesis. His guidance throughout the year has improved this thesis in an uncountable number of ways. It is sad to know that I will no longer be able to attend one of his memorable lectures and hope that one day I am able to inspire someone like he can.

I would also like to thank the entire Business Informatics research group of the UHasselt, for enduring my presence within their team for the past year. I feel honored to be given this experience.

Paul, Dirk and Rutger, thank you for your time and useful insights that have allowed me to enhance my framework.

I would like to thank my fellow students, Yannick, Valérie and Charley, with whom I have shared many laughs and memories throughout college life and without whom this thesis would have been finished at least a month earlier. But I would not want to change that for the world; it has been a great pleasure to attend university with you three.

And last but definitely not least, I would like to thank my parents and grandparents for their tremendous support throughout school, university and life.

This thesis marks the end of my academic career. Whoever you are, I want to thank you for reading this thesis—which has led me down the rabbit hole that is blockchain—and I hope that you might learn something useful, however little that might be.

Dimitri G.K. Schepers

Samenvatting

Door verschillende artikels die spreken over de “disruptieve kracht” van blockchain en door het succes van cryptovaluta zoals Bitcoin, komt deze nieuwe technologie terecht op de radar van alsmaar meer bedrijven. Ze zien zichzelf geconfronteerd met de vraag of ook hun organisatie door blockchain overbodig gemaakt kan worden; zo niet, of het een meerwaarde kan betekenen voor hun bedrijf. Dit is echter geen simpele taak. Het gebrek aan goede voorbeelden, de gefragmenteerde literatuur en de redelijk technische kennis die vereist is, maken het vaak moeilijk voor bedrijven om te achterhalen wat zij werkelijk met deze nieuwe technologie kunnen doen.

Deze thesis hoopt daarom bedrijven hierin te helpen via de ontwikkeling van een theoretisch framework dat de bedrijfswaarde van blockchain beschrijft. Dit framework kan bedrijven helpen om de praktische waarde van blockchain voor hun bedrijf te achterhalen en om discussies hieromtrent te structureren. Het model is ontworpen vanuit een conceptueel standpunt zodat bedrijven uit allerlei sectoren ermee aan de slag kunnen.

Het was ons uitgangspunt dat de bedrijfswaarde van blockchain achterhaald kon worden via het analyseren van praktische blockchain use cases. Omwille van het zeer beperkte aantal blockchain-implementaties die reeds in een bedrijfscontext zijn uitgevoerd, hebben wij ons hiervoor gebaseerd op academische papers die een blockchain-prototype presenteren dat in een bedrijfscontext is ontwikkeld. Via een casestudie van 15 blockchain use cases werd zo inductief de bedrijfswaarde van blockchain achterhaald en in een framework gegoten. Via interviews met drie blockchain-experten werd de theoretische correctheid van het framework bevestigd.

Ons onderzoek heeft uitgewezen dat er zes fundamentele waardedrijvers van blockchain-technologie zijn, die de verschillende soorten toegevoegde bedrijfswaarde mogelijk maken: (1) decentralisatie, (2) cryptografische beveiliging, (3) transparantie, (4) data-onveranderlijkheid, (5) gedistribueerde consensus en (6) *smart contracts.* We hebben vervolgens twee perspectieven ontdekt die een impact hebben op de manier waarop blockchain bedrijfswaarde genereert. Als een samenwerkingsplatform leidt blockchain tot een kostendaling, en als een coördineringsplatform tot een opbrengststijging.

Dankzij de gestructureerde omschrijving van hoe blockchain bedrijfswaarde helpt creëren en/of capteren, die wij in deze thesis presenteren, kunnen organisaties gericht aan de slag met het achterhalen of en hoe blockchain een meerwaarde kan betekenen voor hun bedrijf. Ons framework zal organisaties zo helpen in hun zoektocht naar een waardevolle blockchain use case in hun bedrijfsspecifieke context.

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In God We Trust
All Others Must Use Blockchain

1 Introduction

That's the wonderful and terrible thing about technology.
It changes everything.

—Solomon Epstein, in *The Expanse* by James S.A. Corey

Bitcoin has been and continues to be at the center of attention in an increasing number of news articles, with opinions ranging from calling it a scam to—quite literally—the new gold. At every major price drop, adversaries of this very first digital coin are eager to let us know that the bubble has finally burst, as they predicted it most definitely would. However, up until now Bitcoin has managed to come out stronger of every crash. Recently, the USD/bitcoin exchange rate took a severe dive in September 2017, following the (temporary) ban of ICOs in China. At the time of writing, however, the rate is more than fully recovered at $7.500, up by a staggering 220% year to date. The crypto market capitalization as a whole rose even more than 300% over this period.

Whatever the fate of Bitcoin and other cryptocurrencies might be, there is general agreement from researchers and professionals alike that the underlying technology of Bitcoin, called *blockchain*, holds a lot of great potential; enabling a decentralised digital currency is only the tip of the iceberg. As an immutable append-only public ledger that validates and records transactions without the need nor presence of a trusted central authority, blockchain—a general purpose technology—attracts the interest of every industry.

Business models that have been constructed around offering this central authority to others are facing the threat of being disrupted. Every company that currently acts as a middleman and trades transactions between two parties could theoretically be replaced by a blockchain, e.g. crowdfunding companies, real estate agencies, music record companies and insurance brokers to name a few. The services that these middlemen are offering—which is to manage trust—can be replaced by some piece of code, rendering their businesses almost completely obsolete. Many businesses are meanwhile investigating how blockchain might deliver additional value to their organisation. Speeding up inter-organisational transactions, transparently tracking ship containers and safely storing land registration data are just a few of the many proof-of-concepts that have been recently developed using blockchain technology. New blockchain use cases are being discovered every day all around the world.

Nevertheless—despite all the hype, various blockchain consortia being established and many reports being published—a recent survey by Gartner (2018a) of 3.138 CIOs revealed that only 1% of them had indicated that they are currently investing and deploying blockchain technology in their organisation. A remarkable 34% of the surveyed CIOs have stated no interested in the technology whatsoever, while another 43% mentioned that it was "on the radar" but that they currently had no action planned. Allen and MacDonald (2016) give a plausible explanation when they state there is an "immense entrepreneurial problem underpinning the discovery of applicable opportunities for blockchains" (as cited by MacDonald, Allen, & Potts, 2016, p. 7).

This work therefore aims to structure the promise of blockchain technology. For many businesses, the added value of using blockchain technology is still unclear due to the existence of a large number of fragmented articles, papers, presentations, videos, etc., which often present inconsistent views towards the usefulness of blockchain technology. We therefore aim to build a theory of the fundamental business value of this breakthrough technology, by analyzing various blockchain use cases. Hopefully, this inductively discovered theoretical framework will be (1) a contribution to the existing blockchain knowledge base and (2) a useful guide for businesses to help identify valuable blockchain applications for their organisations.

This work is structured as follows. The remainder of this section identifies the existing research gap in blockchain literature that we hope to (partially) close with this work, introduces our four research questions and elaborates on the followed research methodology and design. Section 2 describes the essence of blockchain technology and discusses the concept of business value. In Section 3, the results from our case study are given and our theoretical framework of the business value of blockchain is presented. Section 4 concludes and gives directions for future research.

1.1 Research gap

In 2016, the first systematic review of blockchain literature was conducted in order to identify the existing research gaps and provide recommendations on future research directions (Yli-Huumo, Ko, Choi, Park, & Smolander, 2016). Unfortunately, however, they narrowed their search down to papers with a technical perspective, while excluding papers with an economic and business perspective. It is exactly this latter perspective that constitutes the focus of this work since critical voices consider the technology to be over-hyped[1] and of little practical use. F. Glaser (2017, p. 1543) adequately summarizes the current state of blockchain as “an innovative technology in search of use cases.”

Some argue that blockchain is, in essence, simply “a novel way to manage data” and therefore “competes with the data-management systems we already have” (Peck, 2017, p. 38), while others believe blockchain to be a “foundational technology” with “the potential to create new foundations for our economic and social systems” (Iansiti & Lakhani, 2017, para. 5). It is clear that these different views convey diverging beliefs about the true value of blockchain.

More recently, a blockchain research framework was constructed by Risius and Spohrer (2017) that examines the current state-of-the-art of blockchain research. Their work confirmed the aforementioned trend that “research has predominantly focused on technological questions of design and features, while neglecting application, value creation and governance” and that “application-oriented contributions to blockchain research appear to be scarce” (Risius & Spohrer, 2017, pp. 385–386). Using their recommendations we hope to (partially) fill this existing research gap with this work. One of the prospective

[1] For example, Gartner, a market research firm, yearly publishes a hype cycle for emerging technologies; in 2017, blockchain was placed at “the peak of inflated expectations” (Gartner, 2017b).

research questions Risius and Spohrer (2017, p. 389) propose, that lies at the intersection of *measurement and value* (as the activity that blockchain researchers can undertake) and *firms and industries* (as the level of analysis), is:

How does blockchain provide added value for companies to conduct transactions within the company or with customers, other companies, stakeholders and the government?

We start from the premise that blockchain solutions are almost always built ad-hoc without any sort of established framework or principles in mind. We therefore aim to discover a theoretical framework of the business value of blockchain in this work, that hopefully guides developers in discovering the value that blockchain might have for their specific situation or application.

1.2 Research questions

Due to the lack of a clear, extant theory on the value that blockchain might have for organisations, as explained in the previous subsection, the main research question we hope to answer in this work is the following:

How does blockchain provide added value for businesses?

In order to make this question more tangible and to structure our approach in answering this question, we divide it into the following four specific research questions that are answered consecutively in this text.

Research question 1. What is blockchain?

Research question 2. How can we define *business value* in the context of blockchain?

Research question 3. Based on empirical data from blockchain use cases, what is the added business value of blockchain that we can discover?

Research question 4. What are the elements and their respective relationships of a theoretical framework of the business value of blockchain?

Research questions 1 & 2 are discussed in Section 2 and serve as preliminaries that are necessary for answering research questions 3 & 4, which are the main focus of this work and the subject of Section 3.

1.3 Research methodology

The exploratory nature of the research that we want to conduct in this work due to the novelty of blockchain advocates the use of qualitative methods (Creswell, 2007). Since our goal is to build a theory of the business value of blockchain by using empirical data from use cases, two qualitative research methods seem particularly appropriate: grounded theory and case study research. In this section, we first describe both methods and explain how they can be used for theory building. Afterwards, we explain our chosen approach and present our research design. Figure 1 visualizes the interconnection between the three qualitative research methods that form the basis of this work.

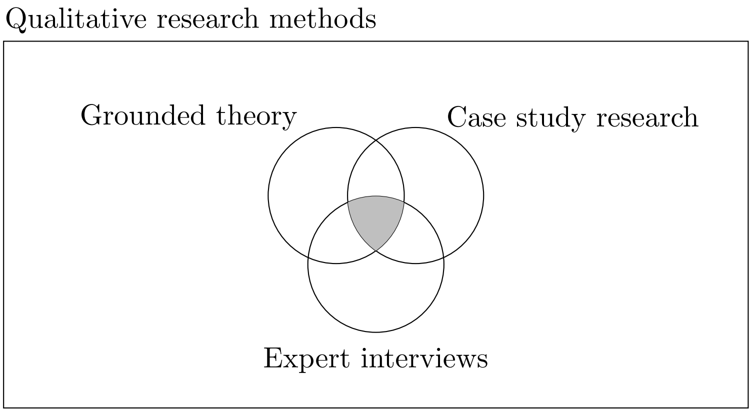


Figure 1: The qualitative research methods on which this work is based.

1.3.1 Grounded theory

Even though we do not intend to conduct a grounded theory study as such in this work, many of the concepts and methods that are used in case study research were first proposed by the American sociologists Glaser & Strauss in their pioneering work on *The Discovery of Grounded Theories* (1967). We therefore briefly review this qualitative research method that was the first to legitimize the use of qualitative research in developing new, contextualized theories from data (B. Glaser & Strauss, 1967). The goal of grounded theory is the bottom-up construction of a theory that tightly fits the data from which it originates. This inductive approach towards theory building breaks with the prevalent hypothetico-deductive approach that is used to test theories or, more specifically, the hypotheses that can be derived from them. In contrast, the deliberate absence of hypotheses and existing theories at the outset of a (classical) grounded theory study is of great importance according to Glaser (1978, 1992) since this information might bias the researcher when collecting and analyzing the data and could therefore result in a theory that is ungrounded from the data. However, Suddaby (2006, p. 634) argues that the grounded theory method does not offer "an excuse to ignore the literature" and "to enter the field without any knowledge of prior research", but rather that the researcher should be knowledgeable of this bias. To quote Siggelkow (2007, p. 21): "an open mind is good; an empty mind is not."

The term *grounded theory* is used to refer to both the method of progressively identifying and integrating concepts and categories from data in order to build a new theory, as well as to the theory that results from applying this method. This research method is structured around the following four key principles (Willig, 2013):

- theoretical coding,
- theoretical sampling,
- constant comparative analysis,
- theoretical saturation.

Theoretical coding refers to applying a coding paradigm that enables the researcher to integrate raw, low-level data into meaningful, higher-level categories. Subsequently, as the (dis)similarities between the different categories, that have been discovered, are compared, new theory emerges that captures all the variations inherent in the data. With theoretical sampling—as opposed to, e.g., random, statistical and purposive sampling—the emergent theory decides which data should be collected next. This leads to a constant iteration between data collection and data analysis. New data can either challenge, validate or further refine the emergent theory until theoretical saturation occurs—this happens when no new categories nor inter-categorical variations can be discovered from the data and therefore also no new theoretical insights (B. Glaser & Strauss, 1967). These four principles are also extensively used in good case study research, as will be explained further in this text.

Since the first publication in 1967, several researchers have proposed their own variant of the original grounded theory method. Most notably is the split between Glaser and Strauss themselves (see, e.g., Heath & Cowley, 2004). Together with Charmaz (2006), they currently form the three main versions of grounded theory that can be distinguished today. Each of them is based on a different research paradigm: Glaser, Strauss and Charmaz can be related to the positivist/objectivist, post-positivist and interpretivist/constructivist paradigm, respectively (Matteucci & Gnoth, 2017). While Glaser remained true to the classical approach, Strauss, together with Corbin (1990), introduced a more structured approach for applying grounded theory that also (partially) relied on deductive reasoning. Charmaz, on the other hand, argues that "categories and theories do not *emerge* from the data, but are *constructed* [rather than *revealed*] by the researcher through an interaction with the data" (Willig, 2013, p. 77). All three versions of grounded theory have their own perspective on various methodological characteristics, such as the role of the researcher, the role of related literature and the kind of theory that emerges from the data (Matteucci & Gnoth, 2017).

We believe that is important to keep this background information on grounded theory in mind when conducting case study research. From the following description of this latter research method, it will become clear that many of the concepts and methods used in case study research were inspired by the work of Glaser & Strauss.

1.3.2 Case study research

Case studies are in-depth scientific investigations of a certain subject of study (the case) and are ideal for the exploratory stage of a new research topic, "for which existing theory seems inadequate" (Eisenhardt, 1989a, p. 549) to "capture the complexity of the [phenomenon] we are examining" (Creswell, 2007, p. 40). Important hereby are the contextual conditions of the case, which are taken into account when examining the case. These conditions are not controlled by the researcher, which distinguishes case study research from experimental research. Yin (1984, p. 1) favours the use of case studies as a research strategy "when 'how' or 'why' question are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context." The ability of case study research to use a wide variety of data sources (documents, questionnaires, artefacts, interviews, etc.) and to investigate a phenomenon in its specific context gives it a unique strength over other methods, such as surveys and historical studies.

Case study research is mainly used in the social and life sciences and has been applied in numerous subfields (Yin, 1984), e.g. organizational and management studies, business administration, political studies, city planning, etc. Furthermore, Lee (1989, p. 33) states that "there is a strong case-study tradition in the academic field of management information systems." Since we consider blockchain to be an information system (see, e.g., Swan (2015, p. 92), who uses the term "information technology"), we argue that case study research is an appropriate research method to analyze *the business value of blockchain technology* due to the novelty of the phenomenon, the business focus of this work and the existence of a large number of blockchain use cases.

Rowley (2002) and Dubé and Paré (2003) emphasize the importance of good research design and implementation in order to overcome the often-heard criticism of case study research, i.e. the lack of rigor and objectivity. However, the main challenge for case study research is to go from simply describing phenomena to expanding the existing knowledge base of a certain topic, since case studies "provide little basis for scientific generalization" (Yin, 1984, p. 10). This is why we aim to build a new, non-existent theory of the business value of blockchain by using proven research methods and a well-built research design. Ridder (2017) distinguishes four different case study research designs:

- Gaps and Holes, as represented by Yin (1984);
- No Theory First, as represented by Eisenhardt (1989a);
- Social Construction of Reality, as represented by Stake (1995);
- Anomalies, as represented by Burawoy (1991, 1998).

Yin (1984) was the first to define the case study as a research strategy and to develop a topology of case study designs. While Yin stresses the importance of the *a priori* definition of propositions and theories (during the design phase, before data collection), and therefore takes a positivistic and deductive approach to case study research, Eisenhardt—while also a positivist—uses a more inductive approach, which better relates to grounded theory. Eisenhardt (1989a) prefers to use case study research for inductive theory building, rather than for hypothetico-deductive theory testing. She argues and has proven (see e.g., Eisenhardt, 1989b) that is possible to build a theoretical framework by (analytically) generalizing from specific cases. Similar to grounded theory, the kind of case study research design that is chosen has an impact on the kind of theory that emerges from the data. Ridder (2017) constructed a theory continuum that relates Eisenhardt's approach to theory building and Yin's approach to theory development and testing.

Taking the goal of this work—constructing a theory of the business value of blockchain—and the current lack of extant blockchain theory into account, Eisenhardt's inductive approach seems especially applicable for the purposes of this work. It is also one of the most cited and influential research designs in case studies (Ravenswood, 2011). We therefore follow Eisenhardt's *Process of Building Theory from Case Study Research* (see Table 1) in Section 3 of this text, rather than Yin's methodology. The other aforementioned research designs by Stake and Burawoy are not suitable for the goal of this work due to their rather specific application field and start from existing theory, respectively.

The first step in Eisenhardt's roadmap is to discover a research gap, from which one or multiple research questions can be defined (Eisenhardt & Graebner, 2007). This was already done in Section 1.1 and Section 1.2, respectively, in order to ascertain the usefulness of this work. Next, some tentative a priori constructs and/or variables with reference to extant literature are specified in order to facilitate their measurement when, in a later stadium, the cases are being analyzed. This phase is the focus of Section 2.1, where we discuss blockchain technology. We, however, do not elaborate on the relationships between those variables and on existing theories at the outset of the case study since "theory-building research is begun as close as possible to the ideal of no theory under consideration and no hypotheses to test" (Eisenhardt, 1989a, p. 536).

Table 1: Process of building theory from case study research.

Step	Activity
1. Getting started	Definition of research questions Possibly a priori constructs Neither theory nor hypotheses
2. Selecting cases	Specified population Theoretical, not random, sampling
3. Crafting instruments and protocols	Multiple data collection methods Qualitative and quantitative data combined Multiple investigators
4. Entering the field	Overlap data collection and analysis, including field notes Flexible and opportunistic data collection methods
5. Analyzing data	Within-case analysis Cross-case pattern search using divergent techniques
6. Shaping hypotheses	Iterative tabulation of evidence for each construct Replication, not sampling, logic across cases Search evidence for "why" behind relationships
7. Enfolding literature	Comparison with conflicting literature Comparison with similar literature
8. Reaching closure	Theoretical saturation when possible

Source: Adapted from Eisenhardt (1989a, p. 533).

For our specific research design decisions related to steps 2 and 3 on *selecting cases* and *crafting instruments and protocols*, we refer to Section 1.3.3 on research design. Generally, however, in multiple-case designs, cases are selected on two grounds (Yin, 1984; Eisenhardt & Graebner, 2007): either to confirm the results of the other cases (literal replication) or to challenge previously discovered results when contrasting findings are discovered (theoretical replication). Literal replication leads to trust in the emergent theory, while theoretical replication leads to a refinement and higher generalizability of the emergent theory (Yin, 1984). This is why cases are not randomly sampled—as in statistical analyses—but rather for their ability to replicate (confirm), refine or extend the discovered relationships and thus the emergent theory (cf. B. Glaser & Strauss, 1967). The use of this 'validation by replication' logic leads to a "rich, theoretical framework" (Yin, 1984, p. 46) that is both rigorously constructed and externally valid, due to the analytic—as opposed to statistical—generalization method.

Constantly comparing and alternating between data analysis, data collection and the emergent theory (step 4) is paramount for good case study research as it helps to iterate "toward a theory which closely fits the data" (Eisenhardt, 1989a, p. 541). This is also exactly what grounded theorists aim to do (cf. B. Glaser & Strauss, 1967). Within-case analysis (step 5) is meanwhile used "to become intimately familiar with each case as a stand-alone entity. This process allows the unique patterns of each case to emerge before investigators push to generalize patterns across cases" (Eisenhardt, 1989a, p. 540). This last part refers to cross-case analysis, which is used to compare the similarities and differences among cases in order to find patterns from which constructs can be built and/or extended. Eisenhardt (1989a) advocates the concurrent use of various tactics for cross-case analysis in order to corroborate patterns across these tactics; looking at the data in divergent ways reduces the information-processing biases that are inherent to the researcher.

By using the case study evidence, the analysis phase also leads to the identification of various relationships between the constructs of the phenomenon under investigation, which is step 6 in Eisenhardt's process (1989a). By searching for and combining within-case and cross-case patterns, and by tabulating (see, e.g., Miles & Huberman, 1994) this case evidence, (1) the constructs are sharpened and (2) the relationships between the constructs are verified using the aforementioned replication logic. As the evidence helps to discover the underlying theoretical reasons behind the relationships—which improves the internal validity of the findings—the hypotheses emerge from the data. In essence, measuring constructs and verifying relationships are the two keys to shaping the hypotheses.

Finally, by continuously iterating between the case data, the emergent theory and the related research literature (step 7), the theoretical framework eventually takes shape. Eisenhardt (1989a, p. 545) states that "tying the emergent theory to existing literature enhances the internal validity, generalizability, and theoretical level of theory building from case study research", but only if both similar and conflicting literature are studied. The process ends when theoretical saturation occurs (step 8). For adding cases, this is the point at which incremental learning becomes minimal; while for iterating between theory and data, this is the point where incremental improvement to the theory becomes minimal (B. Glaser, 1978; Eisenhardt, 1989a).

Eisenhardt (1989a) asserts that her methodological and rigorous *Process of Building Theory from Case Study Research* wil generate a theory that is highly likely to be (1) novel, (2) testable and (3) empirically valid. However, she also cautions the researcher: "intensive use of empirical evidence can yield theory which is overly complex, [...] narrow and idiosyncratic" (Eisenhardt, 1989a, p. 547). The strategic selection of cases is therefore instrumental to the generalizability and parsimony—two of the eight[2] hallmarks of good scientific research—of the resultant theoretical framework.

1.3.3 Research design

Next, we describe the research design that is followed in Section 4 of this text and justify our design choices. Yin (2004) states the importance of a transparent description of the followed research design in order to make the scientific nature of case study research apparent and to distinguish it from mere journalistic work. A case study should therefore establish an unambiguous *chain of evidence* and *audit trail* that enables the external reader to follow the researcher's process of data collection and analysis, but also his reasoning from the initial research questions up until the ultimate conclusion. Consequently, this will enable the reader to independently assess the validity of the results and in the meanwhile offer him the possibility of replicating the research. Table 2 gives an overview of the research design choices on which this work is based.

Table 2: Overview of the research design choices.

Research characteristic	Design choice
Type	Exploratory study
Nature	Qualitative research
Method	Multiple-case study research
Paradigm	Positivist
Logic	Inductive: Eisenhardt's (1989a) approach
Population	Blockchain use cases explained in academic papers
Unit of analysis	One blockchain use case paper from an holistic perspective

Research method. We believe that for a complex technology, such as blockchain, there is a need for an in-depth analysis into the phenomenon. A qualitative research method is favourable because the research questions address soft issues and do not require quantification, but rather search for an understanding of the phenomenon (Creswell, 2007). A case study seems particularly appropriate since the value of (a specific) blockchain should be studied in its particular context[3]. It is our contestation that the value of blockchain is greatly dependent on the context in which it is applied; a comprehensive

[2]The other six hallmarks are purposiveness, rigor, testability, precision and confidence, replicability, and objectivity (Sekaran & Bougie, 2013).

[3]Recall that Yin (1984, p. 13) defines a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context [...]" and Eisenhardt and Graebner (2007, p. 25) who note that "case studies emphasize the rich, real-world context in which the phenomena occur."

theory of the value of blockchain cannot be discovered by merely studying the underlying technology in isolation, but rather by studying various concrete applications of this technology and their specific value proposition. Furthermore, Flyvbjerg (2006, p. 219), while paraphrasing the words of Thomas Kuhn, notes that “a scientific discipline without a large number of thoroughly executed case studies is a discipline without systematic production of exemplars, and a discipline without exemplars is an ineffective one.” This work is—to our knowledge—the first case study of the business value of blockchain. We follow a mulitiple-case study design since they are more robust and testable, enable broader exploration, place more confidence in the generalizability of the findings, lead to sharper constructs and relationships, result in a more parsimonious theory, and thus provide a stronger base for theory building in general (Yin, 1984; Eisenhardt, 1989a; Eisenhardt & Graebner, 2007).

Reasoning method. Even though blockchain originates from the field of computer science, a formal science, the focus in this work lies on its business value, an economic concept, which relates it to the social sciences. Locke (2007, p. 2) contends that “theory building in the social sciences, management and psychology included, should be inductive.” The lack of extant theory on the added business value of blockchain (Risius & Spohrer, 2017) and the exploratory nature of our research therefore justify the inductive nature of this work. This design choice does not pose any direct issues since—as discussed earlier—Eisenhardt (1989a; 2007) has developed a proven method for inductively building a theory from case studies. Also Flyvbjerg (2006, p. 224) disproves the common misunderstanding about case studies which says that “general, theoretical (context-independent) knowledge is more valuable than concrete, practical (context-dependent) knowledge” and argues that “concrete, context-dependent knowledge is [. . .] more valuable than the vain search for predictive theories and universals.”

Case population. A clearly defined case population is crucial because it helps to control for “extraneous variation and helps to define the limits for geneneralizing the findings” (Eisenhardt, 1989a, p. 537). Due to the very small number of businesses who have already realized an actual blockchain implementation, the type of data that is analyzed in this work is limited to the documentation of blockchain use cases and proof-of-concepts that present a working prototype and exhibit a strong focus on a potential business application. Since case studies usually use multiple methods of data collection, we compensate our limitation (of only using documents) by constraining ourselves to studying only academic papers from high-quality journals and conference proceedings. This way, their factual correctness and validity are guaranteed as much as possible. To achieve a least some level of data triangulation, we have tried to collect papers from a wide variety of journals from various fields. Eisenhardt (1989a) proposes to analyze between four and ten cases. Since the exact number depends on when theoretical saturation is reached and since we focus more on cross-case analysis because the efficacy of deep within-case analysis is rather restricted, 15 cases were eventually analyzed. Furthermore, Dubé and Paré (2003, p. 622) stress the importance of a pilot case, especially for exploratory studies, since they help to “discover inadequacies in the initial [research] design.” A recent special issue of Springer’s Business & Information Systems Engineering journal (Beck, Avital, Rossi, &

Thatcher, 2017, p. 382) presents “a portfolio of [four] nascent blockchain applications that illustrate the technology’s potential.” These four use cases are given in Table 3 and serve as the pilot cases of this work. The cases that are to be analyzed next are discovered based on the principle of theoretical sampling. In Appendix B, the abstracts of all the analyzed use cases can be found.

Table 3: Overview of the four pilot cases.

Authors	Title
Parra Moyano & Ross	KYC* optimisation using distributed ledger technology
Notheisen, Cholewa & Shanmugam	Trading real-world assets on blockchain—an application of trust-free transaction systems in the market for lemons
Hyvärinen, Risius & Friis	A blockchain based approach towards overcoming financial fraud in public sector services
Egelund-Müller, Elsman, Henglein & Ross	Automated execution of financial contracts on blockchains

*Know your customer.

Unit of analysis. In this work, the unit of analysis of the case (subject) under investigation is a specific blockchain use case paper with its particular value proposition and contextual properties, e.g. the industry setting. Due to the limited possibility of deep within-case analysis, our study observes the cases from an holistic (as opposed to embedded) perspective.

1.3.4 Expert interviews

When theoretical saturation was reached and the theoretical framework is final, expert interviews were conducted. These interviews are not to be seen as a data source, but rather as a “reality check” for the resultant theory. Due to the exclusive use of academic papers, it might be possible that the touch with reality is lost. We therefore want to confirm the correctness and external validity of our findings with these interviews.

Eisenhardt and Graebner (2007, p. 28) recommend to interview diverse, highly knowledgeable profiles “who view the focal phenomena from diverse perspectives.” In Table 4, the three persons that were interviewed are briefly presented. As can be seen, they work in different industries and therefore (presumably) have divergent views on the topic of blockchain.

1.3.5 Literature review

The first goal of the literature review is to define the term *blockchain* and to discuss the innovative characteristics of this technology. A clear definition of blockchain is necessary to guide us in our search for appropriate use cases. In doing so, we discover (tentative) constructs which facilitates their measurement in the following use case analysis phase, as prescribed by Eisenhardt in her *Process of Building Theory from Case Study Research*

Table 4: Overview of the three interviewees.

Name	Function	Company name	Type of company
Dirk Neefs	Blockchain and distributed ledger project manager	Cegeka	Large IT services provider
Rutger Bevers	Interim blockchain developer	SettleMint	Start-up
Paul-Emmanuel Tasiaux	Senior IT advisor	KPMG	Multinational consultancy firm

(1989a). It is, however, important not to overdo this literature review since this might bias the researcher, which hinders him to conduct the research with an open mind, free from assumptions, hypotheses and especially theories about the business value of blockchain. The second goal of the literature review is to define the term *business value* in the context of blockchain technology. These two aforementioned objectives will be the subject of the following section, that we have titled Preliminaries.

2 Preliminaries

It is perhaps well enough that the people of the nation do not understand our banking and monetary system, for if they did, I believe there would be a revolution before tomorrow morning.

—Henry Ford, American business magnate

In this section, we first explain our interpretation of the two parts of the title of this work; we elaborate on *blockchain* itself and afterwards discuss the meaning of *business value* in the context of this breakthrough technology. Next, we review the related literature from an economic, governance and business perspective.

2.1 Blockchain

In this subsection, we (1) briefly describe the history and precursors of blockchain, (2) explain hash functions, (3) elaborate on Bitcoin, which is the very first implementation of a blockchain, and on its underlying structure, components and principles, (4) distinguish between the various types of blockchains and (5) frame blockchain in the broader concept of ledgers, in order to finally arrive at (6) a definition of blockchain as it is used in the remainder of this work.

2.1.1 History

The financial crisis of 2007–2008 culminated on the 15$^{\text{th}}$ September 2008, when investment bank Lehman Brothers filed for Chapter 11 bankruptcy protection. Over the next months, many other financial institutions followed, which led to massive bailouts from governments in an attempt to prevent the world's financial system from collapsing. Global markets plummeted at rates only comparable to the Great Depression of the 1930s. A world-wide credit and currency crisis ensued.

Like a phoenix, risen from these financial ashes, Satoshi Nakamoto introduced *Bitcoin* to the world. He published a white paper on *Bitcoin: A Peer-to-Peer Electronic Cash System* at the height of the crisis, on the 31$^{\text{st}}$ October 2008. Two months later, the first Bitcoin block was mined—the genesis block—in which Nakamoto included the following text:

> *The Times*
> *03/Jan/2009*
> *Chancellor on brink of second bailout for banks.*

Bitcoin, the first decentralized peer-to-peer digital currency, was his panacea for the non-transparent and failing monetary system. We write "his", but Nakamoto's gender, like his identity, remains unknown to this date, giving him the almost cult-like status of a modern-day Robin Hood.

Earlier attempts at electronic cash systems had all failed (see, e.g., e-gold and Chaum's (1998) Ecash), which makes the sheer simplicity of Nakamoto's digital currency even more remarkable. His invention was solely based on (1) cryptographic methods that had been around for decades and (2) Haber & Stornetta's research on time-stamping from the 1990s. Nakamoto, however, cleverly combined these two methods with (3) Dai's (1998) insights on digital currencies when there is no government to issue them, and (4) Dwork & Naor's (1993) invention of the proof-of-work protocol, as implemented by Back's (2002) Hashcash[4] system.

Bitcoin is the very first application of something that we nowadays call "a blockchain." The term blockchain is, however, never used by Nakamoto in his white paper; the phrase "a chain of blocks" (Nakamoto, 2008, p. 7) is the closest he gets. The first known mention of this phrase goes back to 1976, when a patent, titled *Message Verification and Transmission Error Detection by Block Chaining*, was filed by inventors Ehrsam, Meyer, Smith, and Tuchman (1978), with property rights assigned to IBM. Even though this patent (also in the field of cryptography) presents a structure similar to the Bitcoin/blockchain architecture, it has no direct link to the current use of the word. In a certain cryptography mailing list, the phrase "block chain" was often used in discussions about Bitcoin, but also in earlier discussions about Hashcash. In the following years, when Bitcoin gained popularity, the current spelling of the word blockchain became mainstream. This etymological history has, however, led to the fact that there is no generally accepted definition of the term blockchain. Nevertheless, most definitions roughly include the same elements and characteristics of this new technology. We therefore aim to construct our own definition of blockchain in this subsection, after the related literature has been studied.

2.1.2 Hash functions

In order to understand how the Bitcoin blockchain works, it is important to first be familiar with the working of hash functions, which play a large role in cryptography and computer networks. A cryptographic hash function $h : \{0,1\}^* \to \{0,1\}^l$ converts data of arbitrary size (the *message*) into a bit-string with a fixed length l (the *hash* or *digest*), while (ideally) adhering to the following distinct properties (Naor & Yung, 1989):

- The function is deterministic, i.e., the same input always results in the same output.
- The function is easy to compute (and therefore it is also easy to verify the hash).
- A "small" change in the input results in a "large" change in the output, i.e., the new output appears uncorrelated to the original output.
- Pre-image resistance: h is a one-way function. This means that it is infeasible to invert the function, i.e., reconstructing the message from the hash.

[4] Contrary to what its name indicates, Hashcash is not a digital currency, but a system to limit email spam and denial-of-service attacks.

- Second pre-image resistance: given an input x, it is "difficult" to find an input y, satisfying $h(x) = h(y)$ and $x \neq y$.
- Collision resistance[5]: it is "difficult" to find two strings x and y, with $x \neq y$, satisfying $h(x) = h(y)$.

The Secure Hash Algorithms (SHA) are a famous example of a family of cryptographic hash functions, designed by the NSA, that are extensively used when communicating over a computer network, e.g., in the SSL/TLS protocol. When we hash the title of this work, *The Business Value of Blockchain*, using the SHA-256 function—which is also used in bitcoin mining—we obtain the following result:[6]

`0f1dafa2922c57ca09d23d358c4d83e3a67335203d392a6947be258a7dcc0e93`

Even a small alteration, such as removing the article from the title, and thus hashing the phrase *Business Value of Blockchain*, results in a completely different hash:

`4a3b0a2553c892a64612760586efbe7aa08b84123959982a66ecc1d4aa5da6f3`

Note that both hashes are of equal length, even though the input message is not. It is also apparent that is infeasible to retrieve the original message from the hash, unless an attacker has the resources to brute force every possible combination of characters.

Hash functions are used in asymmetrical cryptography. In this system, each user has a pair of keys: a public and a private key. The first key is publicly broadcasted and therefore available to every interested party, while the latter must be kept secret by the owner. A message that is encrypted with a private key can only be decrypted with the related public key and vice versa. Note that—even though this might seem illogical at first sight—it is not possible to decrypt a message with the same key that was used to encrypt it; this is the asymmetrical nature of the two keys.

This system has two functions. The first is *encryption*: sending a secret message over an unsafe network is made possible by encrypting the message with the receiver's public key since only he can decrypt the message with his private key. The second function is *authentication*: the sender hashes a message, encrypts this hash with his private key and sends the message as well as the hash to the receiver; the receiver also hashes the message, decrypts the received hash with the sender's public key and verifies wether both hashes are the same. If this is the case, the receiver has proof that the message was not altered during transmission and that it was sent by the correct person. This latter function is used to add a *digital signature* to a message. Note that it is possible to combine both functions for one message, i.e., simultaneously encrypting and digitally signing a certain message.

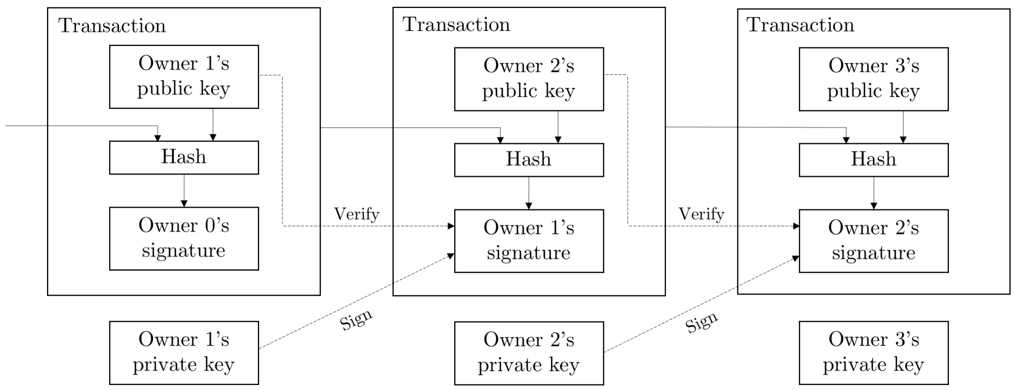
[5] Note that collision resistance implies second pre-image resistance, but not vice versa.

[6] The reader might notice that the result is converted to hexadecimal notation rather than to binary notation, as was indicated by our definition. Similarly, the input should also be in binary notation according to our definition. However, this is both handled by the SHA-256 function and does not change any of the aforementioned properties.

2.1.3 The Bitcoin blockchain

The Bitcoin blockchain can be thought of as an electronic ledger that contains information on the ownership of bitcoins, a digital currency. Like a regular ledger, it keeps track of all transactions that take place, i.e., when the ownership of a bitcoin switches hands. Historically, this record keeping is performed by trusted intermediaries, such as a bank or a notary. If we wish to eliminate this central party, however—which is the objective of Bitcoin—there needs to be a way (a protocol) to achieve consensus on the ownership of bitcoins among all the holders, i.e., who owns how many bitcoins?

It is clear that the actors in this system will try to convince others that they have more bitcoins than they really do. Imagine a situation where Bob has 8 bitcoins and sends them to Alice, but simultaneously also sends the same 8 bitcoins to Eve. Due to the latency in the network, it can very well be the case that nor Alice nor Eve are already informed of the other transaction when they receive Bob's 8 bitcoins. Since they both have reason to believe that Bob has a sufficient amount of bitcoins to pay them, they both send him the article that he has purchased. However, only one transaction will eventually be registered since Bob does not have enough bitcoins to pay them both, which leaves Alice or Eve empty-handed, depending on which transaction is processed last. This issue is called the double-spending problem and earlier attempts at peer-to-peer digital currencies have failed to properly address it. Nakamoto (2008, p. 1) was the first to come up with a solution to this problem by using "a peer-to-peer distributed timestamp server to generate computational proof of the chronological order of transactions."



Source: Adapted from Nakamoto (2008, p. 2).

Figure 2: Diagram of a bitcoin that switches owners twice.

In the Bitcoin network, everyone is exclusively known by his or her public key. This key is an address to (or from) which bitcoins can be sent.[7] A bitcoin itself can be seen as a chain[8] of digital signatures of all the past owners of that specific bitcoin. When the current owner wants to send this bitcoin, he first hashes the data of the previous transaction of that bitcoin and the receiver's public key. Next, he digitally signs this

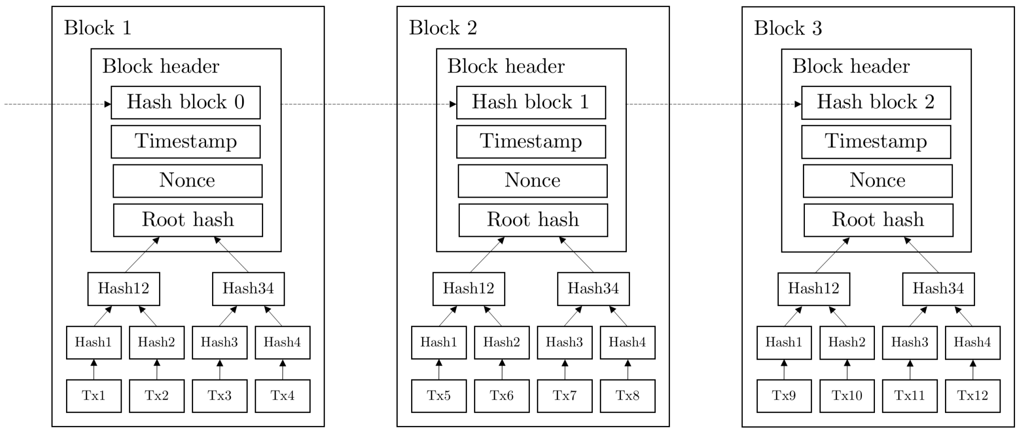
[7]If you are enjoying this text so far, you can for example donate some bitcoins to the author via his public key address: `1HR3zdvU66i9YHVjtj7vgZtcxSVQSLopNv`.

[8]Confusingly, this is not *the* blockchain, which will be explained later.

hash with his (the sender's) private key. Finally, he adds this combination (the public key of the receiver, the hash and his digital signature) to the end of the chain (coin) and sends it to the network. Using the sender's public key, everyone in the network can verify that the sender could legitimately make this transaction, since he is the only one with access to his private key. Figure 2 visualizes this process of sending a bitcoin.

This system enables the network to verify that the sender was the genuine owner of that bitcoin since his public key was at the receiving end of that bitcoin's previous transaction. This mechanism does, however, not solve the aforementioned double-spending problem. As a result, the network needs another mechanism to agree on a single history of the correct order of all transactions. Since there is no perfect way to decide whether Alice or Eve should receive Bob's 8 bitcoins, the blockchain mechanism is only concerned with making sure that coins are not double-spent.

When someone wants to make a transaction, this is publicly announced to the entire network (cf. Dai, 1998). The nodes in the network start collecting all these transactions and combine them into a block. The nodes then reformat these transactions into a Merkle Tree in order to obtain its root hash.[9] Next, similar to the concept of a timestamp server[10], the root hash of the Merkle Tree is combined together with the current timestamp, the hash of the previous block and a nonce.[11] The timestamp together with the root provide proof that the included transactions existed at that specific point in time, while the hash of the previous block is added to create the chain. Further in the text, the purpose of this "block chaining" will become clear. Figure 3 visualizes the inner workings of the Bitcoin blockchain.



Tx = transaction.
Source: Adapted from Nakamoto (2008, pp. 3–4).

Figure 3: Diagram of the structure of the Bitcoin blockchain.

[9]An example of a Merkle tree, or hash tree, is shown at the bottom of each block in Figure 3. The data at the "leaves", or child nodes, are consequentially hashed to obtain their parent hash, until eventually only one parent remains, i.e., the root hash (Merkle, 1982).

[10]A timestamp server is used to proof that a specific piece of data existed at a certain point in time. It works very similar to the Bitcoin blockchain, but with the disadvantage that a trusted third party is required for preserving the data integrity, which is not the case with Bitcoin.

[11]In reality, there a few more data elements, e.g., the magic number, the version number, the transaction counter, the block size etc. These are, however, not important to understand the fundamental principles of blockchain technology and are therefore not discussed in this work.

The nonce is a random number that the nodes purposefully need to discover by trial-and-error since the hash of the new block's header needs to start with a (dynamically) prespecified number of zero bits. When a node finds a nonce that complies with this restriction, he broadcasts the newly discovered block to the network. Everyone in the network then verifies whether all transactions in that block are correct (which can be done very quickly, see Figure 2) and whether the nonce is correct. While checking the nonce is a very easy process (simply hashing the new block's header to see if the hash has the correct number of leading zero bits), finding the nonce itself is a very computationally expensive[12] process. This computation is the so-called *proof-of-work* of the node and constitutes the consensus mechanism of the Bitcoin blockchain.

It is possible that a blockchain temporarily splits when two or more correct nonces (and therefore blocks) are discovered, resulting in two chains that shortly[13] exist next to each other. The consensus protocol stipulates, however, that "the majority decision is represented by the longest chain, which has the greatest proof-of-work effort invested in it" (Nakamoto, 2008, p. 3). All nodes are intrinsically motivated to follow this instruction, because they otherwise risk to lose any bitcoins that they might have mined when the sidechain they are working on is outpaced by a longer (computationally heavier) chain. This way, the Bitcoin blockchain has a built-in mechanism that encourages all nodes to agree on a single chain, which is how consensus is achieved on the correct ordering of transactions.

This proof-of-work protocol is what makes a blockchain (practically) immutable and a secure storage of data; as more and more blocks are added to the chain, changing a past transaction becomes almost impossible. This is because an alteration of an old transaction creates a chain reaction that requires redoing all the computational work that was done after that transaction. If, for example, five blocks have been "mined" in the meantime, the attacker will have to compute five new nonces to change that transaction (since the existing hash links are no longer correct after the change) and also outpace the original chain, which the (honest) network continues to extend during the attack. Probabilistic calculations show that the chance of a successful attack becomes infinitesimally small, unless the attacker has access to a disproportionally large amount of computing power.

The miners of the blocks of course need to be incentivized for their work and resources (electricity consumption, computing time and hardware depreciation), which also helps to encourage them to stay honest.[14] This is done by including in each new block a transaction that gives a pre-specified number of bitcoins to the creator, which results in

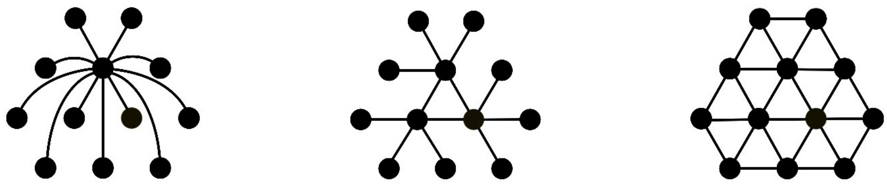
[12] At the time of writing, on average $1,7 * 10^{22}$ hash calculations were necessary to mine a Bitcoin block. This difficulty is adapted dynamically to make sure that one block is mined every 10 minutes, taking the emergence of newer, faster hardware into account.

[13] It is also possible that such a split is made deliberately by (a part of) the network with the intention to last. This is called a *hard fork* and happened, for example, when the original Bitcoin blockchain split into two: a new chain, called Bitcoin Cash, and the original chain, from then on called Bitcoin Core. At the time of writing, two other splits have occurred in the meantime, resulting in the Bitcoin Gold chain and the Bitcoin Private chain.

[14] It can be shown that even for attackers with a large amount of computing power—in some cases—it can be more beneficial to stay honest than to alter their old transactions.

a steady (predetermined) supply of bitcoins to the entire network. This incentive can also be further increased if the users of the network pay the miners a transaction fee for their work.

What we have described here is "an electronic payment system based on cryptographic proof instead of trust, allowing any two willing parties to transact directly with each other without the need for a trusted third party" (Nakamoto, 2008, p. 1). Nakamoto's invention is actually twofold: not only has he invented the first decentralized *cryptocurrency*, the Bitcoin, but he was also the first to design a "trust protocol" (Tapscott & Tapscott, 2016, p. 6) that enables a secure transfer of value over an untrusted network without any central oversight, by using a distributed database (see Figure 4) that guarantees data integrity, called the blockchain. Bitcoin is thus only one specific application (or implementation) of blockchain technology.



(a) Centralized. (b) Decentralized. (c) Distributed.

Source: Adapted from Baran (1964, p. 4).

Figure 4: Three types of network topology.

Due to the fact that a bitcoin has no intrinsic value, is not backed by a real-world asset nor by a central issuer, and due to the increasing interest of (speculative) investors, the price of this scarce digital asset has been very volatile in the past, peaking at $20.000 per bitcoin in December 2017, which gave it a total market capitalization of over $335 billion. This success has sparked worldwide interest in the underlying technology which has led to the emergence of many new cryptocurrencies. Around 1.600 cryptocurrencies existed at the time of writing, each with their own specific purpose and (often) technology.[15]

Some of these cryptocurrencies have almost completely adopted the principles of Nakamoto's original invention, while others have developed and implemented radically new and innovative designs. The cryptocurrency Litecoin is an example of the first group and can be seen as a faster version of Bitcoin, incorporating only minor changes to the original Bitcoin protocol. IOTA, on the other hand, has been developed with the large number of microtransactions that will occur between the billions of smart devices, connected via the *Internet of Things* (Gartner, 2017a), in mind. IOTA uses a *tangle*, a directed acyclic graph, for storing transactions and thus presents a clear break from the blockchain-based approach for constructing a distributed ledger (Popov, 2018). Nevertheless, it still incorporates some of Nakamoto's features, such as the cryptographic puzzle of finding a correct nonce for the node's proof-of-work.

This recent proliferation of new cryptocurrencies has had its impact on Bitcoin's market

[15]All financial numbers on cryptocurrencies that were mentioned in this subsection were retrieved from `http://www.coinmarketcap.com`.

share. Even though Bitcoin's absolute market capitalization exhibits an upward trend and is still double that of its closest "competitor" at the time of writing, its relative market dominance has been rapidly declining since 2017. Figure 5 shows that Bitcoin's market share has dropped to less than 40% since 2018, whereas it consistently managed to keep more than 80% of the total crypto market value in the first 8 years following its genesis.

Even though Bitcoin continues to benefit from its first-mover advantage and from network effects, as quantified by Metcalfe's law[16], Bitcoin's underlying technology—although it might appear new and revolutionary—is already outdated. This first cryptocurrency can be observed as going through the Schumpeterian process of creative destruction (1961) in which existing products are superseded when "new entrants exploit technological discontinuities to displace existing incumbents" (Lieberman & Montgomery, 1988, p. 48). Bitcoin's first-mover advantage is turning into a disadvantage as newer blockchains learn from Bitcoin's mistakes and implement structural improvements to their new designs.

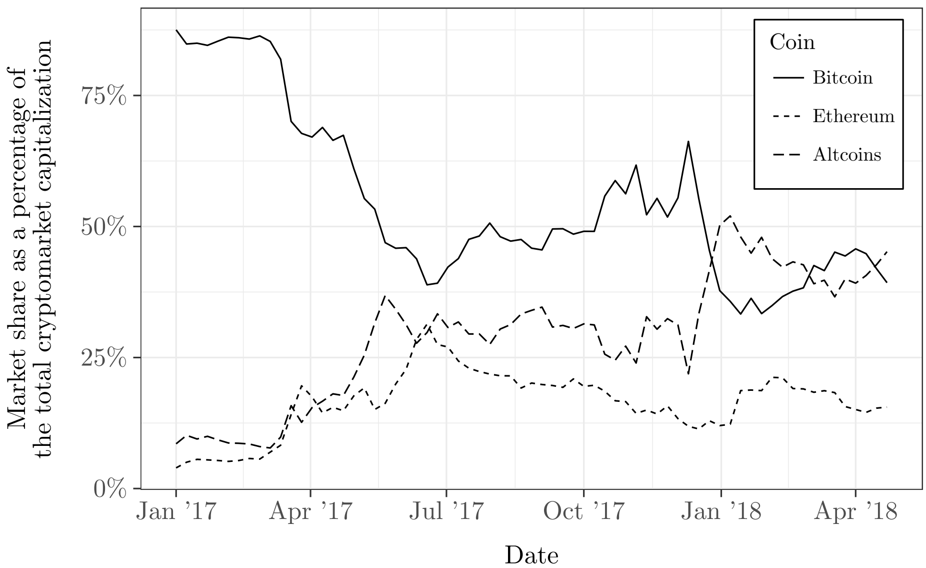


Figure 5: The declining dominance of Bitcoin.

An often criticized element of Bitcoin is its slow transaction speed due to its effective, but inefficient proof-of-work consensus algorithm. Visa, for example, processes 4.500 transactions per second on average, with a peak rate of up to 65.000 transactions per second.[17] Bitcoin's average throughput, on the other hand, is only a mere 3 transactions per second.[18] Even if scalability issues could be overcome, the power required for bitcoin mining would be untenable, since Bitcoin's energy consumption was already in 2014 comparable to that of the entire country of Ireland (Malone & O'Dwyer, 2014). This

[16]The utility of networks, like for example the telephone network, increases as more and more people are connected to it. Metcalfe's law therefore states that the value of a network is proportional to the square of its size. Bitcoin has been proven to follow this law (Alabi, 2017).

[17]This data was retrieved from `https://usa.visa.com/dam/VCOM/global/about-visa/documents/visa-facts-figures-jan-2017.pdf`.

[18]This data was retrieved from `https://blockchain.info/nl/charts/transactions-per-second`.

is why newer blockchains are looking at other consensus mechanisms, such as proof-of-authority, proof-of-space and most notably, proof-of-stake. The question whether Bitcoin, the famous crypto pioneer, and its developer community will manage to keep up with these new competitors is, however, out of the scope of this work.

Even though the term *altcoins* is normally used to refer to all cryptocurrencies other than Bitcoin, we have excluded Ethereum from this group in Figure 5. Ever since 2016, Ethereum has been Bitcoin's main competitor (in terms of market value), only to be surpassed by Ripple during two brief occasions. Ethereum is the brainchild of Vitalik Buterin and aims to be more than only a digital currency. Compared to the Bitcoin blockchain, the Ethereum blockchain enables a lot more interesting functionalities and possibilities, especially for businesses. We therefore briefly describe Ethereum next, which will give a better idea of the real potential of blockchain technology.

2.1.4 Ethereum

If someone wants to use a blockchain, he has two options: either he implements his own independent blockchain, which requires him to write and test all the necessary code, or he can build on top of an existing blockchain. The limited size of the vast majority of potential blockchain applications combined with the distributed nature of a blockchain—that needs a network of a certain size to function in a trustworthy manner—favours the latter option (Buterin, 2014a). Apart from enabling a digital currency, the Bitcoin blockchain's inherent scripting language also offers the capability of creating *colored coins* and *metacoins* on top of its own structure. The first type of coin can be used to create other digital currencies and to represent real-world assets, managed via the Bitcoin blockchain. The idea behind metacoins, on the other hand, is to create a new protocol that lives on top of the Bitcoin protocol. However, those two types of coins are rather restricted in their possibilities and suffer from scalability issues, respectively (Buterin, 2014a).

In the Ethereum white paper, Buterin identifies four shortcomings of Bitcoin's scripting language: (1) it is not Turing-complete, (2) it is value-blind, (3) it lacks state and (4) it is blockchain-blind. Without deep-diving into the technical details of these limitations, this essentially means that advanced applications are not possible on top of the Bitcoin blockchain.[19] Buterin (2014a, p. 13) has therefore developed Ethereum with the intention to create "the ultimate abstract foundational layer: a blockchain with a built-in Turing-complete programming language, allowing anyone to write smart contracts and decentralized applications where they can create their own arbitrary rules for ownership, transaction formats and state transition functions."

This pushes the potential of a blockchain from merely being a distributed transactional database to—additionally—being a fully equipped distributed computing system.[20] It

[19] For more information, we refer to the Ethereum Yellow Paper (see, Wood, 2016).

[20] Ozsu and Valduriez (2011, pp. 1–2) define a *distributed database* as "a collection of multiple, logically interrelated databases distributed over a computer network" and a *distributed computing system* as "a number of autonomous processing elements (not necessarily homogeneous) that are interconnected by a

moves blockchain away from its sole purpose of enabling a cryptocurrency to enabling a practically unlimited number of financial and non-financial applications, thanks to Ethereum's open-ended design. Buterin basically created *blockchain 2.0*, a peer-to-peer (computing) platform that enables two or more actors to interact and transfer assets beyond currency, but still without the central oversight of one specific organisation, as is the case with Uber or Airbnb, for example.

This shift indicates why blockchain has been called a "general purpose technology" with potential gains for many industries (Catalini & Gans, 2017). The aforementioned *smart contracts*, invented by Szabo (1996), are paramount in this new vision for blockchains, and can be seen as "systems which automatically move digital assets according to arbitrary pre-specified rules" (Buterin, 2014a, p. 1). These are pieces of code, written down in a computer language instead of a legal language, that run on a distributed "world computer", which Ethereum essentially is. Smart contracts can, for example, be used to put money in escrow that is automatically released to the vendor when the purchaser receives the good, or to place a bet between two parties about the weather tomorrow, which will be checked by the smart contract itself at a predetermined source, such as a certain weather website. Smart contracts can be combined to create entire distributed computer programs, called decentralized applications (or DApps). An even further logical extension of smart contracts are *decentralized autonomous organizations*, where "long-term smart contracts [...] contain the assets and encode the bylaws of an entire organization" (Buterin, 2014a, p. 1).

2.1.5 A taxonomy of ledgers

Blockchains are only one type of the broad range of ledgers that currently exists. A first distinction can be made based on the number of copies of the ledger: if there is only one, the ledger is centralized; if there are more—as in the case of blockchain—the ledger is distributed. Within this latter group, a second distinction can be made based on the data structure that is used. Blockchain is again only one specific type of possible data structures. There are, however, others, such as the aforementioned directed acyclic graphs (DAGs), as used by, e.g., IOTA. More recently, hybrid structures were introduced, that, for example, combine features of both DAGs and blockchains, called a *block-lattice* in the case of Nano (LeMahieu, 2018). Real-time global settlement system Ripple, on the other hand, uses a distributed ledger that is neither a blockchain nor a DAG, but rather a hash tree. We can therefore conclude that a wide spectrum of distributed ledgers exists that will continue to grow and evolve in the future.

Furthermore, it is important to explain how distributed ledgers relate to cryptocurrencies. The Merriam-Webster Dictionary defines a cryptocurrency as "any form of currency that only exists digitally, that usually has no central issuing or regulating authority but instead uses a decentralized system to record transactions and manage the issuance of new units, and that relies on cryptography to prevent counterfeiting and fraudulent transactions."

computer network and that cooperate in performing their assigned tasks." Blockchain clearly fits both definitions.

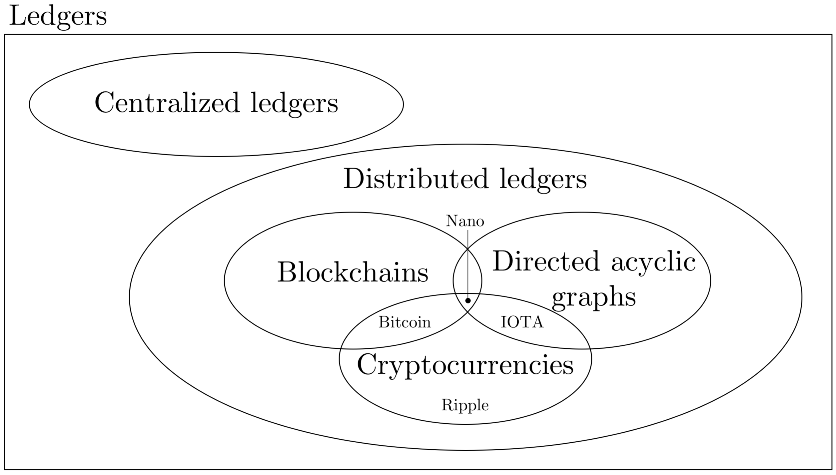


Figure 6: Venn diagram of the different types of ledgers.

This definition is remarkably appropriate and specific, while it additionally captures all the possible variations of cryptocurrencies. As can be observed, there is no notion of the exact data structure that is to be used. This is correct since cryptocurrencies can be built using blockchains, DAGs, etc. Nevertheless, to our knowledge, all cryptocurrencies currently use some sort of distributed system, as also correctly identified in the above definition. Furthermore, the mention that there is “usually” no central issuer takes cryptocurrencies such as Ripple’s XRP into account. Figure 6 visualizes all the above mentioned terms and their interrelationships. Take special note of the fact that distributed ledgers do not necessarily need to “produce” a cryptocurrency.

Another way to classify distributed ledgers, apart from their data structure, is on the basis of the specific access rights that are granted to the different nodes/users. A first distinction can be made based on the right to participate in the consensus mechanism in order to validate transactions. If this right is restricted to certain nodes, the ledger is said to be *permissioned*; otherwise, the ledger is said to be *permissionless* (Bitfury, 2015; Walport, 2016). A second distinction is based on restrictions that limit who can submit new transactions to the ledger (before they are verified) and who can read the transactions that are contained in the ledger. Depending on the absence or presence of these submit and read restrictions, the ledger is said to be *public* or *private*, respectively. Whether both submit and read restrictions need to be in place, or whether the presence of only one of both suffices to call a ledger private is up to debate (see, e.g., Bitfury, 2015; Buterin, 2015a).

Table 5 summarizes (our grounded perspective of) this second method for classifying distributed ledgers. A special type is included, called a *consortium* ledger, that is used to distinguish private ledgers that are owned by a single entity from ledgers that are owned by multiple entities, such as R3, which is a consortium of more than 200 financial institutions. Note that there are only five different names (such as, e.g., a public permissionless ledger) for the 16 (theoretically) possible types of distributed ledgers,

Table 5: Restriction-based classification of distributed ledgers.

	Permissionless		Permissioned		
	Public	Private	Public	Consortium	Private
Submit restrictions	No	Yes/No†	No	Yes/No†	Yes/No†
Read restrictions	No	Yes/No†	No	Yes/No†	Yes/No†
Write* restrictions	No	No	Yes	Yes	Yes
Single entity ownership	No	Yes/No	No	No	Yes
Degree of centralization	⟶				
Examples	Bitcoin, Ethereum	Monero, Zcash	Ripple, Stellar	R3's Corda	Hyperledger Fabric

*Validating transactions via participation in the consensus mechanism.
†Either submit or read restrictions must be present, or both.

since there are 2^4 yes/no combinations possible based on the four different characteristics. This explains the confusion that often arises when using these terms.

2.1.6 Definition

Now that we have elaborated on the history, the components, the inner workings and the various types of blockchains, we aim to define this specific type of distributed ledger. Table 6 presents ten blockchain definitions from various prominent blockchain researchers and other established sources (in no specific order). These definitions serve as guidelines to help us construct our own definition of blockchain, which has to be comprehensive, yet also has to strike a balance between being too narrow and being too broad, in order to exclude all irrelevant use cases but at the same time also capture all relevant use cases.

Based on a critical analysis of those ten definitions and by contrasting them against the aforementioned fundamental properties and possible variants of blockchain, our own definition reads as follows:

Blockchain is a (public or private) distributed ledger that transparently records transactions, which are made either by the networked nodes themselves or by the inherent self-executing computing platform (via smart contracts), but only if they are deemed valid according to a (permissioned or permissionless) protocol, that is also used to achieve consensus on the chronological order of those transactions, which are practically immutable once they are registered by the database system, due to its cryptographically secured structure, consisting of chained blocks of data.

Next, we discuss the reasoning behind the in- or exclusion of the various characteristics in our definition.

Distributed. The distributed nature of all blockchains is inherent to the design of its structure and of great importance for the proper functioning of its protocol. Some definitions use *decentralized* instead, but—using Baran's terminology (see Figure 4)—*distributed* better captures the typology of a blockchain network. Furthermore, it is our

Table 6: A selection of blockchain definitions.

Reference	Definition
Nakamoto (2008)	A peer-to-peer distributed timestamp server to generate computational proof of the chronological order of transactions. (p. 1)
Beck et al. (2017)	A distributed ledger technology in the form of a distributed transactional database, secured by cryptography, and governed by a consensus mechanism. A blockchain is essentially a record of digital events. However, it is not "just a record," since it can also contain so-called smart contracts. (p. 381)
Walport (2016)	A type of database that takes a number of records and puts them in a block. Each block is then "chained" to the next block, using a cryptographic signature. This allows block chains to be used like a ledger, which can be shared and corroborated by anyone with the appropriate permissions. There are many ways to corroborate the accuracy of a ledger, but they are broadly known as consensus. (p. 17)
Risius and Spohrer (2017)	A fully distributed system for cryptographically capturing and storing a consistent, immutable, linear event log of transactions between networked actors. (p. 386)
Davidson et al. (2016b)	A new 'general purpose technology' in the form of a highly transparent, resilient and efficient distributed public ledger (i.e. decentralized database). (pp. 2–3)
Wright and De Filippi (2015)	A distributed, shared, encrypted database that serves as an irreversible and incorruptible public repository of information. (p. 2)
Buterin (2015b)	A magic computer that anyone can upload programs to and leave the programs to self-execute, where the current and all previous states of every program are always publicly visible, and which carries a very strong cryptoeconomically secured guarantee that programs running on the chain will continue to execute in exactly the way that the blockchain protocol specifies. (para. 8)
Iansiti and Lakhani (2017)	An open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way. The ledger itself can also be programmed to trigger transactions automatically. (para. 2)
Vermont Statutes (2017)	A mathematically secured, chronological, and decentralized consensus ledger or database, whether maintained via Internet interaction, peer-to-peer network, or otherwise. (12 V.S.A. § 1913, para. 1)
Gartner (2018b)	A type of distributed ledger in which value exchange transactions (in bitcoin or other token) are sequentially grouped into blocks. Each block is chained to the previous block and immutably recorded across a peer-to-peer network, using cryptographic trust and assurance mechanisms. Depending on the implementation, transactions can include programmable behavior. (para. 1)

opinion that *distributed* implies characteristics such as *open*, *peer-to-peer*[21] and *shared*, which is why those are left out.

Ledger/database. These two words are used interchangeably in literature and we have opted to use both. The phrase *a (distributed) ledger* has almost become a synonym for *blockchain* and clearly emphasizes the focus on transactions. *Database (system)*, on the other hand, highlights the technical nature of a blockchain and relates it to an information system, which we believe blockchain to be.

Consensus protocol. The presence of a protocol to achieve consensus on the validity and order of transactions is also added. Similar to all the definitions in Table 6, we do not specify this protocol, since different blockchains can adopt different algorithms, e.g., proof-of-work, proof-of-stake, etc.

Cryptography. Every blockchain uses some sort of cryptographic algorithm to achieve its *immutability*. We have added the word *practically*, however, because forks executed by nodes with enough computing power can alter transactions, even though this is highly irregular. We prefer not to use the word *incorruptible*, because blockchains with, e.g., a link to external systems (such as the aforementioned weather site) can become corrupt if the data they receive is falsified.

Chained blocks. The high number of definitions that do not contain any information whatsoever about the specific data structure of a blockchain is quite remarkable. Those definitions are too broad and are thus also applicable to other data structures, such as directed acyclic graphs for example. We have therefore opted to incorporate the phrase *chained blocks of data* in our definition.

Other characteristics were excluded because they were (1) implied by the characteristics that were included (e.g., *immutability* implies *irreversibility*[22]), (2) too restrictive (e.g., *encrypted*), (3) too context-dependent (e.g., *resilient* and *efficient*), or (4) a result rather than a characteristic (e.g., *trust*).

Even though we believe that we have constructed a generally sound definition of blockchain—especially for the purposes of this paper—we want to stress that it is highly likely that others arrive at a different, yet equally correct definition due to their own idiosyncratic perspective, emphasis and context, like ours.

2.2 Business value

Price is what you pay. Value is what you get. Even though American investment guru Warren Buffett might be an open critic of Bitcoin, which he has called "a mirage" and "rat poison squared", he did share some interesting insights with the world, such as

[21] One can even argue whether every blockchain is really peer-to-peer; in the case of a permissioned network, for example, some nodes are restricted in their abilities to participate in the consensus mechanism, which undermines the idea of the network consisting of equally valued "peers".

[22] According to us, being unable to change and delete the data (immutability) also means not being able to go back to a previous state (irreversibility). This is, however, a semantic discussion that is out of the scope of this work.

the above quote. (Business) value is a very complex and abstract concept that cannot simply—or at least solely—be expressed in hard financial figures. Since we intend to discover the business value of blockchain with this work, some clarification of the term is required.

The *paradox of value* asks whether water—a material that is crucial for life, yet is very cheap—has more value than diamonds—a material that is of very little effective use, yet has a much higher price than water. Adam Smith explains in his magnum opus *The Wealth of Nations* (1776) that "the word value, it is to be observed, has two different meanings, and sometimes expresses the utility of some particular object, and sometimes the power of purchasing other goods which the possession of that object conveys. The one may be called 'value in use;' the other, 'value in exchange.'" Based on this quote, we conclude that we are interested in the first meaning of the word *value* in this work, i.e., the utility of blockchain. An interesting remark is that the value of (some) blockchains can also be studied from a "value in exchange" perspective, i.e., by analyzing the market price of the underlying token (a cryptocurrency such as bitcoin), but also by analyzing its use as a payment method. This latter approach is, however, out of scope and not preferable for the purposes of this work.

Blockchain, as a system that allows two or more networked actors to transact, requires us to look at businesses from a broad perspective—as an entity surrounded by a complex environment. Moore (1996, p. 26) was the first to define a *business ecosystem* as "an economic community supported by a foundation of interacting organizations and individuals—the organisms of the business world. The economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisms also include suppliers, lead producers, competitors, and other stakeholders." We therefore start from the premise that blockchain technology has the potential to add value not only for a business's internal processes, but also—and presumably even more—for its external processes that the organisation shares with the various stakeholders with whom it interacts.

An extensive amount of academics, managers, journalists and others have written about businesses and the related concept of value. One of those is Peter Drucker, the father of modern management theory, who was the first to stress that creating customers is the only valid purpose of a business; every organisation should therefore be centered around offering value to its customers (Drucker, 2001). Michael Porter, another business strategy thought leader, developed a tool, called the *value chain*, that is used to "disaggregate the firm into the activities that underlie competitive advantage" in order to identify how a business adds value along the way (Porter, 1985, p. 27). Porter also stresses the pervasive role of technology in an organisation's value chain.

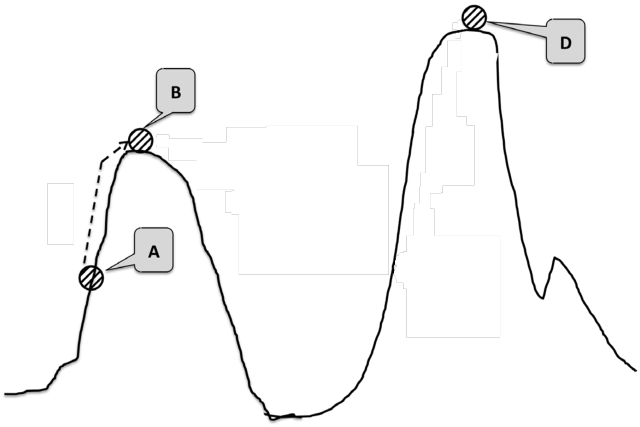
Value proposition is an interesting term that relates remarkably well to both Drucker's and Porter's understanding of value, because it can be interpreted from either a business or a customer perspective. From the first perspective, the term is used to refer to "one of the 'decision variables to create competitive advantage' and [. . .] as part of a 'profit oriented' business logic on the way to creating value and challenging a firm to gain profits. Other scholars, however, describe value proposition as the value received by customers and a core component of the business model as the 'proposition, which is accepted, rejected or unnoticed by the customers'" (Antonopoulou, Nandhakumar, & Panourgias, 2014, p. 4).

The aformentioned business model construct has gained traction in recent years, both by practitioners as well as academics (Wirtz, Pistoia, Ullrich, & Göttel, 2016). Osterwalder and Pigneur (2010, p. 14) give a concise, yet apt definition: "a business model describes the rationale of how an organization creates, delivers, and captures value." In other words, companies should deliver a certain benefit to their customers, by organizing themselves appropriately, to finally subtract enough value from its customers for their own profit-making (Teece, 2010). By developing a proper value proposition, a business can create value which will satisfy its customers' needs. However, there should also be an "underlying economic logic that explains how [an organisation] can deliver value to customers at an appropriate cost" (Magretta, 2002, para. 3).

Business models are inherently exposed to internal as well as external changes; technology takes up a large part of the latter group. Since new technologies can facilitate new business models (Baden-Fuller & Haefliger, 2013), technology-driven innovations can be ruthless for businesses that fail to adapt (see, e.g., Kodak, Nokia and Blockbuster). However, they can also present opportunities and be a source of competitive advantage (Chesbrough & Rosenbloom, 2002; Baden-Fuller & Haefliger, 2013). As explained by Teece (2010, p. 183): "figuring out how to capture value from innovation is a key element of business model design." Chesbrough and Rosenbloom (2002) furthermore stress the influence of the value network around a firm (cf. the business ecosystem) on capturing value from the commercialization of an innovation.

Business models can explain why an innovative technology has led to business success or failure (Baden-Fuller & Haefliger, 2013). New technologies almost always necessitate business model innovation, which can be defined as "a process that deliberately changes the core elements of a firm and its business logic" and which is either incremental or radical (Bucherer, Eisert, & Gassmann, 2012, p. 184). These two distinct avenues for business model innovation are especially important when technology is the driving force, because technology can have an impact on value creation, delivery as well as capturing (Teece, 2010). Incremental innovation occurs when a business enhances or upgrades its current business model and thus "tries to reach the highest point on the current hill" that it is on. Radical innovation, on the other hand, occurs when a business disrupts current business models in order to climb to the top of "the highest [currently reachable] hill", as visualized in Figure 7 (Norman & Verganti, 2014, p. 79).

Recall the focus of our work, as expressed in our main research question: *How does blockchain create added value for businesses?* We put special emphasis on the word "added" because the implementation of a blockchain should either be an improvement to a business's current IT systems (and therefore also to its business processes) or create a totally new value-adding product or service. IT systems, such as blockchain, do not create value on a stand-alone basis, but rather by the (positive) impact that they have



Source: Adapted from Norman and Verganti (2014, p. 79).

Figure 7: Hill analogy of incremental and radical innovation. In the first type of innovation, a business goes from point A to point B, while in the second type, a business tries to reach point D.

on business processes (Harris, Herron, & Iwanicki, 2008).

In this work, we will therefore use the term *business value* as the benefit that a certain blockchain implementation promises to offer to the current or future operations of a business, its employees, its customers and/or any other stakeholder, and in doing so increases an organisation's ability to create, deliver and/or capture value. Additionally, we define *value enabler* and *value driver* (which are used interchangeably in this text) as any factor that enhances this value (cf. Amit & Zott, 2001).

3 Results

It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts.

—Sherlock Holmes, in *A Scandal in Bohemia* by Arthur C. Doyle

The above quote adequately summarizes the intention of this work. By starting from "facts", in the form of proposed use cases, we aim to derive a theory that captures the business value of blockchain. In this section, we present and discuss the findings of our case study. For more information on the research process that led to these findings, we refer to Appendix A. Additional information on the analyzed cases can be found in Appendix B.

3.1 Findings

Our case study has gradually led us to discover that blockchain use cases can be divided into four groups and that the specific group to which a certain use case belongs, has an impact on the kind of business value that it creates. We therefore first present our use case classification framework and the associated groups. Next, we explain the two perspectives on blockchain technology that we have identified through our case analysis and how they relate to business value.

3.1.1 Use case classification

Classification frameworks are an established instrument in information systems research and can help to structure knowledge (Farbey, Land, & Targett, 1995). By removing inter-group variation, they also make it possible to simplify the theory building process because they allow the researcher to start from smaller theories—one per group—to eventually build one comprehensive theoretical framework. Other blockchain researchers have proposed classification frameworks for, e.g., blockchain adoption (Iansiti & Lakhani, 2017) and decentralized consensus systems (F. Glaser & Bezzenberger, 2015).

We present a new classification framework that divides blockchain use cases along two dimensions: the first is used to indicate whether the party with whom a business will interact via the proposed blockchain is an existing or a new kind of partnership[23] for the organisation, while the second is used to indicate if the proposed application (e.g., a service, product or process) is completely new or already exists in the company. This division allows us to distinguish four different types of blockchain use cases, as visualized by the 2×2-matrix in Figure 8. Next, we consecutively discuss these four different types of blockchain use cases.

[23]We use the term *partnership* very broad in this context. It is used to refer to any group with whom a business might share a blockchain, e.g., partner companies but also competitors, employees, customers, the government etc.

		Application	
		Existing	New
Partnership	Existing	Type 1	Type 3
	New	Type 2	Type 4

Figure 8: Blockchain use case classification framework.

3.1.1.1 Type 1

A recent report by Deloitte (2017) shows that blockchain is currently escaping the technological ideation and prototyping phase, and slowly entering into the phases of business prototyping and innovation (to finally reach the business value generation phase). This explains why type 1 use cases are the most prevalent in blockchain literature; most organisations only recently started experimenting with this novel technology—if at all. It is only logical that companies first try to improve their existing processes and services with current partners—of which they are very knowledgable and with whom they have built a trusting relationship, respectively—before they try to apply blockchain technology in the uncharted territory of completely new applications with unknown partners. Typical type 1 use cases are process improvements between financial institutions and supply chain partners (e.g., Lucena, Binotto, Momo, & Kim, 2018). Currently, these are executed either via an intermediary (e.g., Notheisen, Cholewa, & Shanmugam, 2017) or via a centralized ledger of one of the business partners (e.g., Azaria, Ekblaw, Vieira, & Lippman, 2016).

The emergence of these kind of use cases are also fuelled by the growing trend of blockchain consortia that are quickly being established in various industries: most notably in the financial services industry, but also in others, such as health care, logistics and energy (Gratzke, Schatsky, & Piscini, 2017). Blockchain as a "business-to-business workflow tool" benefits from this collaborating collective of different companies, who set standards to increase interoperability and develop the necessary infrastructure. In the meanwhile, the participating organizations collectively search for the opportunities that this new technology might bring to their industry, yet also for the threats that it imposes on their business models. This provides companies with a relatively easy, low-risk way to stay up-to-date on the technology while it reduces their FOMO—fear of missing out. Ultimately, however, the emergence of these consortia are "a consequence of the technology itself": since blockchains operate as a platform between various organizations—and due to network effects—it makes sense to develop a distributed ledger together with the other partner companies with whom an organisation will be sharing that ledger (Gratzke et al., 2017, p. 3).

3.1.1.2 Type 2

In type 2 use cases, blockchain enables businesses to work together on an application that was previously done independently but can be improved by a partnership, which was previously impossible because they did not trust a centralized system due to conflicting business goals (Lucena et al., 2018), because they are unable to agree on a central provider (Fridgen, Radszuwill, Urbach, & Utz, 2018), or because of other trust issues (Weber et al., 2016).

For example, Parra Moyano and Ross (2017, p. 412) propose to create an interbank ledger to proportionally share the costs of the know-your-customer verification process among competing financial institutions; this would allow them to avoid making the exact same task independently, which would deliver "far greater cost savings than would any effort to merely make these duplicated tasks more cost efficient." This is only possible because contributors can be compensated and documents can be shared in an anonymous manner. Lycklama à Nijeholt, Oudejans, and Erkin (2017) propose a similar system that allows competing factoring service providers to lower costs by collectively identifying fraudulent customers.

3.1.1.3 Type 3

Type 3 blockchains constitute cases where a new service or process is instantiated with a current partner group of a company. Vo, Mehedy, Mohania, and Abebe (2017), for example, propose to use a blockchain to build a pay-as-you-go car insurance application that offers current and/or future customers a much more precise invoice for the services rendered by the company.

3.1.1.4 Type 4

Type 4 use cases are the newest and most innovative applications of blockchain. Sikorski, Haughton, and Kraft (2017), for example, present a proof-of-concept in which a blockchain-enabled energy market place is created, that uses machine-to-machine interactions to automatically execute atomic transactions. This, for example, makes it possible that a car manufacturing company, that uses solar panels for his own energy requirements, to monetize his excessively produced energy in a peer-to-peer market to a neighbouring company. This transaction was previously not executed by the car company and constitutes a new partnership.

3.1.2 Collaboration platform

Our case analysis led us to conclude that blockchain, by enabling a shared ledger, allows businesses to work together in numerous ways with various partners, e.g., business partners (Fridgen et al., 2018), competitors (Parra Moyano & Ross, 2017), employees (Ying, Jia, & Du, 2018), customers (Azaria et al., 2016), governments (Hyvärinen, Risius,

& Friis, 2017), etc. As a result, the first perspective on blockchain that we propose is as a *trustless collaboration platform for data exchange.* As an independent, neutral technology, blockchain can replace intermediary firms by providing a secure exchange platform for data and transactions between networked actors. As a result, the need to rely on costly third-party intermediaries will decrease substantially, i.e., *disintermediation* or *cutting out the middleman.*

While existing intermediaries solve—among others—problems of uncertainty and asymmetric information (adverse selection and moral hazard), they take advantage from their opportunistic position, while benefitting from economies of scale and network effects, to obtain significant market power. Furthermore, in addition to the fee they receive, intermediaries often monetize the information that they handle, resulting in privacy risk, and are able to select which transactions to execute and, especially, which not to execute, resulting in censorship risk (Catalini & Gans, 2017). The inefficient nature of their existence is explained by the fact that they extract more value from transactions than they can add to them. Blockchain technology, as a neutral and efficient platform, can fill the role of an intermediary without the associated costs and risks.

There are six fundamental characteristics of blockchain technology that make its disintermediating power possible and enables it to offer business value: decentralization, cryptographic security, transparency, data immutability, distributed consensus and programmable smart contracts[24]. We call these *value enablers*; sometimes they are also referred to as *value drivers.* Together and independently, these value enablers make it possible for businesses to use blockchain technology to their advantage. The definition of blockchain as it was constructed in Section 2.1.6 shows many similarities with these value enablers.

In the remainder of this section, we first consecutively discuss these six enablers and how they lead to business value. Next, we show how certain *value amplifiers* can further increase the business value of blockchain.

3.1.2.1 Value enablers

The following six value enablers were present in all analyzed use cases and are paramount for the well-functioning of a blockchain. Nevertheless, there are some dissimilarities between use cases, resulting from a higher or lower dependence on one or more value enablers to deliver business value. We give examples in the following paragraphs to highlight these differences.

Decentralization

The decentralized[25] infrastructure of a blockchain network has some inherent benefits;

[24] Smart contracts are not necessarily required for disintermediation (see, e.g., Bitcoin), but do offer substantial business value, as will be explained later.

[25] Recall that if we use Baran's terminology (see Figure 4), *distributed* better captures the typology of a blockchain network. However, during the case study, it was observed that *decentralized* is most often put forward as the value driver, while *distributed* is most often used in the phrase "distributed ledger"

there is no single point of failure (see, e.g., Notheisen et al., 2017) and thus no "central target for content attack" (Azaria et al., 2016, p. 29). This "security by design"—further enhanced by the cryptographic security—reduces the risk of the system being hacked; centralized systems on the other hand have known some infamous data breaches over the course of history, such as Yahoo, Target, Ashley Madison etc. Furthermore, a blockchain can easily be restored even if all but one node are compromised since all (full) nodes contain a copy of the entire database (Yuan & Wang, 2016). As a consequence, blockchains can guarantee a very high reliability (i.e., consistent performance) and availability (i.e., 100% uptime).

Cryptographic security

Cryptographic algorithms make blockchains secure in (at least) four ways. First, by using hash references, as explained in Figure 3, the blocks of data are chained together making a blockchain a (practically) immutable data storage. Secondly, data that is stored on (public and private) blockchains can be encrypted, which makes the data incomprehensible for nodes without the correct decryption key. Thirdly, most blockchains use public/private-key cryptography in order to (pseudo-)anonymize its nodes. These last two benefits, combined with the absence of an intermediary firm, enable blockchains to guarantee the privacy of its users and their data. Fourthly, a user's private key is used to digitally sign every transaction made, thereby authenticating himself "without disclosing any sensitive information" (Ying et al., 2018, p. 3).

The transparency of blockchains, discussed below, is sometimes put forward as a major disadvantage of the technology by laymen. This is, however, often a misinterpretation of the term. Azaria et al. (2016), for example, present a use case where a blockchain contains pointers to highly confidential medical data that is stored off-chain and only accessible by persons with the right access permissions. Another system by Zyskind, Nathan, and Pentland (2015) makes it possible to store private data on the blockchain itself and even though this data might be transparent to everyone, they cannot understand it, because the data is encrypted and scattered over different nodes. Parra Moyano and Ross (2017) developed an interbank-ledger where customer data is securely shared between the banks that share in the verification costs, while this data stays hidden for those banks that do not. Ying et al. (2018) exploit a blockchain to set up a market between a company's employees and various suppliers, without the need of disclosing any personal identity information.

Data immutability

We have chosen to incorporate *data immutability* as a value enabler, even though one could argue that the real value enabler is cryptographic security—discussed above—since the data becomes immutable because cryptographic hashes are used to link the data together. However, the fact that blockchain data is immutable is not really an

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and to explain the database structure. Nevertheless, these two terms are neither a dichotomy, nor part of a certain spectrum. It is therefore more of a convention when to use one of both terms.

advantage as such; mistakes for example cannot be corrected.[26] It does lead, however, to a tamper-proof data storage—which is crucial in most cases (e.g., Parra Moyano & Ross, 2017)—and thus also guarantees *data integrity*. Khaqqi, Sikorski, Hadinoto, and Kraft (2018) propose an emission trading scheme which eliminates fraud by using a reputation-based system that requires credible data; the data integrity of a blockchain makes this possible. In case of a conflict, blockchains act as the single source of truth to settle disputes, thereby reducing conflict resolution costs (Parra Moyano & Ross, 2017).

Distributed consensus

Blockchains use a specific protocol, e.g., proof-of-work, proof-of-stake, "for the secure updating of a state according to some specific state transition rules, where the right to perform the state transitions is distributed" (Buterin, 2014b, para. 2). Every (permissioned) node has the right to verify each transaction (i.e., *data verification*) and only if the transaction is approved by a majority of the nodes is it appended to the blockchain. This leads to fewer errors and fewer possibilities to commit fraud. Ultimately, this leads to *data validity*, which, combined with data integrity (see previous paragraph), enables a *single history of the truth*.

By instantaneously and costlessly[27] verifying transactions, blockchain enables an *ex ante* audit within the marketplace itself. "Verification goes from being costly, scarce and prone to abuse, to being cheap and reliable", and can be implemented at a much lower scale than before (Catalini & Gans, 2017, p. 10). This will lower operation costs for businesses, especially settlement, clearing and reconciliation costs, as verification becomes commoditized.

For example, Hyvärinen et al. (2017) propose to use a blockchain as a cross-border information system to verify the eligibility of foreign investors that ask for a tax refund, to avoid fraudulent claims. In the current process, the necessary refund documents can easily be forged and not properly verified due to a lack of information. The automatic verification of documents by blockchain can speed up this process (see also, Fridgen et al., 2018) and lead to less fraud (see also, Vo et al., 2017).

Transparency

The *transparency* of a blockchain is where most of the above benefits come together. The linear data log makes it possible to trace every transaction back to its origin. This enables users to track and monitor the provenance of goods throughout the supply chain and to check compliance to company policy and regulations (Lucena et al., 2018). Furthermore, the blockchain can serve as an *audit trail* to hold certain people *accountable* for wrongdoings (Khaqqi et al., 2018). Since everyone works with the same shared ledger, uncertainty and disputes are reduced as information asymmetry issues disappear (Notheisen et al., 2017) and communication is sped up (Lucena et al., 2018). Blockchain drastically enhances the prevalent current practice in which information is spread over

[26]See, e.g., (Notheisen et al., 2017) for some ways to mitigate this transaction risk.

[27]Or at least so low that the cost is considered to be irrelevant compared to the value of the transaction.

different ledgers, which often leads to inconsistent and outdated information for each party resulting in financial losses (Lucena et al., 2018; Auberger & Kloppmann, 2017).

Smart contracts

Smart contracts are programmable, self-enforcing pieces of code operating on a blockchain. They allow the automated execution of a transaction when certain conditions are met according to pre-specified business logic rules. Smart contracts can be used to, e.g., avoid duplicate tasks (Parra Moyano & Ross, 2017); halt transactions if certain conditions do not comply with previously agreed terms, thereby reducing transaction risk (Notheisen et al., 2017); trigger the dissemination of payments without manual intervention, thereby minimizing expenses (Hyvärinen et al., 2017); reduce counter-party risk by enabling escrow agreements (Notheisen et al., 2017); and reduce manual errors in general by automating transactions (Vo et al., 2017). Generally speaking, they reduce manual (re)work and errors, as well as settlement and clearing times, thereby "minimizing bureaucratic and organizational efforts related to the administration and maintenance of databases" (Notheisen et al., 2017, p. 430). Ultimately, this leads to end-user satisfaction and efficiency gains (Hatane, 2015).

3.1.2.2 Value amplifiers

Blockchain implementations can further enhance their delivered business value if certain *value amplifiers* are included into the system. These are distinct from the value drivers, in the sense that they are not necessarily present in all blockchains. We discovered the following four value amplifiers through our case study.

Industry 4.0

The Fourth Industrial Revolution is blurring the lines between the physical and digital world, which can help blockchains in many ways. For example, because "all actions outside of the transaction process cannot be fully secure and [therefore the] residual risk of someone inserting corrupted information [into the blockchain] remains", blockchains can benefit from cyber-physical systems and the Internet of Things "to relieve trusted third parties from data provision duties" and thus to mitigate the risk of fraudulent data input (Notheisen et al., 2017, p. 436). Sikorski et al. (2017) propose a blockchain-enabled market where machine-to-machine communication—also part of Industry 4.0—is used for autonomous electricity trading, thereby lowering overhead costs.

Third party integration

Blockchains can benefit from the integration of third parties who are not necessarily part of the transaction that is being executed on the platform. A national regulator or external audit firm, for example, can be granted access to a private blockchain, thereby making use of the audit trail to investigate compliance and adherence to laws and regulations. Parra Moyano and Ross (2017), for example, include a national regulator in their blockchain system to check adherence to KYC regulations via the immutable audit trail, thereby freeing companies from the costly burden of being required to repeatedly prove their legal behaviour. Furthermore, Catalini and Gans (2017) explain that, even though the nature of intermediation will change due to blockchain, intermediaries will still be able to add substantial—although different—types of value in a blockchain-based market by offering complementary services.

Standardization

The collaboration between organizations is often hindered due to inoperable IT systems. Each company has it own suite of programs that can almost never be easily connected to those of a collaboration partner. This increases costs which impedes the cooperation. Blockchain can offer a solution to these problems, as a shared platform that is not owned by one single company (Azaria et al., 2016). Furthermore, a blockchain implementation often induces an *ex ante* standardization and digitization of operations, thereby improving operational efficiency (see, e.g., Fridgen et al., 2018; Egelund-Müller, Elsman, Henglein, & Ross, 2017).

Data economics

Blockchains, which are essentially large data storages, contain many different forms of information that might be interesting to various stakeholders. Azaria et al. (2016), for example, propose to use aggregate, anonymized medical data as a mining incentive for researchers, public health authorities, etc. Since blockchains can enable the data provider to keep the access permissions in his own hands, it also becomes possible to sell this data to interested parties. They call this *data economics*, which presents opportunities for, e.g., market research firms to be integrated into blockchain platforms in order to extract this data at a certain price.

3.1.2.3 Theoretical framework

In Figure 9, we visualize all of the above mentioned concepts and their interdependencies. Although we did not go into detail on all the idiosyncratic value manifestations of all the use cases that were analyzed, the above paragraphs have presented ample examples that explain how blockchain (1) mitigates various risks, (2) allows for efficiency gains and, in general, (3) lowers costs.

However, two blockchain use cases could not be explained by our theoretical framework (see, Vo et al., 2017; Sikorski et al., 2017). These are the cases that relate to type 3 and type 4 of our classification framework in Figure 8. We explain how these two use cases are able to increase revenue, rather than decrease costs, in the following section, which presents our second perspective on blockchain.

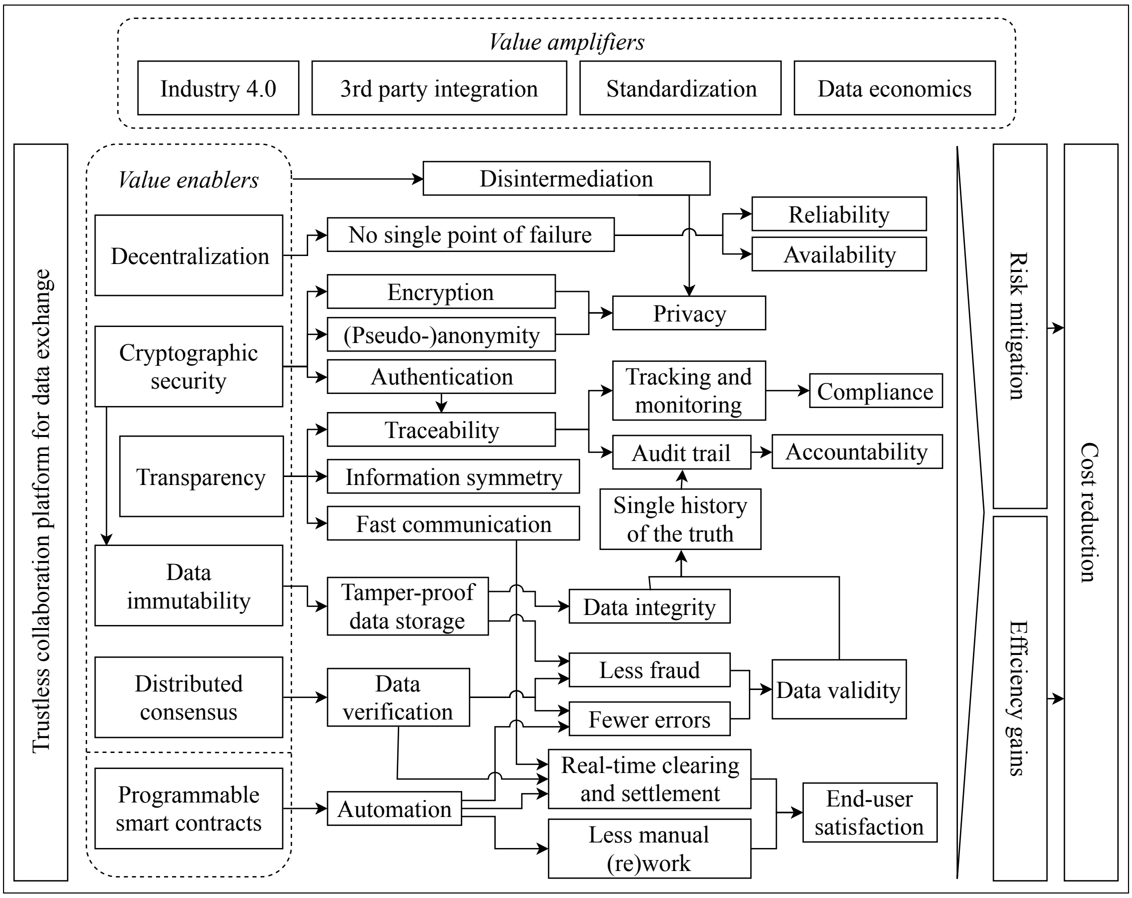

Figure 9: Theoretical framework of the business value of blockchain as a collaboration platform.

3.1.3 Coordinating platform

As explained in the previous paragraph, two cases did not fit our theoretical framework. We have attempted to find more similar use cases in academic papers, but our efforts were unsuccessful. Neither were our interviewees able to point to applicable cases. Therefore, due to this limited number of "polar" use cases, and our focus on cross-case analysis, replication logic cannot be applied and we will probably fail to build a sound theory if we were to do so (Yin, 1984; Eisenhardt, 1989a). Nevertheless, "a single case can be a very powerful example" (Siggelkow, 2007, p. 20). Here specifically, it demonstrates that our theory of the business value of blockchain is currently incomplete. To tackle this problem, we first draw on a body of blockchain and economics literature and next, with the help of our two cases, we try to build a second, tentative theory of blockchain that can serve as input for future research. As more and more use cases are published, it will become possible to confirm, adjust or reject our proposed hypotheses.

3.1.3.1 Transaction costs

Cooperation—collaboration—increases transaction costs[28]; the use of IT, however, can lower these costs (Clemons & Row, 1992). The rise of the Internet, for example, led to a drastic decline in communication and—subsequently—transaction costs. Intermediaries launched new platforms and global marketplaces "where individuals, products and services could be matched more effectively than ever before" (Catalini, 2017, para. 1). While, the Internet continues to challenge the outdated value chains of traditional brick-and-mortar stores, blockchain has been put forward by various authors as the logical next step in this transformation process (see, e.g., Tapscott & Tapscott, 2016; Davidson, De Filippi, & Potts, 2016a).

When discussing a technology that enables two parties to transact more efficiently—as proven in our theoretical framework—it is difficult not to mention the work of Nobel Prize laureate Ronald Coase. In his seminal paper on *The Nature of the Firm* (1937, p. 395), Coase argued that firms only emerge because of the existence of transaction costs and that "a firm will tend to expand until the costs of organising an extra transaction within the firm become equal to the costs of carrying out the same transaction [outside the firm]."

Tapscott and Tapscott (2016, pp. 92–93) paraphrase the three different types of transaction costs, as identified by Coase, as: "the costs of search (finding all the right information, people, resources to create something); coordination (getting all these people to work together efficiently); and contracting (negotiating the costs for labor and materials for every activity in production, keeping trade secrets, and policing and enforcing these agreements)." Tapscott and Tapscott (2016) proceed to show that a platform running on blockchain technology has the available tools (smart contracts, immutability, transparency, etc.) to drastically lower all aforementioned costs, while additionally removing the requirement of mutual trust between transactors (or in an intermediary) because trust is embedded within the platform itself. They conclude by stating that blockchain therefore has the potential to "re-architect" the firm as we know it. Catalini and Gans (2017) furthermore explain that blockchain technology is able to lower transaction costs by lowering the cost of networking. Networks often require significant capital and labor investments, but blockchains lower the costs of bootstrapping and maintaining these networks, thereby changing the potential scale and scope of online platforms.

3.1.3.2 Case evidence

The above economic insights present us with a context to frame our two special cases. Our current theory and perspective present blockchain as a collaboration platform and a more efficient way to conduct business, thereby lowering costs. Davidson et al. (2016a, 2016b) call this perspective "innovation-centred", i.e., blockchain as a new, general-purpose information and communication technology (ICT). Similar to our findings, they state that

[28] We define *transaction costs* as the costs that are incurred when making an economic trade in a market, apart from the price of the good or service.

blockchain can drop the costs currently incurred by using expensive centralized solutions, which will therefore lead to gains in total factor productivity. Swan (2015) agrees with this perspective and identifies blockchain as the fifth major disruptive technology and computing paradigm, after mainframes, PCs, the Internet, and mobile/social networking.

Through our case study, we have discovered that blockchain is able to lower costs, many of which are transaction costs, e.g., information asymmetry costs, counter-party risk costs, conflict resolution costs etc. According to Davidson et al. (2016a, 2016b, p. 7), this leads to a second, more transformational approach to blockchain as governance-centred, i.e., blockchain as "a new species of rule-system for [the] economic coordination" of the actions of groups of people. They contend that blockchain should be seen as a new type of economy or, better yet, a catallaxy, defined by Hayek (1998) as a spontaneous, self-organized economy. As such, blockchain will compete with the traditional institutions of capitalism, e.g., firms, markets, networks and even governments. Davidson et al. (2016a) therefore urge not to add blockchain to the list of technological revolutions that have driven capitalism through a process of creative destruction and productivity growth over the years (such as the invention of, e.g., steam power, electricity, computers and the Internet) but to approach it as a new institutional technology with the capabilities to "disrupt governance" and businesses.

However, it is our hypothesis that this second perspective does not necessarily pose a threat to businesses. As evidenced by the case of Vo et al. (2017), businesses can benefit from this reduction in transaction costs because it enables new services and products to emerge, that were otherwise economically infeasible due to high transaction costs. Firms have been described by Jensen and Meckling (1976, p. 311) as a "nexus of a set of contracting relationships." One of those relationships is between a business and its customer and in the case of Vo et al. (2017), blockchain makes it possible for insurance companies to close a contract with a customer on a much lower scale, per ride as opposed to, e.g., per three months. In a normal setting, a business would incur too many costs to make this a profitable deal.

The case of Sikorski et al. (2017) presents similar evidence. Here a new marketplace is created on a blockchain, which enables businesses to sell their products and services (energy in this case) to customers it does not even know, because the blockchain can serve as a trustless platform for executing these transactions. As with the other case, the transaction can occur on an atomic level, which would not have been economically feasible without a blockchain.

3.1.3.3 Tentative theory

Through our case study and literature review, we have identified three value drivers for this second theory on the business value of blockchain. First, as explained above, by lowering transaction costs, blockchain is able to lower the scale at which transactions become economically feasible for a firm to execute. This allows new products and services to emerge, as well as new customers to be reached and thus new markets to be created.

Second, the pervasiveness of blockchain, i.e., blockchain combines an infrastructure, application and presentation layer by design (F. Glaser, 2017), offers a comprehensive solution for businesses that can easily be deployed. Furthermore, if we combine this benefit with a blockchain's ability to contain an inherent value token, new marketplaces can easily be bootstrapped and maintained (Catalini & Gans, 2017). This drastically lowers the complexity for firms to close contracts with its customers (Davidson et al., 2016a), which is further enhanced by the automatic handling of transactions enabled by smart contracts.

These conclusions are confirmed by Gupta (2017, para. 6) who states that "transaction costs [...] keep the number of partners in a value network small. But if locating and locking in partners becomes easier, more comprehensive value networks can become profitable, even for quite small transactions" and by Nowiński and Kozma (2017, p. 184) who states that "when the transaction size is relatively small, blockchain technology can generate business which would be unfeasible in the presence of intermediaries and the costs which they generate."

Figure 10 presents our second perspective, which we have coined "blockchain as a coordinating platform", as blockchain is able to coordinate new kinds of transactions automatically for a firm that would otherwise be economically infeasible. However, we want to stress that this is a tentative theory, and that its hypotheses should be tested in a case study that is better grounded in data than ours. Next, we discuss our two discovered perspectives in the light of business value.

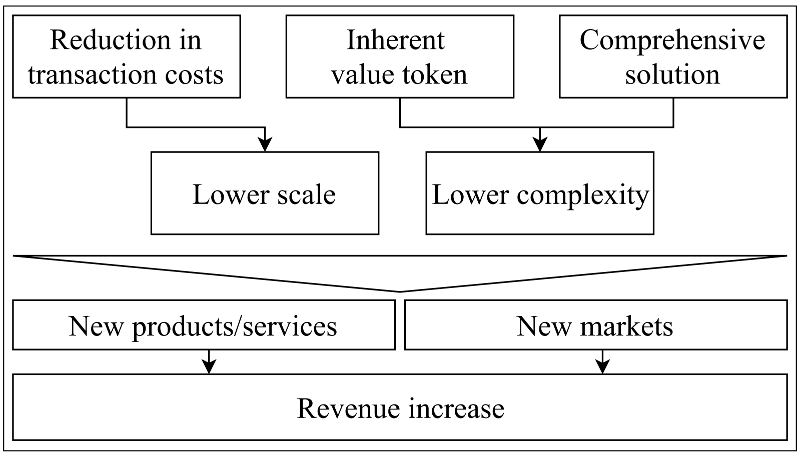

Figure 10: Theoretical framework of the business value of blockchain as a coordinating platform.

3.2 Discussion

Through our case study, we have discovered two diverging avenues on how blockchain can generate business value. This first is as a collaboration platform, allowing business to transact more efficiently with current partners, as well as with new partners in ways which were previously infeasible, impossible or even unimaginable. These use cases promise to offer efficiency gains, less risk and therefore the reduction of various costs that business are currently confronted with. This is a kind of incremental innovation (see Figure 7), as it enables the optimization of a business' current operations. In business model terminology, this means that the value delivery and value capturing capabilities of a business are improved. It is here that the bulk of blockchain use cases is currently situated.

This trend was predicted by Baden-Fuller and Haefliger (2013, p. 420): "the fact that positive effects of technological innovation on business performance are easily observed [often diverts] attention from questions about how business models change in the wake of innovation." However, some blockchain researchers have dared to venture into this new direction. Type 3 and type 4 use cases present radical types of innovation, where blockchain enables new products and services to be created, and new markets to be reached. We include these cases in our second perspective on blockchain as a coordinating platform. These applications present novel business models, are focused on new ways of value creation and thus generate new revenue streams for businesses.

"If the first post-blockchain awakening phase was about efficiency and saving money, the next will be 'more about creating new customer solutions and experiences that don't easily exist today'," summarizes Tanaya (2016, para. 13). However, blockchain is only currently escaping the technological ideation and prototyping phase, and slowly entering into the phases of business prototyping and innovation, to finally reach the business value generation phase Deloitte (2017). Therefore, these transformative applications will probably not be implemented in the near future. Nevertheless, Iansiti and Lakhani (2017) urge companies to invest and evaluate the possibilities of these blockchain applications today, as they can unlock a large potential for future growth.

4 Conclusion

A conclusion is the place where you got tired of thinking.

—Martin H. Fischer, German physician

Because businesses have a hard time discovering valuable blockchain applications for their enterprise, this work has presented the first theoretical framework of the business value of blockchain. Based on 15 blockchain use cases, that present a working prototype, we followed Eisenhardt's case study process to build a theory of the business value of blockchain, that is grounded in data. Our analysis led us to the conclusion that there are two diverging perspectives on blockchain—based on the novelty of the application which it enables—that lead to two distinct ways in which a business can benefit from a blockchain implementation.

The first, which is the most present in current literature, is that of blockchain as a collaboration platform. As a trustless shared ledger, blockchain allows for data exchange between business partners, competitors, employees, customers, governments and other groups situated in a business' ecosystem that is currently either impossible, facilitated by a trusted third party or centrally managed.

We have identified six fundamental value enablers that allow blockchain technology to make its disintermediating power possible and allow it to offer business value: decentralization, cryptographic security, transparency, data immutability, distributed consensus and programmable smart contracts. Together and independently, these value enablers make it possible for businesses to use blockchain technology to their advantage. We furthermore identified four value amplifiers than can enhance a blockchain's business value: Industry 4.0, third party integration, standardization and data economics.

As a collaboration platform, blockchain is used to optimize current business operations by (1) mitigating risk, (2) enabling efficiency gains and, in general, (3) reduce costs. As such, it can be used to enhance the value capturing and value delivering capabilities of a business model.

The second perspective on blockchain, of which only very few use cases exist as of yet, is that of blockchain as a coordinating platform. To enable this, a blockchain builds (1) on its capability to drastically reduce transaction costs, (2) on its comprehensive solution that it can offer and (3) on its inherent value token, to lower the scale at which transactions become economically feasible and to lower complexity for a firm. As such, blockchain is able to make new products and services possible and allows a business to reach new markets, thereby enhancing a business model's value creation aspect.

Limitations and future research

The contributions of this work must be considered in light of its limitations, many of which present avenues for future research. We discuss these next, and hope that they inspire more people to conduct research at the intersection of blockchain and business.

First, there is a clear lack of negative examples. Currently, the analyzed use cases are mere proof-of-concepts, rather than actual implementations, which makes it difficult to ascertain if the proposed business value can actually be achieved or is overhyped by its respective authors. This is worsened by blockchain's current position at "the peak of inflated expectations" (Gartner, 2017b), which makes it difficult to find conflicting (negative) literature. By focusing on research in which a working prototype is presented, we have tried to mitigate this risk as much as possible by starting from the currently best possible proxy of real business value. When, in the future, more blockchains are implemented in a real business setting, it will be insightful to test if our theoretical framework exhibits this bias—even though we have tried to discover the fundamental underlying value drivers of blockchain that are not case-specific.

The second limitation is related to the above one; blockchain technology was still developing at the time of writing and probably will for many years to come. New use cases with new value propositions are being proposed every day. Only when the technology has matured and all the technical drawbacks have been resolved, will it be possible to build a fully comprehensive theory of the business value of blockchain.

Thirdly, a second phase of this research would be to study if our newly developed theoretical framework is as useful for businesses as we state. The framework is from a rather theoretical nature and it might very well be the case that it needs to be made more concrete and practical for businesses to recognize its value. Via workshops that are organized together with various businesses in order to study if our framework can help to find useful blockchain applications, we can identify its inherent issues.

Fourthly, if a blockchain implementation were to be analyzed as a cost-benefit analysis, we have discussed the potential benefit side of the story. The cost side, however, also has to be taken into account. Blockchains are still a long way from maturing and currently suffer from technical limitations, such as scalability, latency and hard forks issues. Even though many of these constraints are likely to be of transient nature and will be solved in the future (F. Glaser, 2017), other costs will remain; these include implementation costs but also costs that derive from insolvable issues such as an impaired process flexibility for example (Fridgen et al., 2018).

Fifthly, this was the author's first endeavour at case study research, as well as at blockchain research. By extensively studying established literature, he has tried to make himself as familiar as possible with best practices and the existing knowledge base of both topics. However, case study is an art that requires many attempts to achieve at least some level of perfection (Stake, 1995). Furthermore, the broad scope of this research and the limited available time and resources, might in hindsight have been an overly ambitious combination. Nevertheless, by clearly defining the generalizability of our findings and by discussing the limitations of our research, we believe that we have transparently discussed the theoretical and practical contribution of this work.

Finally, we call for more research on the value creation aspect of blockchain. As evidenced by our case study, too many businesses are focused on process optimizations that result in efficiency gains and cost reductions. It is our opinion that the real business value of blockchain lies in its potential to enable new services and products that were infeasible—or even unimaginable—before Satoshi Nakamoto's groundbreaking invention.

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The secret to creativity is knowing how to hide your sources.

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Appendices

You read a book from beginning to end. You run a business the opposite way. You start with the end, and then you do everything you must to reach it.

—Harold S. Geneen, American businessman

A Research process

In this appendix, we describe the research process that we have followed in order to obtain the results as presented in Section 3.

A.1 Sampling

As mentioned in Section 1.3.3 on research design, we started with four pilot cases. It became quickly apparent, however, that more cases were required in order to draw grounded conclusions. This is why we opted to add six more cases to the sample. Three of those originate from Risius and Spohrer's blockchain research framework (2017). They identified ten papers at the intersection of *measurement and value* and *firms and industries*—the focus of our work—of which three were deemed applicable for this work (i.e., presented a working prototype): Sikorski et al. (2017) on machine-to-machine interactions; Azaria et al. (2016) on medical data storage; and Yuan and Wang (2016) on intelligent transportation systems. The other three of the six new cases were already read by the author before the start of this research and were added since the author deemed them applicable as well: Lucena et al. (2018) on grain quality assurance tracking; Fridgen et al. (2018) on cross-organizational workflow management; and Weber et al. (2016) on untrusted business process monitoring and execution.

These ten cases enabled the author to construct a first theory on the business value of blockchain. It was observed that nine of those ten cases were centered around the topic of optimization and therefore led to a reduction in costs. They all exhibited similar patterns and constructs, and presented a view of blockchain as a collaboration platform. However, this perspective on blockchain could not explain some types of value that were identified, e.g., the decline in social complexity (case 7) and the automated coordination (case 10). This theory gap was further enlarged by case 5 that did not focus on cost reductions and efficiency gains—as the other cases did—but rather on trade and market creation.

We therefore believed that a second perspective on blockchain was needed to explain all types of variations found in the data. Consequently, we searched for more blockchain use cases that were not oriented towards business optimization. By searching the databases of various publishers, such as Elsevier, IEEE and Springer, we managed to find four more applicable use cases. However, after analysis, only one of those four case clearly exhibited this new perspective of blockchain as a coordinating platform. We conducted a second thorough search, but no more similar cases could be found. Finally, we added one more case to see if theoretical saturation was reached for the collaboration platform perspective, which appeared to be so. For the second perspective, we constructed a tentative theory based on the little available data. These 15 cases combined enabled us to build our final theory as presented in Section 3.

A.2 Within-case analysis

Before being analyzed, information that is collected for a case study must be prepared by relying on data reduction, data display, data categorisation and data contextualisation techniques (Miles & Huberman, 1994). First, the chosen use cases were read in order to get a first idea of the specific topic and how blockchain was applied. During a second reading, important text fragments were highlighted using three different colors: a first for essential contextual information, a second for the issues and/or problems that the current setting exhibits, and a third for all the concepts and constructs that related to the value of using blockchain. While the focus of this work is on the latter, the first two are equally important to understand the context of the value and to find cross-case patterns.

Next, text codes were used to summarize the highlighted sentences. Duplicate (and very similar) codes were removed, while the remaining codes were used to summarize every use case on a sheet of paper. We want to stress that these text codes were not the only input to the theory building phase, but rather were used to facilitate the subsequent cross-case analysis. We often went back to the original text when this was deemed necessary to fully understand the context and relationships between constructs. An example of the coding process is given in Table 7 for the first use case. Finally, for each case, we drew a small framework of the business value of blockchain, as if it were a single case study.

A.3 Cross-case analysis

For the second part of the analysis, we compared the results of the cases with each other, in search of similar concepts and patterns. In a first iteration, this was done pair-wise, as suggested by Eisenhardt (1989a). Next, in a second iteration and by using standard techniques for cross-case analysis, e.g., tabulating (see, Miles & Huberman, 1994), we were able to identify the most important sources of value, the related constructs, and types of business value, and were able to corroborate our findings. We tried to name the discovered concepts and constructs as generic as possible without being too restrictive.

Next, by searching for similar and dissimilar patterns, while continuously iterating between data analysis and data collection, our final theory took form. In a last step, we read each case again to see if it could be explained by our theoretical framework. As stated in Section 3, not all cases could be explained by our framework, which is why we built a second theory in a similar manner as the first. However, due to the little amount of available data, this theory is still tentative and requires further investigation.

A.4 Expert interviews

When the theoretical framework was final, we conducted three semi-structured interviews with experts on blockchain technology, as explained in Section 1.3.4. We first asked them their perspective on the business value of blockchain before we showed them our framework, to reduce bias. These interviews confirmed our main findings, helped us to rename some concepts to make them less ambiguous, and helped us to refine some of the discovered relationships.

Table 7: Coding the paper of the first case.

Context	
Text fragment	**Code**
Know-your-customer due diligence process.	Process
Anti-money-laundering (AML) and KYC regulations.	Regulations
Corporations need to verify all their subsidiaries before being granted KYC verification.	Verification
Allows customers to carry out the full KYC process with only one financial institutions, and later on to share the result.	Reduced repetition of work Information sharing
Interbank collaboration.	Collaboration
The KYC process consists of an exchange of documents between the customer and the financial institution that intend to work together.	Information exchange
The process is repeated every time the customer intends to work with a new financial institution.	Repetition of work
Regtech, that aim to use technology to improve the implementation of regulations.	Regtech
KYC can be improved by, for example, improving auditors' effectiveness in assessing KYC and AML practices.	Auditing
A permission-based system can be of great value.	Permissioned
Can a DLT-based solution reduce the cost of the KYC process for financial institutions and improve the customer's experience?	Cost reduction Improved customer experience
It would need to enable its user to obtain a tamper-proof record of the KYC process in the case of conflict.	Tamper-proof record
It would have to reduce the costs of the current KYC process and distribute the remaining costs in a proportionate manner.	Cost reduction Cost sharing
The system would need to not compromise the responsibility of banks with regard to conducting the KYC process.	Not compromise responsibility
The need for interbank collaboration.	Interorganisational collaboration
Cooperation with the national regulator.	Cooperation with regulator
Central role of the national regulator.	Central role of regulator
The need to identify the individuals involved at each step of the KYC approval process.	Identification of users
Importance of keeping all the documents of a specific customer on a secure local storage facility with only the hashes of each document stored on the DLT.	Secure local storage
Protect customer privacy with regard to cyber attacks.	Protect privacy
Assign to the national regulator the role of maintaining the system.	System maintenance
Ensure the proportional sharing of the cost of conducting the core KYC verification process.	Cost sharing
Maintain the privacy standards.	Privay standards
No institution can become a free rider.	No free riders
A permissioned database that stores the documents that require a certain privacy.	Permissioned
In the proposed solution, the regulator is assigned a central role as a trusted third party (TTP) and owner of the "fabric layer".	Regulator as TTP
In most Western countries the risk of a corrupt regulator is considered low.	No corrupt regulator

Issues	
Text fragment	**Code**
The know-your-customer (KYC) due diligence process is outdated and generates costs of up to USD 500 million per year per bank.	Outdated Customer verification costs
Increased regulatory costs incurred due to the know-your-customer (KYC) verification process.	Regulatory costs
KYC and AML stand out [for a bank to] as a pretty significant inefficiency and problem case.	Inefficiency
Since that process is long, and tends to lengthen with the size of the corporate entity concerned, the starting point of a given business relationship between a customer and a financial institution is usually delayed, which represents opportunity costs for both parties.	Slow process Opportunity costs
Laborious task.	Manual labor
89% of customers do not have a good KYC experience.	Bad customer experience
The process is costly for financial institutions.	Costly process
May expose them to large fines if it is not conducted in accordance with the exisiting regulations.	Fines due to non-compliance Costly fines
Every time a custome initiates a relationship with a financial institution the costs of the KYC verification process recur.	Repetition of work
Current inefficiencies.	Inefficiency
High costs for financial institutions and the low satisfaction of customers when conducting a core KYC verification process.	High costs Low customer satisfaction

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Table 7 – continued from the previous page.

Value	
Text fragment	Code
Reduces the costs of the core KYC verification process.	Verification cost reduction
Improves customer experience.	Improved customer experience
Only conducted once for each customer, regardless of the number of financial institutions with which that customer intends to work.	Reduced repetition of work
Results of the core KYC verification can be securely shared.	Secured sharing of information
This system allows for efficiency gains, cost reduction, improved customer experience, and increased transparency throughout the process of onboarding a customer.	Efficiency gains
	Cost reduction
	Improved customer experience
	Increased process transparency
A solution to the increased costs of the KYC process and the lack of customer satisfaction.	Cost reduction
	Improved customer experience
Allows us to observe the KYC cost structure at an aggregate level for all financial institutions.	Aggregate overview
Tackle the inefficiencies that emerge from the duplicated conduct of similar tasks by all participating institutions.	Efficiency gains
	Reduced repetition of work
DLT allows us to render the execution of duplicated tasks completely unneccesary, and this delivers far greater cost savings than would any effort to merely make these duplicated tasks more cost efficient.	Cost reduction
	Reduced repetition of work
DLT enables the creation of a chronological, decentralized, interbank ledger in which financial institutions that need to conduct the same KYC verification tasks for that customer can verify the result of the process that has already been conducted for that customer	Interorganisational
	Decentralized
	Reduced repetition of work
Avoiding conducting duplicated KYC verification tasks.	Reduced repetition of work
Allows the cost of the KYC process to be shared proportionally among the financial institutions.	Cost sharing
Single point of truth.	Single point of truth
Only source of information, accepted by any involved party should conflict occur.	Single point of truth for conflicts
The KYC process only needs to be carried out once by each customer.	Reduced repetition of work
Reduces the aggregated cost of the KYC process as a whole.	Aggregate cost reduction
Respects the privacy of the participants.	Privacy
Increases transparency in case of a conflict.	Increased transparency for conflicts
The use of DLT reduces the aggregate cost of KYC.	Aggregate cost reduction
The audit effectiveness could be increased and information asymmetries reduced by an ISO standard for an internal control assessment model for KYC.	Better auditing
Reduce the aggregate cost of the KYC process and distribute these lower costs proportionally among the financial institutions participating in the system.	Cost reduction
	Cost sharing
A more efficient and transparent KYC verification process.	Efficiency gains
	Increased process transparency
Distributed ledger that serves as an immutable record and clearing system via which to proportionally distribute the costs of the KYC process among the participating institutions.	Immutable record
	Cost sharing
The clearing itself, however, is conducted via the smart contract, which comes along with very low clearing costs for this solution.	Smart contracts
	Reduced clearing costs
The proportionality condition ensures that the costs are shared proportionally.	Proportionate cost sharing
The irrelevance condition ensures that the financial institution that conducts the core KYC verification process does not have an incentive to prefer that another institution conducts the core KYC verification process and vice versa.	Alignment of incentives
The privacy condition ensures that the financial institutions that work in the system cannot know with which other financial institutions the customer is working, unless the customer reveals that information (privacy is required among finan- cial institutions).	Privacy
The no-minting condition ensures that no financial institution can simulate having conducted a core KYC verification process in order to be compensated by other institutions for work that it has not done.	Fraud avoidance
The exchange of these documents occurs outside the distributed ledger to protect the privacy of the customer.	Privacy via off-chain exchange
This will later on protect the privacy of financial institutions and customers.	Privacy
The core KYC process only has to be undertaken once.	Reduced repetition of work

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Table 7 – continued from the previous page.

Value	
Text fragment	Code
Its result can be used by as many financial institutions as required by the customer.	Information sharing
The cost of conducting the core KYC verification for one customer is now the cost m of one single KYC (and not k $\times$ m, as in the current practice).	Customer verification costs reduction
Higher financial stability that would result form the regulator's ability to easily and routinely check the KYC process.	Better monitoring
The whole compensation scheme that enables the cost reduction and cost sharing within the system is only possible thanks to the use of DLT.	Cost reduction
	Cost sharing
Improvements in terms of auditing and tracking.	Better auditing
	Better monitoring
Single point of truth should disagreement occur.	Single point of truth for conflicts
Immutable nature of the record created by DLT-based solutions cannot be matched by other technologies.	Immutable record
The proposed system allow collaboration between financial institutions that do not necessary trust one another.	Trustless inter-organisational collaboration
Allows for anonymous collaboration – such as anonymous compensation and anonymous document sharing.	Anonymous collaboration
An institution can be anonymously and proportionately compensated by others for the efforts conducted to verify a customer.	Anonymous compensation
Allow institutions to communicate with one another without revealing their identities.	Anonymous communication
Ensure that each institution abides by all relevant regulations at all times.	Conformance to regulations
Interbank collaboration.	Inter-organisational collaboration
DLT eliminates high central authority fees.	Reduction in central authority fees
The automation of a process.	Process automation
Increases information available if a dispute should occur.	Information availability for conflicts
Reduces settlement time compared to other technologies.	Reduced settlement times
Reduces business costs.	Cost reduction
Reduce the aggregated cost of KYC.	Aggregate cost reduction
The main efficiency gain that this IS proposes is the avoidance of the same tasks being duplicated by different financial institutions.	Efficiency gains
The avoidance of the same tasks being duplicated by different financial institutions.	Reduced repetition of work
Possible to distribute the costs of the core KYC verification process proportionately.	Cost sharing
Monetary savings.	Cost reduction
Increased efficiency.	Efficiency gains

B Use cases

Table 8 contains the titles, authors, years of publication and abstracts of the blockchain use cases that were studied in this work, sorted in the chronological order in which they were read and analyzed.

Table 8: The abstracts of the analyzed blockchain use cases.

#	Reference	Title & Abstract
1	Parra Moyano and Ross (2017)	**KYC optimization using distributed ledger technology** The know-your-customer (KYC) due diligence process is outdated and generates costs of up to USD 500 million per year per bank. The authors propose a new system, based on distributed ledger technology (DLT), that reduces the costs of the core KYC verification process for financial institutions and improves the customer experience. In the proposed system, the core KYC verification process is only conducted once for each customer, regardless of the number of financial institutions with which that customer intends to work. Thanks to DLT, the result of the core KYC verification can be securely shared by customers with all the financial institutions that they intend to work with. This system allows for efficiency gains, cost reduction, improved customer experience, and increased transparency throughout the process of onboarding a customer.
2	Notheisen, Cholewa, and Shanmugam (2017)	**Trading real-world assets on blockchain: An application of trust-free transaction systems in the market for lemons** Since its introduction in 2008, blockchain technology has outgrown its use in cryptocurrencies and is now preparing to revolutionize a multitude of commercial applications including value and supply chains, business models, and market structures. This work follows design science research to guide the implementation of a blockchain-based proof-of-concept prototype that enables the automated transaction of real-world assets, such as cars, and provides a valid, transparent, and immutable record of vehicle history to market participants, authorities, and other third parties. The contribution of this study to existing research is threefold: First, it introduces a built-in mechanism to reduce transaction risk resulting from the irreversibility of transactions in blockchain-based systems. Second, it replaces a trust-based, centralized, and bureaucratic register with a tamper-free and autonomous transactional database system that comprises a secure registration and transaction process. Third, it proposes a novel approach to mitigate adverse selection effects in lemon markets by providing a reliable, transparent, and complete record of each marketable asset's history. In total, the findings in this article illustrate the potential of blockchain-based systems but also highlight technological shortcomings and challenges for commercial applications, such as scalability or privacy issues.

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Table 8 – continued from the previous page.

#	Reference	Title & Abstract
3	Hyvärinen, Risius, and Friis (2017)	**A blockchain-based approach towards overcoming financial fraud in public sector services** In financial markets it is common for companies and individuals to invest into foreign companies. To avoid the double taxation of investors on dividend payment – both in the country where the profit is generated as well as the country of residence – most governments have entered into bilateral double taxation treaties, whereby investors can claim a tax refund in the country where the profit is generated. Due to easily forgeable documents and insufficient international exchange of information between tax authorities, investors illegitimately apply for these tax returns causing an estimated damage of 1.8 billion USD, for example, in Denmark alone. This paper assesses the potential of a blockchain database to provide a feasible solution for overcoming this problem against the backdrop of recent advances in the public sector and the unique set of blockchain capacities. Towards this end, we develop and evaluate a blockchain-based prototype system aimed at eliminating this type of tax fraud and increasing transparency regarding the flow of dividends. While the prototype is based on the specific context of the Danish tax authority, we discuss how it can be generalized for tracking international and interorganizational transactions.
4	Egelund-Müller, Elsman, Henglein, and Ross (2017)	**Automated execution of financial contracts on blockchains** The paper investigates financial contract management on distributed ledgers and provides a working solution implemented on the Ethereum blockchain. The system is based on a domain-specific language for financial contracts that is capable of expressing complex multi-party derivatives and is conducive to automated execution. The authors propose an architecture for separating contractual terms from contract execution: a contract evaluator encapsulates the syntax and semantics of financial contracts without actively performing contractual actions; such actions are handled by user-definable contract managers that administer strategies for the execution of contracts. Hosting contracts and contract managers on a distributed ledger, side-by-side with digital assets, facilitates automated settlement of commitments without the need for an intermediary. The paper discusses how the proposed technology may change the way financial institutions, regulators, and individuals interact in a financial system based on distributed ledgers.

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#	Reference	Title & Abstract
5	Sikorski, Haughton, and Kraft (2017)	**Blockchain technology in the chemical industry: Machine-to-machine electricity market** The purpose of this paper is to explore applications of blockchain technology related to the 4th Industrial Revolution (Industry 4.0) and to present an example where blockchain is employed to facilitate machine-to-machine (M2M) interactions and establish a M2M electricity market in the context of the chemical industry. The presented scenario includes two electricity producers and one electricity consumer trading with each other over a blockchain. All participants are supplied with realistic data produced by process flow sheet models. This work contributes a proof-of-concept implementation of the scenario. Additionally, this paper describes and discusses the research and application landscape of blockchain technology in relation to the Industry 4.0. It concludes that this technology has significant under-researched potential to support and enhance the efficiency gains of the revolution and identifies areas for future research.
6	Azaria, Ekblaw, Vieira, and Lippman (2016)	**MedRec: Using blockchain for medical data access and permission management** Years of heavy regulation and bureaucratic inefficiency have slowed innovation for electronic medical records (EMRs). We now face a critical need for such innovation, as personalization and data science prompt patients to engage in the details of their healthcare and restore agency over their medical data. In this paper, we propose MedRec: a novel, decentralized record management system to handle EMRs, using blockchain technology. Our system gives patients a comprehensive, immutable log and easy access to their medical information across providers and treatment sites. Leveraging unique blockchain properties, MedRec manages authentication, confidentiality, accountability and data sharing – crucial considerations when handling sensitive information. A modular design integrates with providers? existing, local data storage solutions, facilitating interoperability and making our system convenient and adaptable. We incentivize medical stakeholders (researchers, public health authorities, etc.) to participate in the network as blockchain "miners". This provides them with access to aggregate, anonymized data as mining rewards, in return for sustaining and securing the network via Proof of Work. MedRec thus enables the emergence of data economics, supplying big data to empower researchers while engaging patients and providers in the choice to release metadata. The purpose of this short paper is to expose, prior to field tests, a working prototype through which we analyze and discuss our approach.

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Table 8 – continued from the previous page.

#	Reference	Title & Abstract
7	Yuan and Wang (2016)	**Towards blockchain-based intelligent transportation systems** Blockchain, widely known as one of the disruptive technologies emerged in recent years, is experiencing rapid development and has the full potential of revolutionizing the increasingly centralized intelligent transportation systems (ITS) in applications. Blockchain can be utilized to establish a secured, trusted and decentralized autonomous ITS ecosystem, creating better usage of the legacy ITS infrastructure and resources, especially effective for crowdsourcing technology. This paper conducts a preliminary study of Blockchain-based ITS (B2ITS). We outline an ITS-oriented, seven-layer conceptual model for blockchain, and on this basis address the key research issues in B2ITS. We consider that blockchain is one of the secured and trusted architectures for building the newly developed parallel transportation management systems (PtMS) , and thereby discuss the relationship between B2ITS and PtMS. Finally, we present a case study for blockchain-based realtime ride-sharing services. In our viewpoint, B2ITS represents the future trend of ITS research and practice, and this paper is aimed at stimulating further effort and providing helpful guidance and reference for future research works.
8	Lucena, Binotto, Momo, and Kim (2018)	**A case study for grain quality assurance tracking based on a blockchain business network** One of the key processes in Agriculture is quality measurement throughout the transportation of grains along its complex supply chain. This procedure is suitable for failures, such as delays to final destinations, poor monitoring, and frauds. To address the grain quality measurement challenge through the transportation chain, novel technologies, such as Distributed Ledger and Blockchain, can bring more efficiency and resilience to the process. Particularly, Blockchain is a new type of distributed database in which transactions are securely appended using cryptography and hashed pointers. Those transactions can be generated and ruled by special network-embedded software – known as smart contracts – that may be public to all nodes of the network or may be private to a specific set of peer nodes. This paper analyses the implementation of Blockchain technology targeting grain quality assurance tracking in a real scenario. Preliminary results support a potential demand for a Blockchain-based certification that would lead to an added valuation of around 15% for GM-free soy in the scope of a Grain Exporter Business Network in Brazil.

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Table 8 – continued from the previous page.

#	Reference	Title & Abstract
9	Fridgen, Radszuwill, Urbach, and Utz (2018)	**Cross-organizational workflow management using blockchain technology – Towards applicability, auditability, and automation** Bringing Blockchain technology and business process management together, we follow the Design Science Research approach and design, implement, and evaluate a Blockchain prototype for cross-organizational workflow management together with a German bank. For the use case of a documentary letter of credit we describe the status quo of the process, identify areas of improvement, implement a Blockchain solution, and compare both workflows. The prototype illustrates that the process, as of today paper-based and with high manual effort, can be significantly improved. Our research reveals that a tamper-proof process history for improved auditability, automation of manual process steps and the decentralized nature of the system can be major advantages of a Blockchain solution for cross-organizational workflow management. Further, our research provides insights how Blockchain technology can be used for business process management in general.
10	Weber et al. (2016)	**Untrusted business process monitoring and execution using blockchain** The integration of business processes across organizations is typically beneficial for all involved parties. However, the lack of trust is often a roadblock. Blockchain is an emerging technology for decentralized and transactional data sharing across a network of untrusted participants. It can be used to find agreement about the shared state of collaborating parties without trusting a central authority or any particular participant. Some blockchain networks also provide a computational infrastructure to run autonomous programs called smart contracts. In this paper, we address the fundamental problem of trust in collaborative process execution using blockchain. We develop a technique to integrate blockchain into the choreography of processes in such a way that no central authority is needed, but trust maintained. Our solution comprises the combination of an intricate set of components, which allow monitoring or coordination of business processes. We implemented our solution and demonstrate its feasibility by applying it to three use case processes. Our evaluation includes the creation of more than 500 smart contracts and the execution over 8,000 blockchain transactions.

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11	Ying, Jia, and Du (2018)	**Digital enablement of blockchain: Evidence from HNA group** Blockchain, the distributed ledger underlying bitcoin, has attracted much attention and stimulated rich discussions. However, extant discussions are mostly conceptual expositions, and empirical evidence of how to use the technology is limited. This case analysis fills this gap by conducting a study on Hainan Airlines (HNA) group, a large conglomerate, which has successfully implemented a blockchain-enabled E-commerce platform to offer employees flexible benefits. The case study unveils that blockchain of value in three ways: 1) issuing crypto-currency, 2) protecting sensitive information, and 3) eliminating institutional intermediaries. These findings provide a reference point for IT and general managers who intend to use blockchain to digitally enable their organizations further.
12	Khaqqi, Sikorski, Hadinoto, and Kraft (2018)	**Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application** Emission Trading Scheme (ETS) has dual aims to reduce emission production and stimulate adoption of long-term abatement technology. Whilst it has generally achieved its first aim, its issues are hindering the accomplishment of the second. Several solutions have been proposed to improve ETS?s efficacy, yet none of them have considered the advancement of Industry 4.0. This paper proposes a novel ETS model customised for Industry 4.0 integration. It incorporates blockchain technology to address ETS?s management and fraud issues whilst it utilizes a reputation system in a new approach to improve ETS efficacy. Specific design of how the blockchain technology and reputation system are used to achieve these objectives is showed within this paper. The case study demonstrates the inner working of reputation-based trading system—in which reputation signifies participants performance and commitment toward emission reduction effort. Multi-criteria analysis is used to evaluate the proposed scheme against conventional ETS model. The result shows that the proposed model is a feasible scheme and that the benefits of its implementation will outweigh its drawback.
13	Lycklama à Nijeholt, Oudejans, and Erkin (2017)	**DecReg: A framework for preventing double-financing using blockchain technology** Factoring is an important financial instrument for SMEs to solve liquidity problems, where the invoice is cashed to avoid late buyer payments. Unfortunately, this business model is risky as it relies on human interaction and involved actors (factors in particular) suffer from information asymmetry. One of the risks involved is 'double-financing': the event that an SME extracts funds from multiple factors. To reduce this asymmetry and increase the scalability of this important instrument, we propose a framework, DecReg, based on blockchain technology. We provide the protocols designed for this framework and present performance analysis. This framework will be deployed in practice as of February 2017 in the Netherlands.

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14	Vo, Mehedy, Mohania, and Abebe (2017)	**Blockchain-based data management and analytics for micro-insurance applications** In this paper, we demonstrate a blockchain-based solution for transparently managing and analyzing data in a pay-as-you-go car insurance application. This application allows drivers who rarely use cars to only pay insurance premium for particular trips they would like to travel. One of the key challenges from database perspective is how to ensure all the data pertaining to the actual trip and premium payment made by the users are transparently recorded so that every party in the insurance contract including the driver, the insurance company, and the financial institution is confident that the data are tamper-proof and traceable. Another challenge from information retrieval perspective is how to perform entity matching and pattern matching on customer data as well as their trip and claim history recorded on the blockchain for intelligent fraud detection. Last but not least, the drivers' trip history, once have been collected sufficiently, can be much valuable for the insurance company to do offline analysis and build statistics on past driving behaviour and past vehicle runtime. These statistics enable the insurance company to offer the users with transparent and individualized insurance quotes. Towards this end, we develop a blockchain-based solution for micro-insurance applications that transparently keeps records and executes smart contracts depending on runtime conditions while also connecting with off-chain analytic databases.
15	Tian (2016)	**An agri-food supply chain traceability system for China based on RFID & blockchain technology** For the past few years, food safety has become an outstanding problem in China. Since traditional agri-food logistics pattern can not match the demands of the market anymore, building an agri-food supply chain traceability system is becoming more and more urgent. In this paper, we study the utilization and development situation of RFID (Radio-Frequency IDentification) and blockchain technology first, and then we analyze the advantages and disadvantages of using RFID and blockchain technology in building the agri-food supply chain traceability system; finally, we demonstrate the building process of this system. It can realize the traceability with trusted information in the entire agri-food supply chain, which would effectively guarantee the food safety, by gathering, transferring and sharing the authentic data of agri-food in production, processing, warehousing, distribution and selling links.

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