Edited by
Horst Treiblmaier · Roman Beck

Business Transformation through Blockchain

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Preface Volume I

The blockchain and related technologies have taken many academic communities by surprise. Its technological foundations were developed over various decades but were mainly discussed in communities specialized in computer science and cryptography. Even the 2008 seminal publication from the pseudonymous author Satoshi Nakamoto entitled "Bitcoin: A Peer-to-Peer Electronic Cash System" failed to attract immediate attention within the industry, the general public and in most academic communities. In this nine-page paper with an unassuming title, Nakamoto, whose real identity has yet not been revealed, combined various existing technologies and was able to solve the so-called double-spending problem by clever engineering. The result was the first cryptocurrency, a monetary system that should not have been able to survive, if one believes many economic theorists. Yet, over the years, the general public began to take notice, and Bitcoin was able to bootstrap itself into a currency in which people invested fiat money. In parallel to the soaring exchange rates of Bitcoin, various authors became interested in the underlying technology and its potentials. All of a sudden, the "Internet of Information" turned into the "Internet of Value", and wild speculations started circulating about what can potentially be done with this new technology. This phase is far from over and was not stopped by the dramatic losses which Bitcoin experienced at the end of 2017. Given that the technology is still under development, business models are largely unexplored, and a comprehensive legal framework is missing, academics pursuing research that is relevant for the industry started investigating the blockchain phenomenon and related technologies from various angles and with different goals in mind.

This two-volume book entitled *Business Transformation through Blockchain* contains a selection of articles from researchers who are interested in the implications of the blockchain. The focus is not on technical details but rather on the impact the blockchain can have on different industries. A total of 22 papers are divided into six different sections and one appendix. The respective sections are "Foundations of blockchain", "Finance", "Selected Use Cases", "Sustainability", "Society", and "Legal Issues". The first two sections will be published in Volume 1 and the other four in Volume 2. In the section on blockchain foundations, various articles are published that look at the blockchain and related technologies from a broad perspective and investigate topics such as economic impact and long-term adoption. The section on finance includes four chapters that closely investigate financial aspects of blockchain technology, ranging from finding the optimal investment portfolio to novel applications of crowdfunding.

Melanie Swan, who authored the first chapter, discusses how the adoption of blockchain technology might actually contribute to solving a larger class of economic problems related to systemic risk. *Trevor Clohessy*, *Thomas Acton*, and *Nicholas Rogers* conduct a comprehensive literature review and derive, based on the technology-organization-environment (TOE) framework, important blockchain adoption considerations. *Andranik Tumasjan* and *Theodor Beutel* apply agent-based modeling to explore the circumstances under which a decentralized sharing economy business model might achieve widespread adoption. *Florian Glaser*, *Florian Hawlitschek*, and *Benedikt Notheisen* investigate the blockchain as a platform and present technical layers of the system as well as institutional characteristics and governance implications, followed by a discussion of the role of trust in blockchain systems. Finally, *Ben Van Lier* takes a wider perspective investigating the autonomy and self-organization of cyber-physical systems. The second section on finance is opened by *Karl Weinmayer*, *Stephan Gasser*, and *Alexander Eisl*, who explore the question of whether Bitcoin as an unregulated cryptocurrency can have a positive effect on well-diversified portfolios. *Friedrich Holotiuk*, *Jürgen Moormann*, and *Francesco Pisani* take a close look at blockchain in the payments industry. They present the results from a Delphi study and develop a discussion agenda based on pain points and opportunities. *Laurin Arnold*, *Martin Brennecke*, *Patrick Camus*, *Gilbert Fridgen*, *Tobias Guggenberger*, *Sven Radszuwill*, *Alexander Rieger*, *André Schweizer*, and *Nils Urbach* identify industries and use cases that may benefit from adopting blockchain when it comes to crowdfunding. They show how crowdfunding and initial coin offerings differ and how the latter is reshaping the former. Finally, *Paolo Tasca* investigates how the insurance industry might be impacted by blockchain technology.

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Part I

Foundations

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Blockchain Economic Networks: Economic Network Theory—Systemic Risk and Blockchain Technology

Melanie Swan

This chapter discusses how the widespread adoption of blockchain technology (distributed ledgers) might contribute to solving a larger class of economic problems related to systemic risk, specifically the degree of systemic risk in financial networks (ongoing credit relationships between parties). The chapter introduces economic network theory, drawing from König and Battiston (2009). Then, Part I develops payment network analysis (analyzing immediate cash transfers) in the classical payment network setting (Fedwire (Soramäki et al. 2007)) synthesized with the cryptocurrency environment (Bitcoin (Maesa et al. 2017), Monero (Miller et al. 2017), and Ripple (Moreno-Sanchez et al. 2018)). The key finding is that the replication of network statistical behavior in cryptographic networks indicates the robust (not merely anecdotal) adoption of blockchain systems. Part II addresses balance sheet network analysis (ongoing obligations over time), first from the classical sense of central bank balance sheet network analysis developed by Castrén and Kavonius (2009),

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Castrén and Rancan (2013), Gai and Kapadia (2010), and Chan-Lau (2010), and then proposes how blockchain economic networks might help solve systemic risk problems. The chapter concludes with the potential economic and social benefits of blockchain economic networks, particularly as a new technological affordance is created, algorithmic trust, to support financial systems.

Systemic Risk Is an Unsolved Social and Economic Problem in Financial Networks

Economics is a domain that has long been recognized as a complex system that should be investigated with network science, particularly by Potts (2001), Newman (2003), Barabási and Albert (1999), and Kirman (1997). Economic systems are socially constructed, which means that it can be difficult to understand the connections between individual behavior and overall system change. Traditional microeconomic and macroeconomic approaches have proven insufficient for understanding economic networks (Schweitzer et al. 2009). This is because, on one hand, the microeconomic approach tends to focus on modeling individual agent incentives and actions (such as with game-theoretic Nash equilibria and Schelling points), but is not good at predicting macro events. On the other hand, macroeconomic approaches may be able to identify complex system-wide forces, but have difficulty linking these influences to the micro level of individual agent behavior. Thus, network analysis is a method which attempts to incorporate aspects of both in order to identify patterns and understand behaviors which may drive the overall economic system at both the micro and macro levels.

Systemic risk (the risk of collapse of an entire financial system) and the potential for catastrophic failure appear to be an unfortunate feature of the large-scale systems that enable modern life. These systems include epidemics, climate change, species extinction, power grids, and global financial risk. Financial risk is a particularly challenging problem to address. A 2007 US Fed report surveyed industry leaders in various fields (Kambhu et al. 2007). The study found that comparatively little was being spent on overall systemic risk as compared with risk management for individual firms, even though firms acknowledged the high social and economic expenses of systemic risk events to both the national and global economies. Examples of systemic risk events are disruptions to the financial system such as terrorist attacks (9/11; September 11, 2001), US power blackouts (August 14, 2003), and financial crises (1987, 2008, and the 1998 Russian loan default and subsequent collapse of the hedge fund Long-Term Capital Management).

Despite the recognition of the high social and economic costs of systemic risk in financial networks, it is not clear how to solve the problem. One way the problem has been intractable is the inability to effectively model and predict risk events. This is because data have not been available, and there have not been secure and private ways to share data. Simultaneously, there are claims that risk has increased at both the individual and systemic levels as financial networks have become more complex. Both the nature of contracts between parties and the overall structure of contracts in the economy have become more complex (Battiston et al. 2016). Thus, it is more difficult for regulators and market participants to estimate the probability of individual and systemic default than in previous years. The effect of higher complexity means that the economy is less robust and more vulnerable to potential shocks. For these reasons, estimating systemic risk in financial networks is a significant challenge for financial policymaking. This chapter examines how economic network analysis, particularly in the context of blockchain technology, might be employed to address systemic risk in financial networks and reduce the social and economic costs of its impact.

Economic Network Theory

Networks are ubiquitous in economic and social phenomena, and there is a research precedent for studying them with network science methods (Jackson 2008). A network is defined as a group or system of interconnected people or things. Economic network theory is the application of graph theory methods (using mathematical structures to model pairwise relations between entities and their interactions) to study the relational connections between economic agents in networks. Standard models of economic theory are incomplete because they assume perfect conditions and do not take into account the dynamical and evolutionary aspects of real-world interactions. Instead, economic network theory may provide an improved method for modeling and understanding the behavior of economic agents and the overall economy. König and Battiston (2009) discuss the progression in modeling economic network behavior from standard economic theory to game theory to economic network theory as follows.

Standard Economic Theory

The standard neoclassical model of the economy assumes perfect competition, available information, rational behavior, and price flexibility (Hausman 2003). Ideally, these conditions result in market equilibria with an efficient allocation of goods and services. In such a general equilibrium framework, individual decision-making is represented as maximizing a utility function. A utility function is a way of quantifying options so that higher-preference choices rise to the top. As individuals transact based on these preferences, economic equilibria are found.

However, these laboratory-like conditions do not accurately model real-life situations. In practice, competition and information may be imperfect, behavior may not be economically rational, and price discovery may be difficult. Competition is imperfect since agents or firms only tend to interact with a few others out of all of those present in the economy. Information is costly to obtain, particularly related to price discovery and valuation. Thus, decision-making may not be fully rational from an overall market perspective. In addition, economic systems have a living feedback loop in that individual agents are not merely isolated parties reacting to the situation but may be having an impact on the market through their behavior and by cooperating directly or indirectly with other agents to influence supply and demand, and price and quantity.

Game Theory

Game-theoretic approaches have been added to standard economic theory to overcome some of its limitations. First, game theory provides a means of incorporating the dynamical aspects of the feedback loop created by agent behavior updating per new learning. Second, game theory tries to account for agent behavior in the real-life situation of limited information and imperfect competition. The premise is that since agents have limited information in actual conditions, they will try to anticipate the actions of others and adjust their own behavior accordingly. Game theorists therefore attempt to integrate strategically interacting agents (such as individuals and firms) into the general equilibrium framework of standard economics. Specifically, game theorists apply tools to estimate market crossing points such as Nash equilibria (strategically stable positions in which no agent has an incentive to deviate) and Schelling points (natural set points that agents tend to use in the absence of information and communication, e.g. a round number price of $100). Research advances have enhanced economic network analysis with findings from social network analysis, for example, with Bonacich centrality, which is the degree to which the agent is a key player in the network. The two approaches are integrated in the formulation of Bonacich-Nash linkage, in which the Nash equilibrium action of each agent is proportional to that agent's Bonacich centrality (Ballester et al. 2006).

Game theory is a useful step forward, but does not address the two other shortcomings of standard economic theory which have to do with the scope and domain of agent activity within the network. First, although game theory allows that information may be imperfect, models often assume that an agent can quickly process this information, which may not be the case. Thus, the rationality of agents should be bounded to the domain of information which they can feasibly obtain and process. Second, game theory may assume that every agent can transact with every other agent, which is unrealistic in large systems. The environment within which individual agents can reason and transact should be delineated. The conclusion from the game-theoretic approach is that economic models should specify a realistic scope of information the agent can process and interactions the agent can have in the trade environment.

Economic Network Theory

Economic network theory is a third step in this economic modeling progression which attempts to overcome challenges with classical and game-theoretic approaches and provide a way to model the economy as a whole. Network economics more realistically corresponds to the actual behavior of economies because it tolerates ambiguity, is comprised of loosely coupled relations, and incorporates feedback loops. Agents interact with their *neighbors*, who may be similar firms or value chain partners within the same industry (not necessarily those in geographical proximity), and these firms are linked through customers and suppliers to firms in other industries. Through these connections, changes such as new technological innovations, for example, diffuse throughout the network. The rate and extent of diffusion depends on two factors: the structure and the connectivity of the network. An economy is comprised of a variety of agents (individuals, firms, regulators, governments, investors, and other entities). These agents interact in different ways and learn over time to adapt their interactions, meaning strengthen profitable relationships and eliminate costly interactions. The system co-evolves in that not only is the system architecture evolving but also the agents' learning as a contributing factor to this evolution, thus creating an endogenous feedback loop. Network evolution that is dynamical and based on both the structure and the connectivity of the nodes may be an improved approach over microeconomics or macroeconomics, or classic or game-theoretic analysis alone.

There is evidence in support of network analysis modeling in that standard economic analysis and game theory have not been able to reproduce statistical regularities that have been observed empirically in network structures (Schweitzer et al. 2009). Therefore, complex systems methods may be better for making predictions in large-scale networks. The way that network theory makes predictions is by positing and testing the stochastic rules that affect link formation. Specifically, network modeling assesses the characteristic features of agents and their interactions. Two of the principal measures are connectivity and centrality: the nodes' degree of connectivity (number of links) and centrality (measurement of the importance of the node), which can be impacted dynamically and with some degree of randomness. Another important measure for understanding the structure of link formation is analyzing how agent incentives and network formation rules arise endogenously within the system and not as a function of exogenously applied rules (Albert and Barabási 2002).

In network theory models, agents (individuals, firms) are designated as nodes or vertices and are the key compositional elements of the network. Their interactions are called edges or links, and capture the relational content of the system. The nodes may exist in different states, which can be modeled as probabilistic distributions of state variable values. The overall quantity to be measured in the system is called the performance measure (similar to a dependent variable in a regression analysis), which could be a quantity such as liquidity, default risk, or growth. As mentioned, there are two levels of co-evolution in a network: how the content exchanged in the links evolves over time and how the overall network structure of links evolves over time. A heuristic for this is the notion of form and content. The content is the contents of the relational links between agents, and the form is the overall network structure of links. The two evolve at different rates. The link content is more likely to update and reach a new equilibrium state quickly as conditions change, whereas the network structure (the presence of links) takes longer to evolve as nodes and edges are added to and subtracted from the overall network structure.

Co-evolution and Dynamic Process Coupling

The two levels of network processes (content exchanged in the links and the overall network structure of links) are coupled and co-evolve. The evolution of the link structure is dependent on the agents' experience from using the links available to them (their contacts and network neighbors). Agents learn and adapt their behavior within their content links, which leads to an evolution of the overall network structure as agents form and sever links (König and Battiston 2009, 25). This is how the co-evolutionary coupling occurs between agent link use (content) and the network structure (form). The coupling of the fast and slow dynamical processes in a network system is further indicated in a phenomenon called the "slaving principle" (a synergetic ordering that occurs in systems of one order parameter controlling multiple variables) (Haken 2004, 228, 330). The dependent coupling can be seen in the network modeling of R&D networks. For example, one simulation found that the gross return of an agent was proportional to the agent's knowledge growth rate, which was a function of the knowledge levels of the agent's neighbors (König and Battiston 2009, 57–58). A secondary effect was that knowledge may be transferred not only along the shortest network path but along all paths, so that the number of agents to which a given agent is connected can boost the agent's return. Rather than hampering network processes, dependent coupling may serve as a self-organization principle for the system (Gross and Blasius 2008, 4).

Network Construction and Limitations

Considering limitations, since a model is an abstract representation of an underlying phenomenon, there are issues that arise regarding the correspondence and fit of the model, with resulting adjustments to be made for how accurately a model instantiates the actual situation. Network construction entails the abstract conceptualization, representation, and interpretation of a phenomenon. Brandes underlines the importance of conceptualizing a phenomenon first before trying to represent it, and that "a network model should be viewed explicitly as yielding a network representation [e.g. not a direct representation] of something" (Brandes et al. 2013, p. 3). Network construction is thus a crucial step because there might be different ways to set up the network to measure the quantity in question such as default risk, economic growth, or agent choice in economic networks. A related field, cliometrics, uses network models to focus specifically on the performance measure of intangible social goods created in human political and economic systems. Diebolt has a review of 50 such studies (2012).

Considering the different ways to construct a network, the canonical method is the Kauffman NK model (Kauffman and Levin 1987). In this model, N is the number of components (nodes) in the system, and K is the degree of interaction between the components (edges). Table 1.1 has an example of the NK model applied to a gene network. The system is the genome, the N components (nodes) are genes, their K interactions

Table 1.1 Kauffman NK model of network structure

System	Components (N)	Interactions (K)	States	Performance measure
Genome	Nodes: genes	Edges: relations	Gene mutation (Y/N)	Fitness

(edges) are relations, the states the nodes might be in are having a mutation or not, and the performance measure of the overall system is the fitness of the organism. The focus is on the states that the genes might be in (mutated or not) and how mutation occurs and gives rise to the overall performance measure, fitness.

In economic network analysis, the nodes are often human-based entities. This could be individuals, firms, trading regions, or countries. Economic networks analyzed in trade, ownership, R&D alliances, and credit-debt relationships have typically followed this structure. The method of network construction used is to identify the action-taking parties (nodes) in the network and map their relations to each other in a network structure with one-way arrows. In other approaches, notably computer science (possibly flowing more directly from graph theory), the nodes are literally network nodes. For example, in the network modeling of the Internet, the routers and computers that make up the network are the nodes. For the cryptocurrencies analyzed in this chapter, the software wallets are the nodes. Another network construction method uses events as nodes and activities as edges. There could be a more extensive application of network principles in network construction that does not always feature human decision-making agents as nodes and their interactions as edges. Instead, the network might be architected with goods and their flows, values and their amplitude, and business model changes and their diffusion in efforts to evaluate different performance measures. In an alternative assessment of systemic risk, nodes might be contracts and edges might be exposure risk or credit quality. Table 1.2 illustrates some examples of network construction in different domains.

Specific economic network examples are cited on Lines 1–2 of Table 1.2. In economic networks, the goal is to quantify how much of the performance measure (such as wealth, knowledge, or output) is generated, propagated, or diminished by the agents acting in the system. In the

Table 1.2 Network construction examples

	System	Nodes	Edges	Performance measure	Reference
1.	General economy	Agents	Interactions	Degree/quality of interaction	König and Battiston (2009)
2.	Financial credit industry	Firms	Contractual relations between firms	Change in financial condition (assets, solvency ratio)	König and Battiston (2009)
3.	nanoHUB (online R&D collaboration)	Programmers	Contributions, participations	Citation impact	Brunswicker et al. (2016)
4.	Enterprise software (BioPharma industry)	Operating components: business, infrastructure, software	Relations	Propagation cost, network structure	Lagerstrom et al., Jun (2013)
5.	Brain	Brain regions	Connections: anatomical, functional, and effective	Signal transmission	Rubinov and Sporns (2010)
6.	Human musculoskeletal network	Bones (point masses)	Muscles (springs)	Compensatory injury risk	Murphy et al. (2018)

first example (Line 1), nodes are agents, and the performance measure is the degree or quality of their interaction. This could be the degree of an individual's wealth, a firm's output, or an agent's knowledge in R&D collaborations. The second example (Line 2) models the coupling of a dynamic network in the context of credit relations between firms. In this network, links (edges) are contractually established credit relations between firms. Financial variables (such as total asset value or solvency ratio) of one firm are affected when they change in connected firms. Despite that, relations may be fixed until the expiration of contracts, and network link updating cannot occur. Therefore, while links may be modified on a time scale of months, financial variables may vary on a time scale of days. Therefore, the two network processes happen at different rates. The values of the link contents change quickly (coming to a new equilibrium) as information becomes available (e.g. asset value) and is transferred between agents. However, the network structure takes longer to update as links stay in place due to contractual relations that obligate one firm to another for a period of time even if conditions have changed. The content of the links updates faster than the structure of the links. The two processes are coupled in that the network structure evolution lags, yet slaves, the content updating process.

Part I: Payment Networks

Economic Network Analysis: Fedwire Example

A leading example of economic network analysis in payment networks is the Fedwire study. The Federal Reserve Bank of New York commissioned a study of the network topology of interbank payment flows within the US Fedwire service (Soramäki et al. 2006), later published in *Physica A* (Soramäki et al. 2007). The US Fedwire service is a real-time settlement system (instantaneous and irrevocable) operated by the Federal Reserve System among member banks. In 2016, Fedwire processed 148.1 million transfers for a total value of $766.7 trillion (at an average of $5.1 million per transaction) for 9,289 banks (US Fed 2017). The study uses data from the first quarter of 2004. The average value of daily transfers between commercial banks was $1.3 trillion, and the number of daily payments was 345,000 (Soramäki et al. 2007, 319). The average value per payment was $3 million, with a distribution highly right-skewed for a median payment of $30,000. Both the value and volume of daily payments indicated periodicity around the first and last days of the month and on mid-month settlement days for fixed income securities. Overall, 66 banks and 181 links accounted for 75% of the value of daily transfers, and only 25 of the banks were completely connected (having a direct link between them) (ibid.).

The study (results summarized in Table 1.4) uses a directed graph to instantiate Fedwire activity. The nodes are the commercial banks. The edges are the payments sent (a directed link from one bank to another is present in a day if at least one transaction debits the account of one bank and credits the account of another). The average size of the daily network was 5,086 nodes (banks) (ibid., 321). 710,000 links were found between banks over the sample period, with only 11,000 present on all days. On average the network had 76,614 directed links. In comparison, a complete network of similar size would have 25 million links (if all nodes had one-to-one connections). Thus, the connectivity (the number of links relative to the number of possible links) is low, only 0.3%. The interbank payment network is extremely sparse, since 99.7% of the potential links are not used on a given day. The average reciprocity (two-way links) is 22%, meaning banks having payments going in both directions. However, all large-size links (those with more than 100 payments or more than $100 million of value transfer) were reciprocal. Increased reciprocity on large links could be the result of complementary business activity or the risk management of bilateral exposures.

The average path length (the distance from one node to another) is 2.6. In comparison, the average path length of a similar size classical random network is 3.2. The mean eccentricity (maximum distance to another node) is 4.7, and the diameter (the maximum eccentricity across all nodes) ranges between 6 and 7 depending on the day. The interbank payment network exhibits the small-world phenomenon common to many complex networks, meaning that two nodes might not have a direct connection, but any node can be reached from any other node with only a few steps. This is indicated in that although few nodes connect directly, 41% are within two links of each other, and 95% are within three links of each other. The interbank payment network is comprised of a core of hubs with which smaller banks interact. It is a sparse network with low connectivity that is extremely compact. The compact nature may be relevant to the efficiency and resiliency of the payment system. On one hand, the shorter the distances between banks in the network, the more easily liquidity can be circulated between banks. On the other hand, a payment system in which liquidity can flow rapidly such as Fedwire might also be more vulnerable to disruptions in these flows.

The average degree (the number of connections a node has to other nodes) in the network is 15.2. However, the payment network is a hub system in which most banks have only a few connections, and a small number have thousands of links to other banks. Almost half of the banks have four or fewer outgoing links, and 15% have only one outgoing link. The degree distribution is the probability distribution of the degrees (connections) over the whole network. For degrees greater than 10, the out-degree distribution follows a power law with a coefficient of 2.1 (ibid., 325). The in-degree distribution also has a power law coefficient of 2.1. Researchers find similar evidence of scale-free distributions in the Japanese interbank payment system (BOJ-NET) (Inaoka et al. 2004, 20) and the Austrian interbank market (Boss et al. 2003, 3). The BOJ-NET has a power law tail of 2.3 for degrees greater than 20, and the Austrian interbank market has a coefficient of 3.1 for out-degree distribution and 1.7 for in-degree distribution. A similar analysis was performed for Canada's Large Value Transfer System, which did not compute the power law coefficient but did compare other similar network measures (Embree and Roberts 2009, 10). Authors suggest that a degree distribution following a power law distribution with a coefficient in the range of that of the US and Japan (2.1 and 2.3) might be a norm of economic stability in national interbank payment systems.

The correlation coefficients also indicate that the Fedwire network is highly disassortative. This means that nodes of low degree (having few connections) are more likely to connect with nodes of high degree (having many connections). In the disassortivity analysis, the correlation of out degrees is −0.31 (Soramäki et al. 2007, 326). The property of disassortivity is common in technological and biological networks but not in social networks which tend to exhibit assortative properties (people connecting with others who have similar characteristics) (Newman 2003). The implication for economic networks is that assortative networks may be more robust to node removal than disassortative networks and percolate (loosely diffuse) more easily (ibid.).

Another parameter, the average clustering coefficient of the network (the probability that two nodes which are the neighbors of the same node themselves share a link), calculated using the successors of a node, is 0.53 (Soramäki et al. 2007, 326). This is 90 times greater than the clustering coefficient of a comparable random network. The high clustering coefficient for the network as a whole conceals the fact that the clustering across nodes is highly disperse. There are many low-degree nodes (those having few connections). When omitting nodes with a degree smaller than three, the average clustering coefficient increases even more to 0.62. A high level of clustering is observed in many other real-world networks. In a payment network, the clustering coefficient measures the degree of payment activity between a bank's counterparties. Therefore, disruptions in banks with a high clustering coefficient might have a larger impact on their counterparties, as some of the disturbance may be passed on by the bank's neighbors to each other, in addition to the direct impact from the source of the disruption.

Summarizing, the Fedwire network has both a low average path length (2.6) and low connectivity (0.3%). The low connectivity is characterized by a relatively small number of strong flows (transfers) between nodes, with the vast majority of linkages being weak to zero (few or no flows). On a daily basis, 75% of the payment flows involved fewer than 0.1% of the nodes and only 0.3% of the observed linkages between nodes (which are already extremely sparse). The unevenness in link strength (most links are weak) may stabilize the network. The interbank payment network is disassortative and scale-free. The network has a tightly connected core of banks to which most other banks connect. Large banks are disproportionately connected to small banks and vice versa; the average bank is connected to 15 others, but this does not give an accurate idea of the reality in which most banks have only a few connections while a small number of hub nodes have thousands.

The Fedwire network performance was studied during the disruption of 9/11 (Soramäki et al. 2007, 229–330). There were significant changes to the network topology, but it remained resilient. The number of nodes and links in the network decreased, 10% among the most strongly connected nodes (from 5,325 to 4,795) and 5% overall, thereby reducing network connectivity from 0.30% to 0.26%. The average path length between nodes increased from 2.6 to 2.8. The clustering coefficient decreased from 0.52% to 0.47%.

Economic Network Analysis: Cryptocurrency Examples

Digital cryptocurrencies are an emerging sector that is evolving rapidly. Since cryptocurrencies entails the notion of operating a monetary system on a computing graph, network science is a natural mode of analysis for such digital financial networks. What follows is a discussion of contemporary research applying network analysis to cryptocurrencies. Cryptocurrencies are especially amenable to network analysis since currently (unlike fiat currencies), cryptocurrencies have a database of all transactions since their inception. Although known for their decentralized nature, running on distributed networks and not requiring intermediaries such as banks and governments, ironically, cryptocurrencies are also centralized in that there may be a consolidated transaction record, which is not available in traditional financial systems. Table 1.3 shows the three projects discussed here and their network construction.

Table 1.3 Cryptocurrency network analysis summary

System	Nodes	Edges	Performance measure	Reference
Bitcoin	Bitcoin addresses	Transactions	Node richness (balance and connectivity)	Maesa et al. (2017)
Monero	Spending inputs and outputs	Spend relations	Privacy	Miller et al. (2017)
Ripple	Wallets	IOU credit transfers	Liquidity, privacy	Moreno-Sanchez et al. (2016, 2018)

Bitcoin

Maesa et al. (2017) performed a network analysis of Bitcoin data cumulative through December 2015. Theirs is one of the few peer-reviewed journal publications in this field. There are other network analyses of Bitcoin, mainly presented as conference papers, which have a variety of potential issues as diagnosed by Maesa (ibid., 2–3). In particular, Maesa et al. take into account the fact that any one user may have several addresses. The team uses a weighted directed multigraph in their analysis. In the first instantiation of the network, a transaction graph is created. The nodes are Bitcoin addresses. The edges are transfers between addresses (transactions). Then, in a second phase of analysis, the user graph is derived from the transaction graph by a clustering process. Since each user may control several addresses, Bitcoin addresses are initially grouped in single clusters. Then a new graph is defined from this, the user graph, whose nodes correspond to the users and whose edges correspond to value transfers between users. The performance measure is node richness (measured based on account balance and node connectivity). The out-degree distribution is 2.3, and the in-degree distribution is 2.2 (ibid., 10). The average path length is 4 (ibid., 16). Other metrics are not quantified specifically, but the team claims to have evaluated a full suite of graph properties such as density, clustering coefficient, and centrality and that the results are similar to those reported for other complex networks.

The main finding of the study is that the Bitcoin network is observed to have a rich-get-richer property (a concentration of the performance measure, node value or richness, in active network nodes over time). The clustering coefficient is constant over time and similar to that of social networks. The diameter of the nodes was 2050, more constant and much longer than that of other real-world networks, for example, Facebook, which has a higher number of vertices and a diameter of 41 (ibid., 9). The authors theorized that this might be due to the fact that transactions are used not only for payments but also to merge and split user funds. The team concludes that despite having a high diameter, the network's slow decrease over time of the low average distance, together with a relatively high clustering coefficient, suggests a small-world phenomenon (ibid., 10). The benefit of using network analysis as a method was that it allowed certain topological properties to be observed in the graph which could be translated into emerging economic trends such as the rich-get-richer property. Topological analysis also revealed anomalous behavior such as artificial transactions, possibly from malicious users, and thus might be useful for cybersecurity purposes.

Monero

Research is revealing cryptocurrency transactions to be less private than might have been thought given the domain's pseudonymous wallet addressing system. For example, blockchain analytics firm Chainalysis claims that since information related to 25% of Bitcoin addresses is tied to real-world identities, it can account for approximately 50% of all Bitcoin activity (Friedman 2017). Thus, for truly confidential transactions, there is demand for a higher degree of privacy that more fully protects user identity. One mechanism for confidential transactions is zero-knowledge proofs. Zero-knowledge proofs hide the three data elements that can typically be seen in some blockchains: sender address, recipient address, and transaction amount. Zero-knowledge proofs are a key feature of privacy-enhancing blockchains such as Monero and Zcash, and have been announced as a feature that will be available in Ethereum (Buck 2017). Zero-knowledge proofs are a cryptographic software function which confirms but masks the data elements of sender and recipient address and transaction amount. However, unless actual transactions are mixed with false transactions in simultaneous channels, or using other methods, these "private" transactions may also be deanonymizable. Blockchain services offering service-level agreements (SLAs) could emerge to provide cryptographic proof of claims of privacy and confidential transactions.

A working paper from Miller et al. (2017) applies network-theoretic methods to deanonymize Monero transactions. By mapping the Monero transaction flow onto a directed graph, they find that outputs can be linked back to inputs, which makes the blockchain less private than advertised. The study uses data from the Monero blockchain from its inception to January 31, 2017 (block 1236196). The nodes are transaction inputs and outputs. The edges are spend relations, in which an input may be spent in an output. The performance measure is privacy (transaction deducibility). The Monero blockchain is imported as a graph with two kinds of nodes, Inputs and Outputs, with directed edges linking them. The edge relation (spending) is iteratively mapped from a status of UnknownSpend to a Spend amount as transactions are back-calculated. The output node states can register as Spent, Unspent, or UnknownSpend. The Neo4J Cypher query language is used to describe the patterns in the graph.

The study finds that approximately 62% of Monero transaction inputs can be linked back to their originating outputs (ibid., 7). The vulnerability of Monero transactions to deduction analysis varies with the number of mixins (decoys) chosen. Part of the privacy mechanism is that each transaction input can contain decoy links called "mixins." The idea is to mix in many false transaction inputs and outputs with the bona fide transaction inputs and outputs, such that the real transaction is hidden. In a simple example, each input might have six mixins (seven links in total, including the real one). The decoy outputs are dead ends since there will not be any further spend from the fake transactions directed toward them. However, this kind of privacy has a fixed temporal window because it expires. Although there might be full privacy at the time of the transaction, confidentiality erodes over time. This is because while it is impossible to distinguish between mixin input links and bona fide input links initially, over time it becomes possible to guess which links are mixins since the outputs are not used as inputs in subsequent downstream transactions as are real transaction outputs. The overall findings of the study are that in general, transactions with more mixins are less vulnerable to deducibility, and also transactions using later versions of the Monero software.

Ripple

Ripple Overview

Ripple is a real-time gross settlement system, currency exchange, and remittance network initially released in 2012. It handles both immediate cash payments and credit transactions over time. As of January 2018, it was the fourth largest cryptocurrency, with a market capitalization of $51 billion. Ripple is built on a distributed open-source Internet protocol, consensus ledger, and native cryptocurrency called XRP (ripples). The shared public database (ledger) uses a consensus process with validator nodes (credentialed external parties such as MIT) confirming the payment, exchange, and remittance transactions. Transactions may be denominated in traditional fiat currencies, cryptocurrencies, and user-defined currencies such as frequent flier miles or mobile minutes. Ripple's goal is to enable secure, instantaneous, very low-cost global financial transactions of any size with no charge-backs. Ripple is different from other cryptocurrency projects such as Bitcoin, Ethereum, and Monero in that it targets financial institutions and might possibly be a successor to SWIFT, the current global payment system used among financial institutions.

As of October 2017, over 100 worldwide financial institutions were participating in the Ripple network. Members include 12 of the world's top 50 banks such as Santander, BBVA, and Standard Chartered (Meyer 2016). Ripple has been received favorably by an initiative of the US Fed, the Faster Payments Task Force, which calls for next-generation global payment systems. A McKinsey study reviewing projects for the Fed task force cites the Ripple network's ability to allow financial institutions to operate cross-border payments much faster than the two to four days that is common today while providing end-to-end transaction visibility and settlement confirmation to banks (Ripple 2017a). The capability for banks to perform cross-currency transactions in a matter of seconds for a small fee in a publicly verifiable manner could substantially improve financial institution cost and risk profiles. Doing business internationally often requires financial institutions and corporations to pre-fund local currency accounts around the world to quickly send payments in a given market. Ripple estimates that $5 trillion in capital is unproductively committed this way and might be freed for other business uses by using the Ripple network (Ripple 2017b).

Ripple is distinct as a cryptocurrency both technically and conceptually. Technically, propagation through the credit network is orchestrated by path-based settlement. This means that transactions literally flow through the network in a dynamic debiting-crediting path between available network computer nodes from sender to recipient. This is different from Bitcoin and other similar cryptocurrencies, in which submitted transactions are sent to the memory pool on each mining client machine to be confirmed and packaged into transaction blocks that become part of the permanent ledger. Conceptually, Ripple encompasses both the standard notion of cryptocurrencies as a real-time payment system *and*, more fundamentally, a new class of financial network. Ripple is a credit network in which ongoing trust relationships are maintained between parties on the network with a specific financial value attached to them. Ripple is a mesh network of open IOU credits. The name Ripple refers to *rippling*, the idea that transactions can ripple, or flow automatically, across open nodes in the network to their destination, debiting and crediting intermediary wallet nodes without requiring human intervention. As such, Ripple is a credit graph and stores live credit availability in the edges that connect the network nodes. Credit remains resident in the live credit network, which presupposes trust in its on-demand future availability and redemption.

Ripple Network Structure

The Ripple network structure is comprised of gateways, market makers, and users (Moreno-Sanchez et al. 2018). A *gateway* is a well-known business wallet (such as Standard Chartered Bank) that can authenticate and bootstrap credit links to new wallets who want to join the network. Gateways are the Ripple counterparts of commercial banks and loan agencies in the traditional credit model. Gateway wallets maintain high network connectivity. A newly created Ripple wallet that does not have any trust relationships with other wallets can create a credit link to a gateway and, through this relationship, interact with the rest of the network before forming direct links to other wallets. Gateways may likely enforce a known identity credentialing process for new wallets for regulatory purposes (e.g. KYC-AML compliance) and to mitigate risk. Ripple wallet identities (though possibly known to their initial gateway) are pseudonymous to the overall network. The identification process before a new credit link is created and funded may reduce the number of credit links in the Ripple network and gives rise to a regional geographical structure to the network. This results in a slow-mixing, unclustered, disassortative network. The slow-mixing property is similar to that of other networks where link creation requires establishing trust and possibly physical interaction (Dell Amico and Roudier 2009). A *market maker* is a wallet that conducts currency exchange. It receives a certain currency on one of its credit links and exchanges it for another currency on another link, charging a small fee. Transfers between users and gateways are typically executed without any fee.

There are two kinds of Ripple transactions: direct XRP payments between parties and path-based settlement transactions (Moreno-Sanchez et al. 2016). Path-based settlement transactions transfer any kind of credit (fiat currencies, cryptocurrencies, or user-defined currencies) between two wallets having a valid credit path between them. A valid credit path is a network path through wallets that have preestablished lines of credit extended from one wallet to another. A credit path allows transactions to ripple across the network (e.g. flow through a progression of nodes). Edges are undirected in the sense that a dynamic path can be found through network nodes between sender and receiver at the time of the transaction. In the course of the transaction, the credit value on each edge of the path from one wallet to another is updated directionally. Edges in the direction from the sender to the receiver are increased by the amount of IOU credit being transferred, and reverse edges are decreased by the amount, almost simultaneously as the transaction propagates. Edge weights (i.e. the amount of credit availability) must accommodate the amount of the transaction being transferred. A settlement transaction can be split ("packetized") into multiple paths as long as credit is available. The existence of a valid credit path between a pair of wallets is enough to execute a settlement transaction between them. Thus, settlement transactions are possible between arbitrary pairs of wallets, even if they have not extended direct credit links to each other.

Ripple Network Research Studies

At least three studies provide insight into the Ripple network. Armknecht et al. (2015) present an overview of the Ripple network and examine the Ripple consensus process. The study uses Ripple ledger data for the period January 2013–January 2015. The team argues that at that time, counter to developer claims, the consensus process would not prevent the occurrence of forks (the ability to diverge the software protocol and possibly redirect funds). The specific finding was that the size of the intersection set between the Unique Node Lists of any two validating servers would need to be more than 40% of the maximum set size in order to prevent forks and that this was not always happening in the consensus validation process (ibid., 178). The Ripple consensus process has since been updated, and it is presumed that the study's claim is no longer a concern.

Moreno-Sanchez and colleagues have a number of studies and ongoing research in the field. Results from two studies are discussed here: the first (2016) examines the full transaction ledger (direct payments in XRP and path-based settlement transactions) and the second (2018) focuses specifically on the path-based settlement transactions (about half of total transactions). The 2016 study finds that the transaction network is much less private than thought, as they were able to deanonymize 78.7% of the total transactions considered in the representative sample (85,962 XRP payments and 649,640 settlement transactions) (ibid., 449).

The 2018 study conducts a network analysis of the credit transactions executed through path-based settlement. The Ripple credit network is instantiated as a weighted directed graph of IOU credit links. The nodes are wallets. The edges are credit balances available for path-based settlement. Transaction splitting is not allowed. The network performance measure is liquidity, in the form of credit availability and transfer. The study uses data for the four-and-a-half-year period January 2013–August 2017. There were a total of 181,233 wallets, with 352,420 credit links between them (i.e. far from being completely connected with direct links between each of them) and 29,428,355 total transactions (roughly half XRP direct payments and half credit settlement transactions). To study path-based settlement specifically, data were pruned for XRP transactions, anomalous transactions (spam), and older transactions (wallets not used in 2017). This left 8,461,439 transactions.

Ripple Network Study Results

A path-based settlement graph is constituted using the credit settlement transactions. Directed edges are labeled with a dynamic scalar value (weight) indicating the amount of unconsumed credit that one wallet has extended to another wallet. The default wallet setting for making credit available on an edge is lower-bounded by 0 and upper-bounded by infinity, but a stricter upper bound can be specified. The positive weight on an edge represents the amount that one node owes to another. The number of new credit links in the Ripple network grows linearly with the number of wallets, which means that the network density decreases over time and indicates a sparse graph.

For the credit transactions (not the immediate XRP payment transactions), the study calculates standard network measures for the 2017 network slice such as an average degree of 3.88, clustering of 0.07, assortativity of -0.13, and density of 1.0×10^{-5} (Moreno-Sanchez et al. 2018, 3). The average path length is two, with 95% of transactions completing within three hops and 99% within five hops (ibid., 4). The study employs a new method, network motif elicitation, based on the premise that three-node subgraphs may reveal higher-order connectivity patterns. The most frequently occurring three-node motif is the structure of user-gateway-user (which occurs 67.8% of the time out of all of the possible three-node motifs). This further underlines the central role of gateways in the network and is also in line with the low clustering coefficient and disassortativity properties found in the network.

The study finds a slow mixing time, which is not surprising given the small clustering coefficient. The lower bound on the mixing time is 730 (for an Eigenvalue = 0.10 of the transition matrix of the graph) (ibid., 3). Mixing time is a measure of the time it takes a random walk on the graph to approach the stationary distribution of the graph. The stationary distribution is the distribution that is proportional to nodes' degrees (number of links) from each possible source with a relatively small number of intermediaries. A similarly slow mixing time is also exhibited in social networks, 200–500 (Mohaisen et al. 2010, 4). It was thought that mixing time would be fast in social networks, implying that social graphs are well-connected and that any arbitrary destination would be reachable with a probability driven by the stationary distribution. However, social network mixing time is slow, meaning that any node is not quickly reachable from another node. The social graph is less liquid than thought, possibly due to the expensive process of establishing trust (Dell Amico and Roudier 2009). Mixing time is important, not only as a possible quantitative measure of trust but also as a parameter for network security design, in both social and economic networks.

The study analyzed at-risk situations such as network liquidity, resilience to faulty wallets, and the effect of unexpected balance changes. Two risks were identified. First, the study found that, due to the setting of a software wallet parameter, 11,000 wallets, with a total value of US$13 million (as of August 2017), could potentially be at risk of being redistributed to lower credit quality IOUs (ibid., 6). The issue is that credit rippling through nodes may not be innocuous since lower credit quality IOUs might be substituted in place of higher quality IOUs in the process. If wallet parameters are not specified in a certain way, as transactions ripple through nodes, a higher credit quality IOU might be replaced by a lower credit quality IOU. Wallet nodes are exposed to credit risk in that the credit quality of the IOU could change over time. This risk can be avoided by setting software parameters a certain way, particularly the *no_ripple* and the *defaultRipple* flags. This points out the need for user knowledge and best practices regarding the new domain of digital financial networks. The second risk the study found is that although the overall Ripple network has high liquidity, newly emerging regions might be subject to disruption since transactions flow through local gateways. The study also found that one emerging geographical user base of about 50,000 wallets was prone to disruption by as few as ten highly connected wallets in the region. Again, the issue can be remedied by user awareness and the application of a higher degree of control in wallet software settings.

Discussion and Implications of Fedwire and Cryptocurrency Network Analysis

Discussion of Fedwire and Cryptocurrency Economic Network Analysis

The economic network analysis studies for both the Fedwire and the cryptocurrency examples find similar evidence of complex network behavior. The Fedwire payment network indicates a scale-free degree distribution, a high clustering coefficient, and the small-world phenomenon. Bitcoin similarly exhibits small-world and scale-free network properties. Monero also indicates complex network characteristics. The Ripple credit network is shown to be slow-mixing and disassortative. The network is sparse, and density decreases over time because links expand linearly. There is a low clustering coefficient overall, but the core (10,000 wallets) is highly connected. For Fedwire and Ripple (both interbank transfer networks), the core is highly connected, and the rest of the network is highly disperse. The high clustering coefficient for the Fedwire network and the low clustering coefficient for the Ripple network are not directly comparable measures as the Ripple figure is for the credit network (ongoing relationships) and the Fedwire figure is for the immediate payments network. To the extent available, standard network analysis statistics are presented in Table 1.4 (data for Monero are not available).

Table 1.4 Standard network analysis statistics

	Fedwire	Bitcoin	Ripple[a]
Connectivity	0.3%		
Eccentricity	4.7		
Path length	2.6 (41% (2), 95% (3))	4	2 (95% (3), 99% (5))
Diameter	6–7	2050	
Average degree	15.2		3.88
Degree distribution	2.1 (out and in)	2.3 out, 2.1 in	
Clustering	0.53		0.07
Assortativity	−0.31		−0.13

[a] Ripple statistics are for the credit network transactions only (i.e. not including payment transactions)

It is not a surprise that the Fedwire and cryptocurrency examples echo some of the same kinds of complex network characteristics. They both model the same underlying phenomenon, real-life payment networks, which are economic networks that have highly connected cores and are dissortative, small-world, and scale-free. It is a surprise that cryptographic networks are replicating robust financial processes so quickly. The additional finding in the cryptocurrency domain is that all three cryptocurrencies are less private than was thought.

It is known that complex networks are not usually normally distributed (Gaussian), as are the random networks proposed by Erdos and Rényi (1959). Instead, complex networks are more likely to have a Pareto or power law distribution, in the sense that the number of links originating from a given node exhibits a power law distribution. These kinds of networks are characterized as scale-free networks (Watts and Strogatz 1998). Nodes in a network tend to connect to nodes which have more links, as Barabási and Albert further formulate in the theory of preferential attachments (2002, p. 76). This is logical because networks evolve over time, so incoming nodes may prefer to connect to established nodes. A related power law distribution is Zipf's law which is observed in word-use frequency, income levels, and city size. Complex networks also exhibit small-world behavior, in that although direct neighbors may not be linked, it may only take a few hops to reach any node (Barabási and Albert 1999).

Key Findings of the Review of Economic Network Analysis Studies

The key findings of the review of economic network analysis studies are the confirmation that economic payment and credit networks are starting to transition to the digital realm of blockchain networks. The evidence is that cryptocurrency networks are exhibiting the same characteristics as traditional economic networks, which suggests their robustness. The transaction activity is not merely isolated and anecdotal, it is substantial and fully formed. If activity were not shifting to cryptographic networks in a full-fledged manner, the network statistics would not be similar to those of other economic networks. Thus, traditional economic network statistics may be used as a well-formedness condition for evaluating activity in new economic domains such as cryptographic financial networks. Not only is the digitization of money, payments, and credit underway, it is robust and well-formed, at least insofar as cryptocurrency networks exhibit the same standard characteristics observed in other economic networks. One question is how network measures might change as the blockchain industry continues to develop. The hypothesis is that network statistics over time will start to suggest that blockchain economic networks are more than just a replication of existing real-world economic networks, affording new conveyances as well, which can be observed in network analysis.

The first potential change that may be made as blockchain networks scale is more efficient consensus methods, particularly those using proof-of-stake as opposed to proof-of-work mechanisms. Bitcoin, as the first demonstration example of a cryptocurrency, provides strong cryptographic network security (Nakamoto 2008). The Bitcoin blockchain has not been tampered with, only the front-end methods used to access the blockchain such as wallet software and exchange companies. However, the consensus mechanism, proof of work, is computationally expensive and consumes a significant amount of electricity. The design goal of next-generation blockchain protocols is to have distributed consensus mechanisms that are still cryptographically robust in terms of network security but less expensive in resource consumption.

The second potential change in blockchain networks is the nature of the link structure. Two new forms of links could be confidential transactions and payment channels. The distinguishing finding in the cryptocurrency network analysis is less privacy than might have been thought given the pseudonymous nature of the networks. Teams have back-calculated or identified 50% of Bitcoin transactions, 78.7% of Ripple transactions, and 62% of transaction inputs in Monero transactions. Blockchains could become more privacy-rich over time. One implication is that network analysis will become even more crucial as a tool for understanding digital economic networks since activity may be observable only at the aggregate level. The other form of new link structure could be payer-payee interaction through a payment channel, a pre-escrowed deposit against which resources are consumed (Swan 2017). From a network perspective, parties do not need to know and trust each other in real life, and thus the network could become less connected at the core, less dissortative, with a faster mixing time and a faster co-evolution as an indication of quantified trust.

The third potential change is a series of potential shifts in the architecture of transaction execution, to streamline and segment blockchain networks. The overall effect could be a further instantiation of algorithmic trust (built into network operations) as opposed to physical-world trust mechanisms for identifying the parties executing transactions. For example, the notion of a blockchain (blocks of transactions cryptographically hashed together in a sequential order) is being superseded by some projects calling for "blockless blocks," in the sense that a distributed ledger may be cryptographically maintained with hashes that call each other without having to have a block structure. A related method is directed acyclic graphs (DAGs) which do not have sequential blocks of transactions. An example of DAGs is the IOTA project, which uses the architecture of a tangle of transactions. Internet-of-things entities (machine-to-machine transactions) using this network do not need the very high security of financial transactions on the Bitcoin network and have a much smaller peer-based proof-of-work consensus mechanism that consumes much less electricity than the Bitcoin mining operation. Instead of transactions paying a transaction fee, the network is free and runs via peer-to-peer services. Any node submitting a new transaction for confirmation is asked to conduct a small proof of work to confirm two other random transactions on the network. Another proposed structural mechanism that takes advantage of network properties is path-based settlement, which may provide a more efficient method of transfer with greater privacy (Roos et al. 2017).

Part II: Balance Sheet Networks

Economic Network Analysis of Balance Sheets

Economic networks are comprised of both immediate cash transactions (payments) and contractual obligations (debt and credit relationships) that unfold over time. The two functions are differentiated

Table 1.5 Immediate payment transactions vs. ongoing credit obligations

Time frame	Immediate transactions Time t = 0	Ongoing contractual arrangements Time t > 0
Transaction type	Payments	Contracts
Transaction timing	Immediate cash transfer	Future obligations (credit/debt)
Financial market analog	Spot market	Future and options market
Crypto transaction type	Bitcoin transactions	Ethereum smart contracts
Relevant financial data	Fedwire	Balance sheets
Crypto network type	Cryptocurrency payment networks	Ripple IOU credit network

in Table 1.5. Payment is the more immediate, tangible, and measurable activity and was the target of the economic network analyses discussed in Part I. Another form of economic network analysis, balance sheet networks, attempts to model the ongoing credit relationships and mutual financial obligations that link companies in future time periods and contribute more substantially to systemic risk. Network analysis is needed to understand microeconomic and macroeconomic factors together since it is difficult for policymakers to assess the systemic impact associated with the failure of an individual financial institution and the influence of an aggregate shock to the system as a whole on individual firms.

Balance Sheet Networks and Contagion

A key objective of balance sheet network analysis is understanding contagion. Contagion is the degree to which asset value declines are contagious, how one asset decreasing in value is likely to impact the value of others and the market overall. There is higher contagion in dense highly connected interdependent financial networks (Jackson 2008), such as those that comprise a modern economy. Some of the other goals of balance sheet network analysis include quantifying the effects of valuation methods, credit policies, and hedging activities between financial institutions. Balance sheet networks might also be helpful in studying the effects of credit crises, asset bubbles, derivatives, and high-frequency trading.

Data availability is a key challenge in balance sheet network modeling. The required data are not as readily or publicly available as for payment networks. Regulators would be presumed to have better access to data, as far as the information that firms are willing to disclose to meet compliance requirements. Ripple therefore constitutes an important step forward in the endeavor to calculate systemic risk by providing visibility into ongoing credit relationships in the interbank system, which is information that has not typically been publicly available.

Another challenge with balance sheet networks is evaluating the intricacy of the relationships. One firm's assets are another's liabilities, but risk measures do not cancel to zero. An open question is the right amount of interdependence in an economic network to provide stability and resiliency. On one hand, a bank's ability to make contracts with other banks in the system increases its ability to diversify risk. On the other hand, the resulting complexity of contractual arrangements can mean less transparency and higher risk. A more complex economy makes it more difficult for firms and regulators to evaluate the probability of individual and systemic default. Thus, greater complexity may mean that the economy is less robust and more vulnerable (Battiston et al. 2016).

There is a financial contagion literature (many papers published in the wake of the 2008 financial crisis, particularly as curated by Chaturvedi (2017)). These papers propose different methods of using network models for modeling financial contagion. The straightforward way to construct balance sheet networks is to model interbank counterparty relationships as a directed random graph, with the performance measure as the propagation of financial contagion (Hurd 2015). Global regulators have explored this method in a variety of publications. In an IMF Working Paper, Chan-Lau (2010) proposes a balance sheet network model as a directed graph to measure the interrelation of assets and liabilities and how they impact bank capital in cases of economic shock. The graph is constructed so that randomness can be added to either the number of banks (nodes) in the system or the links between them.

Representatives from the Bank of England developed a framework for modeling contagion risk in financial networks in which the actual linkages are unknown, such as in the case of off-balance sheet obligations (e.g. collateralized debt obligations (CDOs)) (Gai and Kapadia 2010, 22–3). A directed network analysis is performed in which the nodes are banks and the links are interbank exposures. The network is highly connected, and the most significant network metric (similar to the Fedwire study) is the degree distribution of incoming and outgoing links, which correspond to assets and liabilities. The overall finding is that while greater connectivity may reduce the probability of contagion, it might also be more severe when it occurs (ibid.). Other factors could amplify contagion in a highly connected interdependent network such as strong aggregate shocks, liquidity risk, and not being bound by counterparty risk (ibid., 20). The study also advised that the past is not the future, as shocks are heterogeneous. Even if a financial system has withstood crises in the past, it may not be similarly resilient in the future.

The European Central Bank (ECB) has ongoing publications applying network theory to financial contagion. In an ECB Working Paper, Aldasoro and Alves (2016) model the web of balance sheet exposures of large European banks with a similarity and core-periphery network analysis method. Banks are connected through an arbitrary number of layers of instrument type and maturity. The network indicates positive correlation in multiple separate connections between parties and a high similarity between layers. The systemic risk contribution of each bank is calculated, which could serve as a policy tool for banking regulators and supervisors. Earlier theoretical analysis by Castrén and Kavonius (2009) and Castrén and Rancan (2013) uses a network model to likewise study the web of balance sheet exposures. They point out that the typical snapshot analysis of balance sheet exposures does not provide a full picture of risk, which should also include the accumulation of risk exposures and the ability to transfer them. They demonstrate this by examining shock propagation across the economy as experienced by four constituencies: financial institutions, nonfinancial firms, governments, and households. The team argues that an important factor in contagion is the degree of accumulated preexisting risk exposures, which can be easily triggered by sudden bursts of volatility in asset values. To include accumulated risk in balance sheet network analysis, the team calls for the construction of stochastic risk-based balance sheets in accordance with standard accounting principles.

Overall, the status of balance sheet network analysis appears to be that publications have primarily focused on proposing models for how balance sheet network analysis should be undertaken. There is a lack of studies published with actual data, possibly because the underlying data and network analysis efforts are private. However, without empirical evidence, the network characterizations for balance sheet networks are unknown. For example, like payment networks, do balance sheet networks exhibit dense highly connected cores and scale-free, small-world, and disassortativity properties? Without results data, it is difficult to gauge activity and progress in this domain. However, blockchain technology may be changing all of this.

Blockchain Economic Networks

This section describes blockchain economic networks, how their implementation might unfold, and how they may address the systemic risk problem left unresolved by balance sheet networks. To clarify terminology, blockchain economic networks and cryptographic economic networks are used interchangeably and mean all varieties of distributed ledgers that include cryptocurrency payment networks and ongoing credit relation balance sheet networks.

Step 1: Digitization of Assets

One implication of blockchain technology is that financial assets and liabilities may be digitized. The new mode of business practice may involve registering assets to blockchains for administration, ownership confirmation, transfer (buying and selling), audit tracking, and compliance. Blockchain land title registry projects are underway (De 2017, 2018; Young 2017), and corporate assets and liabilities, financial and otherwise, might be similarly registered in blockchain inventories.

Digitized assets could mean the ability to have a consolidated view of assets at various permissioned levels of detail. This could be at the department level or firm level internally within organizations, at the industry-wide level for regulators, and at the economy-wide level for central bankers, systemic risk managers, and policymakers. Digitized asset ledgers might be used to calculate global financial risk by keeping a real-time tally of aggregate exposures, with the goal of averting crisis, and at minimum detecting early warning signals.

Having an asset registered to a blockchain means that the private key that controls the asset must be used for any transaction involving the asset. Any attempted transactions without the private key would be invalid. Therefore, there is more scrutiny in the audit trail, and it is less likely for the asset to be pledged in gray-area activities such as undisclosed off-balance sheet obligations. Further, in corporate environments, multiple signatures (multisig functionality) are usually required for asset transactions above certain thresholds, which brings more inspection and audit tracking to the domain of asset management. These requirements suggest that blockchains may make it more difficult to hide and perhaps practically impossible to have off-balance sheet transactions such as collateralized debt obligations (CDOs). There is no "off-balance sheet" since all assets are registered to blockchains. Even if executives colluded, it would be impossible to hide off-balance sheet encumbrances from regulators because the assets and their contractual arrangements would be visible in a financial systems audit (to regulators, not to competitors or the public). Counterparties would not agree to non-blockchain registered transactions because they would lack enforcement. Any encumbrance or other contractual arrangement involving an asset would have to be registered to a blockchain; otherwise the arrangement could not be enforced.

Step 2: Real-Time Asset Valuation and Payment Channels

One consequence of digitized and blockchain-registered assets is that they might be valued with greater ease and even automatically. Currently, balance sheets are a snapshot of values at a past moment in time and do not reflect present market value. The digital instantiation of assets means that smart contracts or other tools could constantly or periodically value these assets in real time. It has long been possible to see continuous market values for assets such as securities and now cryptocurrencies. However, for corporate balance sheets, there has not been a means of real-time asset valuation. With digitized assets, it would be straightforward to obtain immediate values for liquid assets. Illiquid assets could be valued in different ways, applying GAAP-based (Generally Accepted Accounting Principles) methods to business inventory price data drawn from Amazon, enterprise eMarketplaces, and procurement networks. Smart contracts could consult websites such as LoopNet for commercial real estate prices. Again, blockchain economic networks would be constructed in many layers of private views for the different parties involved. The point is that corporate asset and liability values might be mobilized into having real-time valuations, which could have a direct benefit to firms and serve as an important input for balance sheet network modeling. The kinds of balance sheet network models proposed by regulators in the previous section could be instantiated with blockchain balance sheet networks. The financial claims that firms have on one another might be more readily elicited, valued, and assessed on an aggregate basis for improved systemic risk management.

Another consequence of digital assets is the possibility of new forms of financial interaction that make better use of business capital such as payment channels. Since assets are digitized, this means that they may be contractually obligated in ways that provide more assurance and trust to both owner and counterparty. Capital is tied up unproductively in the friction of conducting business, particularly international business. Ripple cites firms having \$5 trillion in local cash balances in their countries of operation. \$3.9 trillion of working capital is obligated in global supply chains (PWC 2015). There is an estimated \$1.5 trillion global trade finance gap (i.e. trade finance transactions rejected by banks but needed for global distribution) (The Economist 2017). Business requirements that have traditionally restricted the use of capital might be eased by blockchain technology's ability to transfer payments immediately and instantiate ongoing credit relationships across borders. Further, blockchains enable a lower cost of detailed control which allows new forms of remuneration structures such as payment channels. Digitized assets mean that it is easy to have "an account relationship" with business partners instantaneously because assets can be trustfully pledged on digital networks without having to know the other party (and verify them in an internal vendor/partner qualification process). Payment channels are the idea of contractually obligating an asset (a prepaid escrow of capital or another asset obligation), tracking consumption of a resource against the escrow and then settling on a net basis in one transaction at the end of the period (Swan 2017).

Step 3: Business Networks, Shared Business Processes, and Shared Ledgers Across Value Chains

One consequence of digitizing operations is that value chains may start to migrate toward single shared business processes for the conduct of operations. Shared business processes in business networks with privacy-specific views are the explicit objective of enterprise blockchain implementations. For example, any party in a certain manufacturer's automotive supply chain might look up an item number in the blockchain-based ID system using the same network-based process. In the implementation of blockchain technologies, business practices might be redesigned and streamlined into shared processes in business networks. The implication of shared business processes is that there could also be shared ledgers which incorporate the economic side of business processes. In the farther future, instead of each firm maintaining its own books, it might have journal entry posting privileges for its activities and a view of its overall activity in the shared ledger that keeps the books for all activity in the value chain. Firms might continue to run their own books until they fully validate and trust the industry shared ledger. The concept is "Ripple for ERP," a single shared set of business processes, accounting books, and legal processes in a value chain (Swan 2018a). Blockchain implementations are underway in the financial sector for shared business processes and ledgers for security settlement and clearing, syndicated loan placement, and interbank transfers (Short 2017; Higgins 2017; Chinsky 2017). Blockchains are providing a means of improving the efficiency of existing operations and also producing even more disruptive change that may force industries to reinvent themselves in new ways. One example of blockchain technology enabling a new business paradigm is that of decentralized stock exchanges, as announced by tZERO (Dale 2017).

Blockchain Economic Network Analysis: Quantified Trust

A blockchain economic network analysis would seek to demonstrate a variety of performance measures. The broader research claim is that not only does blockchain technology modernize banking, finance, and legal operations (and eventually governance) by digitizing them, it also produces social goods such as surety (i.e. lower risk), value creation, and trust. These claims could be tested and quantified. Specifically, the claims are that there are (1) diminished risk and uncertainty due to asset transfer being instantaneous and cryptographically validated, (2) improved value creation since contribution and reward can be more closely linked, and (3) the production of algorithmically derived trust from not having to know or trust counterparties, only the software, including from technical features such as hashing and zero-knowledge proofs (Swan 2018b). These features provide a means of validating information without revealing their contents. Trust is built by the ability to ascertain that assets have been transferred and that other parties have fulfilled their commitments without disclosing the details of the commitments.

Economic network analysis could be employed to quantify the value of the trust creation. A research study could investigate how credit availability decisions are made on the Ripple network. The premise is that the real-money amounts of open credit maintained on the network are a quantitative measure of trust since the credit-extending party assumes that the IOU can be exercised and settled at any future moment. A research question could ask how Ripple wallet owners decide how much credit to make available on their network nodes. Since there are no transaction fees, decision-making may be indirect and game theoretic. Overall, a blockchain economic network theory would seek to demonstrate a beneficial impact, both economically and socially, to blockchain economic networks.

Conclusion

Key Findings

This chapter investigates systemic risk as an unsolved problem in financial networks that has high social and economic costs. Economic network theory is an approach that overcomes issues in both standard economic analysis (by incorporating system dynamics and imperfect equilibria) and some forms of game-theoretic analysis (by bounding the scope of realistic agent behavior). Economic network theory is a method that integrates both microeconomic and macroeconomic approaches in economic modeling to identify patterns and behaviors that drive the overall system at both the individual and aggregate levels. Economic network levels co-evolve at different but interconnected rates as the relational content transmitted between links updates more quickly than the overall structure of links in the network. There are diverse ways to construct an economic network, by identifying the core compositional features (nodes) and their interactions (edges), which interrelate to create, distribute, or diminish the network performance measure in question (such as growth, utility, wealth, knowledge, or output).

An examination of network analysis studies of payment networks (Fedwire, and Bitcoin, Monero, and Ripple in the cryptocurrency domain) finds that the banking and the cryptographic networks display similar characteristics: highly connected cores, disassortativity, scale-free, and small-world network properties. Since the two kinds of networks, banking and cryptographic networks, display the same network statistics profiles, a confirmatory conclusion can be drawn, confirmation that blockchain technology is being adopted robustly in payment networks. Payment networks are concerned with immediate cash transfers; however, balance sheet networks capture the ongoing credit obligations between firms and have a greater impact on financial crises and systemic risk. The problem is that it has been much easier to conduct payment network analysis than balance sheet network analysis due to data availability. Now though, blockchain technology might change this as organizational assets and liabilities could start to become blockchain-registered and digitally transferred.

Future Implications

Blockchain economic networks might greatly improve the ability to manage systemic risk. Digitized credit relationships might be more easily consolidated into interbank risk models by regulators and policymakers. Off-balance sheet obligations could gradually disappear for two reasons. First, it would be practically impossible to have an asset encumbrance or contractual relation that is unknown to the distributed ledger system, because all financial and legal operations of the asset are conducted with the digital ledger. Second, over time, if there is more trust and transparency (in the sense of knowing that other parties are complying, not the specifics of their activity) in the financial system due to cryptographically pledged assets and their immediate transfer, then the need for having off-balance sheet obligations disappears. The financial system could start to have mechanisms to address the risks that prompt off-balance sheet arrangements, and is safer and more transparent as a result.

A further consequence of digital assets and liabilities being blockchain-registered for administration, ownership confirmation, transfer (buying and selling), audit tracking, and compliance is the possibility of real-time balance sheet networks. Not only liquid assets but all assets and liabilities might be valued more regularly and even in real-time by smart contracts querying online procurement marketplaces and instantiating standard accounting principles. Real-time balance sheet views could be extremely useful to enterprise and regulators alike. Industry-wide enterprise blockchain implementations could result in streamlined business processes running on private blockchain-based business networks. There could be a single shared set of business processes, accounting books, and legal processes in a value chain, with participating entities having private views of their activity. The farther future of blockchain business networks (e.g. in the financial services, manufacturing, supply chain, healthcare, and energy sectors) might be instantiation in an enterprise blockchain environment with shared business processes, shared ledgers, and multi-jurisdictional legal and regulatory compliance all embedded in the algorithmic logic of the blockchain economic network infrastructure.

Overall, blockchain economic networks might have a beneficial impact, both economically and socially. The broader possibility is that blockchain technology not only modernizes banking, finance, and legal operations (and eventually governance) by digitizing them, it also produces social goods. Thus, a more modern and efficient world is being created, and also a better world that is more humane through the generation of intangible social goods such as surety, access, equity, choice, and trust, which are available to more persons globally.

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2

Blockchain Adoption: Technological, Organisational and Environmental Considerations

Trevor Clohessy, Thomas Acton, and Nichola Rogers

Introduction

“Change is inevitable … progress is optional.” *John C. Maxwell*

In the past decade, distributed ledger technologies (DLT) have revolutionised approaches to decentralised decision-making. Instead of keeping data centralised in a traditional ledger, DLT encompasses the use of independent computers, often referred to as ‘nodes’, to record, synchronise and share individual transactions in their respective electronic ledgers. Blockchain is one example of a DLT. Transactions can include the exchange of data (e.g., personal identification records) and assets (e.g.,

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tokens, digital currency). Blockchain is a digital ledger which allows for the brokering of trust on a decentralised peer-to-peer network. Blockchain first came to prominence in 2008 as the technology which underpinned the Bitcoin cryptocurrency (Nakamoto 2008). Blockchain, however, is a far more versatile technology! It is anticipated to disrupt a multitude of industries (e.g., health, food, financial, government, tourism) in the next decade (Ito et al. 2017; Önder and Treiblmaier 2018). Blockchain provides adopters with advantages such as anonymity (Zyskind et al. 2015), immutability (Pilkington 2015), transparency (Kosba et al. 2016), security (Mendling et al. 2017) and fast transactions (Kiayias and Panagiotakos 2016). In 2018 the global blockchain technology market is predicted to reach 548 million US dollars in size and is forecast to grow to 2.3 billion US dollars by 2021 (Mehta and Striapunia 2017). Although the global blockchain adoption rate is increasing gradually, as reported by IT analysts such as McKinsey (2017) and Accenture (Treat et al. 2017) and multinational technology company IBM (Bear et al. 2016), the adoption rates in developed countries appear to be rather low. Motivated by blockchain's potential to transform sociotechnical systems, the lack of systematic inquiry pertaining to blockchain adoption, we propose the following research question:

> *What significant technological, organisational and environmental considerations influence blockchain adoption in organisations?*

To investigate this research question, we operationalised innovation theory, which has been extensively used to examine information technology (IT) innovation adoption in organisations (Rogers 1995; Yu and Hang 2010; Van de Weerd 2016; Treiblmaier et al. 2006). Consequently, we conducted a comprehensive review of the blockchain literature using the technology, organisational and environmental (TOE) framework (Tornatzky and Fleischer 1990) to identify significant considerations which influence blockchain adoption in organisations.

This chapter is structured as follows. The next section provides an overview of the blockchain concept and outlines the benefits associated with the technology. Next, we introduce our research approach. Then, the findings from our study are delineated. Finally, we discuss our findings and the study's implications and limitations and present our conclusions.

The Blockchain Concept

This section will first provide an overview of the blockchain concept. Next, we discuss the benefits that can be derived from adopting blockchain technologies. Then, we provide an overview of the TOE framework which we used as a lens to investigate our research question.

The New Technology Kid on the Block

In the past, commerce on the Internet has relied solely on trusted third parties, such as financial institutions, to process any electronic payments. However, in 2008 the introduction of Bitcoin led to a paradigm shift in how transactions are processed worldwide (Nakamoto 2008). Although often going hand in hand, many believe that the success of Bitcoin is not in the service it offers but in the underpinning technology: blockchain (Ross 2017). As can be seen in Fig. 2.1, the term 'blockchain' peaked in December 2017 (Google 2018). This peak coincided with the increasing price appreciation for the Bitcoin cryptocurrency whose price index reached an all-time high of $19,783.21 on *Dec*ember 17, 2017. Blockchain is defined as an open-source dataset, distributed across millions of computers, utilising avant-garde cryptography (Tapscott et al. 2016). Ultimately, blockchain is a secure, decentralised, public ledger, in which every person can view the transaction history in totality, removing the need for a trusted third party (Pilkington 2015).

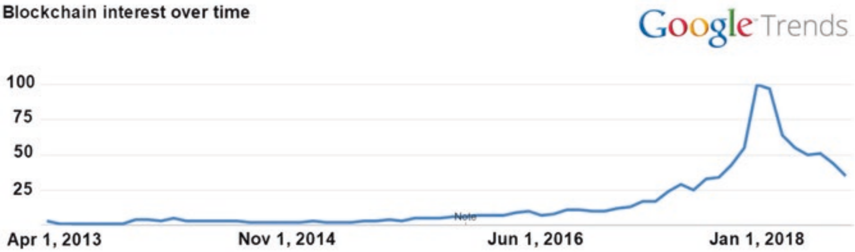

Fig. 2.1 Google trends result for the search term 'blockchain' (Google 2018)

Using Bitcoin as an example, we will now provide an overview of how blockchain technology works. Each block in the chain is an acknowledgement by network participants that the transaction took place and was not fraudulent. Each block contains information from the previous block, thus ordering chronologically, creating a chain of blocks (Nakamoto 2008). To add a block to the chain, it is necessary to solve a cryptographic puzzle, with the solution being included in the block (Wright and De Filippi 2015). It takes approximately ten minutes for the entire network of miners to solve this cryptographic puzzle (Ito et al. 2017). The new transactions must be verified by most users before being added to the ledger. This operation results in approximately a one-hour processing period, which is still a significantly shorter period than that of current financial institutions.

However, solving this puzzle takes specially created computers and consumes vast amounts of energy; hence this task is usually completed by miners. Miners are participants in the blockchain network that solve cryptographic puzzles in the hope of being the first to do so. If the miner is successful in solving the puzzle, they will be awarded 25 Bitcoins. This value halves periodically, as a maximum number of Bitcoins of 21 million has been assigned to control inflation (Nakamoto 2008; Vlasov 2017). Eventually, miners will not be awarded any coins for their work. This design could potentially result in network users refusing to mine cryptographic puzzles, as the cost of doing so is too high. To overcome such an issue, it is possible for the payer to assign a reward to the puzzle themselves, to encourage miners to work on this puzzle promptly. This is usually 1 micropayment, called a Satoshi, or 0.00000001 Bitcoin (Ron and Shamir 2012). In the future, when the maximum limit of 21 million Bitcoins is reached, the rewards of such Satoshis will be the only incentive for miners (Nakamoto 2008).

Proof of work is a key component of this system. As the decision of adding a block to the chain is a majority vote, it was important to decide what type of vote users would have. Instead of one-IP-one-vote systems, blockchain votes are determined by the pool operator and application-specific integrated circuits (abbreviated as ASICS) in large mining pools. This proof-of-work method ensures that the majority vote will always lie with the longest chain, as it has the majority of the computing power invested in it (Nakamoto 2008). Suggestions have been made in the past about substituting proof-of-work for a proof-of-stake method, which splits the blocks proportionally to miners' wealth. It is suggested that this new method would increase the speed of blockchains, as well as reduce the chance of 51% attacks. At the same time though, this new method has not been incorporated into blockchain technology, which has remained unedited since its outset (Pilkington 2015; King and Nadal 2012).

Blockchain Benefits

Blockchain is anticipated to be a core foundational technology spanning multiple industries in the next ten years (Ito et al. 2017). This success of blockchain technology is down to its inherent characteristics and the benefits it provides to its users which include:

Anonymity

Anonymity is a key feature of this infrastructure which attracts individuals and organisations alike to implement it (Zyskind et al. 2015; Reid and Harrigan 2012). Blockchains allow users to only be identified by public keys, an essential element of the cryptosystem. It is encouraged that users generate as many public keys as necessary, with some users creating a new key for each transaction (Nakamoto 2008; Reid and Harrigan 2012). This feature allows any person or organisation to transact any sum of money to any place in the world, with no government intervention and extremely low transaction costs. This has seemed to attract many multinationals to the technology, with blockchain firms receiving $1 billion in investment from global companies such as American Express, Deloitte, Goldman Sachs and the New York Stock Exchange (Crosby et al. 2016).

Immutability

Immutability is a fundamental characteristic of blockchain and has been identified repeatedly as one of the reasons of its success thus far (Pilkington 2015; Tapscott et al. 2016; Iansiti and Lakhani 2017). By virtue of its design, changing one block in the chain would involve changing each subsequent block, as each block contains information of the previous

(Nakamoto 2008). This is infeasible to the linear rate at which the chain expands, with new blocks being issued approximately every ten minutes (Böhme et al. 2015). Although this is seen widely as a strength, it could also be considered a disadvantage as it also means that it would be impossible to edit an entry to the chain, for example, to carry out a remedy or refund (Surujnath 2017). However, the majority believe this is a leading attribute of the system, redefining trust, not in people but in the mathematics behind the technology (Underwood 2016; Nofer et al. 2017).

Transparency

Blockchains can be categorised as being private or public. The sole distinction between a private and a public blockchain is that in a private blockchain context, also referred to as a permissioned blockchain, access to the network is restricted (e.g., an access-restricted platform controlled by a commercial entity, a private equity tracking tool for private equity agreements etc.). Conversely, public blockchains are a completely transparent distributed ledger, with all the users in the network being able to view all transactions that have occurred (Nakamoto 2008; Underwood 2016; Kosba et al. 2016). The allowance for all users to view previous transactions is largely linked to the immutability factor, thus protecting the chain from alterations and tampering (Iansiti and Lakhani 2017). Although it is argued that the lack of privacy could be considered an issue for some users, the transparent nature of the system has been more widely commended than not (Kosba et al. 2016). With multinationals like Deloitte, JP Morgan and Chase and Goldman Sachs investing in blockchain, it may soon become apparent if the transparency of their financial activities is less advantageous as initially thought (Garrod 2016). Blockchain technology has been proven to show characteristics of a disruptive technology, with many applications of the infrastructure being suggested. There has been considerable debate in the technology field as to whether blockchain technology can survive as its own entity, with many experts believing that it will not survive without a monetary value (Pilkington 2015). However, with many potential uses of such a concept, it is unlikely that it will only be utilised in the financial industry. The following are examples of potential blockchain use cases.

Blockchain Use Cases

Smart Contracts

The discussion of smart contracts was in existence long before the advent of blockchain, being first introduced in 1994 by Nick Szabo; however, it is one of the most deliberated uses of the technology to date (Surujnath 2017; Nofer et al. 2017; Kosba et al. 2016; Garrod 2016; Wright and De Filippi 2015). Smart contracts are defined as computer programs that automatically execute the terms of a contract, or contracts that are executed when user interfaces are combined with computer protocols (Crosby et al. 2016; Nofer et al. 2017). It has been argued that Szabo's creative idea can turn into a reality as conducting smart contracts through a decentralised cryptosystem allows unknown and untrusted parties to transact securely, without the need of a third party (Kosba et al. 2016). Pilkington (2015) acknowledges the potential of the application of blockchain technology, discussing Ethereum as a model featuring this idea; however, the lack of transactional privacy has since been identified as a possible flaw to the implementation of smart contracts (Kosba et al. 2016). Potentially suitable contracts that could be created using blockchain include marriage contracts and transnational lending programs (Garrod 2016). A number of risks are involved with the use of smart contracts, such as volatility creating possible market bubbles, as well as the lack of regulation, and the irrevocability of agreements (Piazza 2017). In contrast to this, the risks incurred by smart contracts are greatly reduced in comparison to traditional because they are autonomous, self-sufficient and decentralised (Ross 2017). Because of smart contract's infancy, the advantages and disadvantages may not be clearly defined yet (Surujnath 2017).

Supply Chain Management

It is often identified that supply chains are opaque to consumers, with it becoming increasingly difficult to identify where products originated and where they travelled to. Blockchain could be used in this instance as a transparent ledger that is available on each node and would create a formal log of tracking products in the supply chain (Pilkington 2015; Iansiti and Lakhani 2017). This idea of SCM through blockchain has been conceptualised by Walmart, who are employing the technology to track occurrences of bacteria in food and be aptly able to identify the source and limit the number of items needing to be recalled (Nofer et al. 2017). It has also been implemented in the diamond industry to end unethical behaviour (Nofer et al. 2017; Underwood 2016).

Voting Systems

The contemporary concept can also be extended beyond financial circles into online voting systems, as the anonymisation of data protects personal information, necessary for any voting technology (Zyskind et al. 2015; Extance 2015). By employing blockchain into voting systems, greater transparency would be in existence with each vote being accurately recorded (Pilkington 2015). It has also been suggested that in addition to voting politicians into power, it could also be used to change votes in the event of a political scandal, resulting in a politician no longer having the majority vote (Wright and De Filippi 2015). A blockchain voting system was utilised by the Danish political party Liberal Alliance for internal elections in 2014 (Pilkington 2015). In March 2018, Sierra Leone became the first country in the world to use blockchain to ensure trust and transparency in their presidential election process. Each vote cast in the election, which was monitored by an independent foundation called Agora, was recorded on a private permissioned blockchain (Kazeem 2018).

Micropayments

The use of blockchain technology is currently being incorporated into all Internet browsers and websites by expert programmers. However, it is feared that this may enable a 'metered Internet' in which micropayments may have to be paid (Wright and De Filippi 2015). A micropayment is defined as a very small payment, and in terms of cryptocurrency, this would be a Satoshi, or 10^{-8} Bitcoins (Ron and Shamir 2012; Hernandez 2017). It should be noted though that as the value of Bitcoins increases, a Satoshi may no longer be considered a micropayment and could potentially grow to be quite a large payment. This would be due to the volatility of the currency (Kiviat 2015; Richter et al. 2015). Micropayments would be most commonly sought after in relation to collecting royalties for musicians and artists for work distributed online (Wright and De Filippi 2015). One artist that collects such payments is Imogen Heap from the United Kingdom, who uses blockchain to sell her music (Tapscott et al. 2016). It has also been suggested that the implementation of micropayments would reduce the occurrence of spam mail, as each email would have a micropayment (Wright and De Filippi 2015). Bitcoin has become increasingly competitive in micropayments, but there is no reason to believe that more mainstream organisations would not reduce transaction costs to compete in this industry (Grinberg 2011).

Internet of Things

A suggested widespread utilisation of blockchain technology involves the Internet of things (IoT) in which all communications of smart devices are stored securely (Nofer et al. 2017). IBM and Samsung have already created a washing machine that uses IoT and blockchain technologies to order its own detergent when it is low, showing that what began as an experiment is now globally recognised (Garrod 2016). Blockchain enables IoT or smart devices to transact and communicate in real time, and with the rapid increase of 'mobile wallets', payments can be paid via mobiles (Wright and De Filippi 2015; Ross 2017). One suggested use of blockchain in IoT is as a settlement system. With millions of smart devices communicating and transacting with each other, it is not feasible for banks to process trillions of transactions in real time, and blockchain will come into play in these circumstances (Tapscott et al. 2016). Although not widely implemented yet, the potential is promising.

The Adoption of IT Innovations

IT innovations are now part of the popular business lexicon. Given the significant impact of IT innovations on organisations, IT innovation adoption has regularly been put under the spotlight over the past decades.

There is a wealth of research demonstrating how IT innovations can influence every facet of a company and can lead to enhanced innovation, growth, performance, profitability efficiency and productivity (Barrett et al. 2015; Christensen et al. 2015).

According to Rogers (1995, p. 11), an innovation is "an idea, practice or object that is perceived as new by an individual or another unit of adoption". Whereas innovation can allude to something abstract, like an idea, it can also manifest through new technology. An organisation's decision to adopt an IT innovation can be conceptualised as "a decision to make full use of an innovative IT as the best course of action available" (Rogers 1995, p. 21). Many theories have been used to identify specific considerations that significantly or insignificantly impact the adoption of IT innovations in enterprises. Examples include the technology, organisational and environmental framework (Tornatzky and Fleischer 1990), the perceived e-readiness model (Molla and Licker 2005), the technology acceptance model (Venkatesh and Davis 2000), assimilation theory (Armstrong and Sambamurthy 1999) and theory of reasoned action (Ajzen and Fishbein 1980). For the purposes of this paper, we used the TOE framework as a lens to investigate our research question.

The main objective of the TOE framework (Tornatzky and Fleischer 1990) is to identify technological, organisational and environmental views that influence the adoption of IT innovations in organisations. These views can provide barriers and incentives to IT adoption. The technological view encompasses technological considerations such as complexity, relative advantage, privacy, security and compatibility which can impact existing IT systems in use or the new IT being considered for adoption (Rogers 1995; Treiblmaier and Pollach 2011). The organisational view refers to the internal considerations within an organisation such as prior IT experience, innovativeness, top management support, organisational size, information intensity and organisational readiness (Wang et al. 2010). The environmental view encompasses considerations which impact an organisation's day-to-day business operations such as competitive and industry dynamics, government interactions and regulation (Lippert and Govindarajulu 2006).

Research Approach

Literature Review

The primary objective of our literature review was to analyse the extant empirical research on blockchain to identify significant technological, organisational and environmental adoption considerations. An effective literature review not only makes a significant contribution to cumulative culture but also "creates a firm foundation for advancing knowledge. It closes areas where a plethora of research exists and uncovers areas where research is needed" (Webster and Watson 2002, p. 13). Our motivation was to produce a well-rounded understanding of blockchain adoption, which is currently lacking by carefully describing and then contrasting and comparing an array of sources on the topic. The first step in our analysis of the literature encompassed the sourcing of relevant research resources via scholarly databases and manual searches. To ensure the consistency and reliability of the search and data collection process, we used a three-stage literature mapping protocol (see Fig. 2.2) as prescribed by Kitchenham and Brereton (2013) to search, select, appraise and validate the literature. This mapping protocol ensured that we did not overlook relevant literature which may have been categorised under different headings. This protocol also helped the researchers to define the boundaries in which our review was conducted (e.g., inclusion and exclusion criteria). For the initial *stage 1*, we conducted a rigorous search of seven prominent databases to produce a research resource set which was representative of the status of personal analytics research: EBSCOhost, JSTOR, ProQuest, Google Scholar, PubMed, Scopus and Web of Knowledge. We selected these specific databases because of the multidisciplinary nature of blockchain research. We used the search strings 'blockchain' AND 'adoption', 'blockchain' AND 'TOE', 'bitcoin' AND 'adoption' and 'bitcoin' AND 'TOE'. We included both theoretical and empirical studies and extracted significant considerations which influenced blockchain adoption.

Given the dearth of research pertaining blockchain adoption, grey literature research resources (e.g., conference proceedings, research reports, issue papers, white papers etc.) were also included. Inaccessible research sources were excluded in cases where the library did not access to a full-text

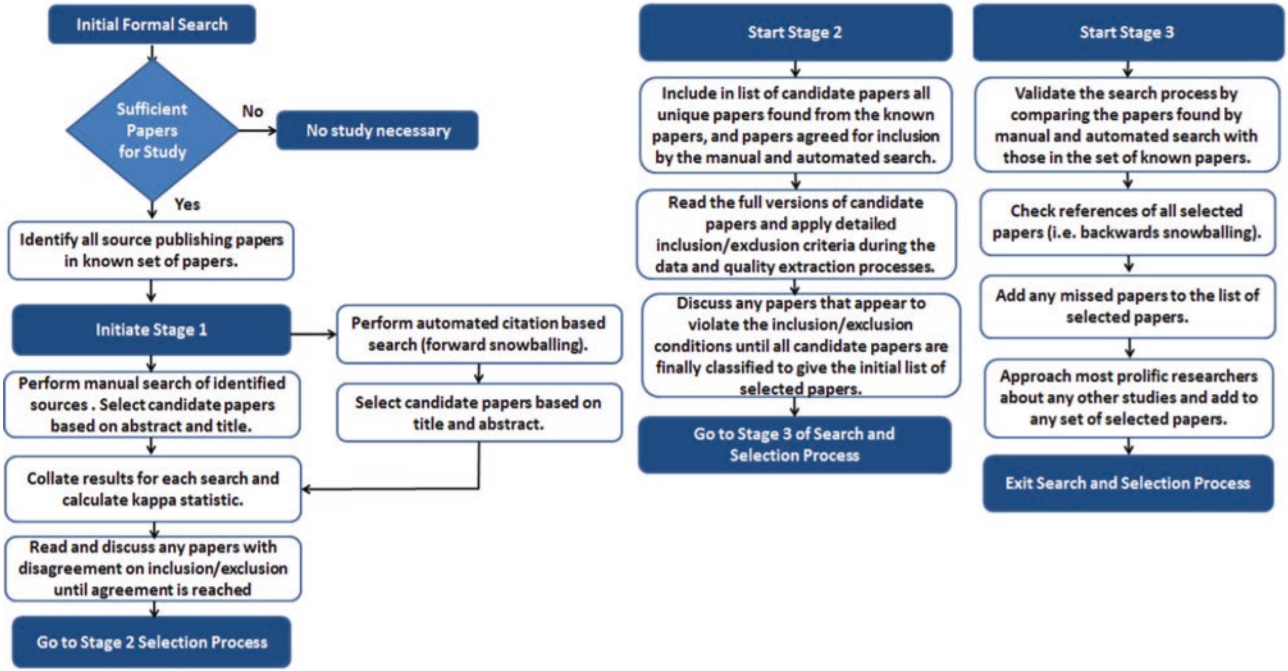

Fig. 2.2 Literature review mapping process. (Adapted from Kitchenham and Brereton (2013))

version or where the library was not subscribed to a publishing resource. All research resources were imported directly into an EndNote database. Using EndNote's 'find duplication' feature, 70 duplicates were removed. The remaining research sources were further filtered using *stage 2* and *stage 3* of the mapping protocol. *Stage 2 selection processes* encompassed a decision-making process to include or exclude relevant research papers from the data extraction process. The "final decision took place when the research sources were read in parallel with data extraction and quality assessment. *Stage 3 search and selection* took place in parallel with data and quality extraction from the research sources identified in s*tages 1* and *2* and comprised three main tasks: search process validation, backward snowballing and researcher consultation" (Kitchenham and Brereton 2013, p. 8).

Table 2.1 presents an overview of the final 16 research resources which we used to identify salient technological, organisational and environmental blockchain adoption considerations.

Findings

Table 2.1 delineates blockchain studies which outline significant technological, organisational and environmental considerations which influence blockchain adoption. Table 2.1 was created based on a comprehensive literature review (Kitchenham and Brereton 2013). Table 2.1 enabled us to extract specific variables that were found to be significant in at least one of the studies, denoted by *. This process enabled us to then create Table 2.2 which provides a summary of the variables according to the number of times that were found to be significant.

As we can see in Table 2.2, specific TOE considerations stand out. From a technological perspective, several considerations emerged as important: perceived benefits, complexity and compatibility. Perceived benefits refer to the study's/author's perception of the benefits (e.g., immutability, security, fast transactions etc.) that will accrue by adopting blockchain technology. Complexity refers to the intrinsic challenges (e.g., validation algorithms, smart contract frameworks, DLT skills etc.) of developing blockchain technologies. Finally, compatibility refers to the ability of blockchain technologies to align with legacy systems (e.g., sup-

Table 2.1 Significant blockchain adoption considerations

No.	Author	Technological considerations	Organisational considerations	Environmental considerations
1	Wang et al. (2016)	Perceived benefits*, data security*, data integrity, complexity*, compatibility*, technology maturity*, uncertainty	Organisational size*, top management support*, organisational readiness*, responding capability	Regulatory environment*, industry pressure*, market dynamics
2	Lansiti and Lakhani (2017)	Relative advantage*, cost savings, complexity*, accessibility, trialability, compatibility*	Technology readiness*, organisational size*, top management support*, value chain readiness	Competitive pressure*, relationship with partners, government policy, business use cases*
3	Guo and Liang (2016)	Cost, data security[a], privacy, relative advantage[a], business concerns[a], compatibility[a], complexity[a], disintermediation[a]	Organisational readiness[a], top management support[a], blockchain knowledge, information intensity	Market dynamics[a], government support[a], regulatory environment[a], industry standards[a]
4	Crosby et al. (2016)	Perceived benefits*, complexity*, relative advantage*, privacy, data security	Customer relationship, top management support*, organisational readiness*, organisational size*	Government support*, regulatory environment*, competitive pressure*, trading partner pressure*

(continued)

Table 2.1 (continued)

No.	Author	Technological considerations	Organisational considerations	Environmental considerations
5	Swan (2015)	Complexity*, relative advantage*, data security*, privacy, disintermediation*	Technology readiness*, organisational readiness*, business model readiness*, relative advantage	Regulatory environment*, public perception of the industry standards*, market dynamics, government support*
6	Shrier et al. (2016)	Complexity*, relative advantage*, perceived benefits*, legacy infrastructure, compatibility*	Organisational readiness*, organisational size*, top management support*, employee disruption	Regulatory environment*, governmental support*
7	O'Dair et al. (2016)	Relative advantage*, perceived benefits*, complexity*, compatibility*, data governance, disintermediation*	Blockchain knowledge, organisational size*, organisational readiness*, business model readiness	Emergence of use case examples, government regulation*, market dynamics, critical user mass*
8	Folkinshteyn and Lennon (2016)	Data security*, privacy, perceived benefits*, disintermediation*, cost savings, continuity of service	Organisational readiness*, customer relationship, size, top management support*	Market dynamics*, trading partner support*, regulatory environment*

(*continued*)

Table 2.1 (continued)

No.	Author	Technological considerations	Organisational considerations	Environmental considerations
9	Tapscott et al. (2016)	Perceived benefits*, data security*, privacy, technology maturity*	Organisational readiness*, organisational size*, business model readiness*, blockchain knowledge*	Government support*, market standards, regulatory environment*
10	Mendling et al. (2017)	Data security*, latency, throughput, usability, hard forks, wasted resources	Organisational readiness*, organisational size*, governance, business models, top management support*	Regulatory environment*, market dynamics, competitive pressure*
11	Pilkington (2015)	Perceived benefits*, complexity*, technology maturity*, compatibility*, permissions (public vs private blockchains) *	Organisational size*, top management support, participation incentives*, innovativeness*, technological readiness*	Competitive pressure*
12	Morabito (2017)	Complexity, perceived benefits, compatibility*, maturity*, cost	Technological readiness, innovativeness*, value chain readiness*, top management support and involvement*, size	Regulatory environment*, government support, business use cases*, trading partner support*

(*continued*)

Table 2.1 (continued)

No.	Author	Technological considerations	Organisational considerations	Environmental considerations
14	Seebacher and Schüritz (2017)	Perceived benefits*, smart contract coding*, complexity	Technology responding capability, information intensity, organisational readiness*, value chain readiness*	Industry pressure*, business use cases*
15	Lindman et al. (2017)	Complexity*, perceived benefits*, technology maturity*, compatibility, technology architecture*	Technology readiness*, value chain readiness, business models, organisational readiness*	Regulatory environment*, market dynamics*
16	Chen et al. (2018)	Perceived benefits*, complexity*, smart contract coding*, energy consumption	Top management support*, organisational readiness*	Market dynamics, governmental projects, industry pressure*

*Considerations found to be significant

ply chain integration, system architectures, provider integration etc.). Next, three organisational considerations stand out: organisational readiness, top management support and organisational size. We provide a description of these three organisational considerations in relation to blockchain adoption in the next section. Finally, two environmental considerations emerged as important considerations: the regulatory environment and market dynamics. In terms of the regulatory environment consideration, with the advent of any new technology (e.g., cloud computing and safe harbour data agreement) that disrupts an industry, governments will need to review and resolve various related issues such as consumer protection, financial integrity and the lack of legislation which is specific to DLT. Market dynamics refers to the rapidly changing blockchain technological landscape which is forcing organisations to review

Table 2.2 Summary of significant blockchain adoption considerations

Technological considerations		Organisational considerations		Environmental considerations	
Perceived benefits	10	Organisational readiness[a]	12	Regulatory environment[b]	11
Complexity	10	Top management support	8	Market dynamics[c]	9
Compatibility	8	Organisational size	8	Industry pressure[d]	5
Data security	6	Business model readiness	4	Government support	5
Maturity	5	Technology readiness	3	Business use cases	3
Relative advantage	4	Innovativeness	2	Trading partner support	3
Disintermediation	4	Participation incentives	1	Critical user mass	1
Smart contract coding	2	Blockchain knowledge	1		
Architecture	1				
Permissions (public vs private)	1				

[a] Includes value chain readiness
[b] Includes government regulation
[c] Includes competitive pressure
[d] Includes industry standards

their existing business processes to assess how they can use blockchain as a technology differentiator.

Discussion, Implications, Limitations and Conclusion

The research question at hand is, ‘What significant technological, organisational and environmental considerations influence blockchain adoption in organisations?’ Our work reveals important technological, organisational and environmental blockchain adoption considerations which can be used as a foundation for advancing the blockchain adoption research agenda. As a background for our subsequent discussion, we focus on how the significant blockchain adoption considerations identified in Table 2.2 can be used to catalyse the blockchain adoption research agenda. As can be seen in Table 2.2, the top three significant organisational considerations are (1) organisational readiness, (2) top management support and (3) organisational size. We will use the top three significant organisational considerations as mediating concepts to guide our discussion. Our reason for focusing on these three considerations is because organisational considerations are often viewed as the most significant determinants of IT innovation adoption in enterprises (Kimberly and Evanisko 1981; Tornatzky and Fleischer 1990; Damanpour 1991). As a result, organisational considerations, such as top management support, firm size, prior IT experience and innovativeness have been widely examined to ascertain the degree to which they constrain or act as a catalyst for the adoption of IT (Grandon and Pearson 2004; Van de Weerd et al. 2016).

Top Management Support

Top management support has been identified as a key recurrent factor critical to the adoption of IT innovations (Sabherwal et al. 2006; Bajaj 2000; Dong et al. 2009; Kulkarni et al. 2017). According to Jarvenpaa and Ives (1991, p. 205), "few nostrums have been prescribed so religiously and ignored as regularly as top management support in the development and implementation of IT". We define top management support as "managerial beliefs about technological initiatives, participation in those initiatives, and the extent to which top management advocates technological advancement" (Kulkarni et al. 2017, p. 7). High levels of top management support for a specific IT innovation ensure the long-term vision, commitment and optimal management of resources, creation of a favourable organisational climate, support in overcoming barriers and resistance to change (Wang et al. 2010; Gangwar, Date and Ramaswamy 2015). In the context of blockchain adoption, top management support plays an important role because blockchain adoption may involve new regulatory requirements, a high degree of complexity, the acquisition of new resources, the integration of resources, the re-engineering of business-to-consumer and business-to-business transactions and information exchanges and the development of new skills and competencies (Swan 2015; Pilkington 2016; Lansiti and Lakhani 2017). A study conducted by Clohessy et al. (2018) confirmed that organisations that had adopted blockchain demonstrated high levels of management support. Furthermore, this study identified that within adopting organisations, top management support for blockchain grew gradually and was influenced by employees who were able to demonstrate real-world value of adopting blockchain in terms of creating blockchain prototypes which were underpinned by viable business models (Clohessy et al. 2018).

Organisational Readiness

Organisational readiness is conceptualised as the availability of specific organisational resources to adopt new IT innovations (Lacovou et al. 1995; Weiner 2009; Wang et al. 2010). This conceptualisation is frequently categorised under several headings, including human resources, financial and infrastructure facets. Human resources facets refer to the presence of employees with the requisite knowledge, skill and experience to adopt new IT innovations (Wang et al. 2010). Next, financial facets refer to the allocated financial resources an organisation commits to new IT innovations (Weiner 2009). While certain research has focused on the financial resources from the perspective of a specific IT innovation (e.g., Lacovou et al. 1995), in general, many studies have focused on financial resources from the perspective of any new IT innovation. Finally, infrastructure facets refer to existing IT platforms on which new IT innovations can be developed (Lacovou et al. 1995). When organisational readiness for a new IT innovation is high, an organisation's management and staff are more likely to initiate change, exhibit greater effort and persistence and engage in enhanced cooperative behaviour (Weiner 2009; Wang et al. 2010). Consequently, this results in a more effective adoption of the new IT innovation. The exact influence of organisational readiness on the adoption of blockchain is currently unclear. While existing theoretical research suggests that organisational readiness has a significant influence on the adoption of blockchain (Swan 2015; Wang et al. 2016), there is currently a dearth of empirical studies which have confirmed that this is the case. A study conducted by Clohessy et al. (2018) confirmed that the presence of sufficient organisational readiness in terms of the availability of financial and employee resources and access to IT infrastructure have a positive influence on a company's decision to adopt blockchain. This research conducted by Clohessy et al. (2018) also identified that the blockchain skills required by organisations for developing blockchain technologies could be categorised under the following technological competency headings: (1) foundational technology (e.g., cryptography, public key architecture); (2) distributed ledger technology (e.g., mining, consensus algorithms); (3) forensics and law enforcement (e.g., money laundering, darknet); (4) markets, economics and finance (e.g., game theory, business modelling); (5) industrial design (e.g., supply chain, IoT) and (6) regulations and standards (e.g., smart contracts and frameworks). Furthermore, the study confirmed that the availability and functionality of cloud-based blockchain development platforms were pivotal in triggering an organisation's decision to adopt blockchain.

Organisational Size

Organisational size is considered an important predictor of blockchain adoption (Tapscott et al. 2016; Mendling et al. 2017). Extant research (e.g., Swan 2015) and industry reports (Clohessy et al. 2018) suggest that large organisations are more likely to adopt blockchain than small and medium enterprises (SME). Many past studies suggest that an enterprises' willingness to adopt a new innovative IT is positively influenced by organisational size (Damanpour 1992). The reasoning behind this is that large organisations possess more complex and diverse facilities which positively contribute to adoption (Lee and Xia 2006). Microenterprises and SMEs, on the other hand, are susceptible to many barriers which constrain their ability to adopt IT innovations such as resource poverty (e.g., lack of IS personnel and expertise) and small IT budgets (Thong and Yap 1995). However, our research indicates that in the case of specific IT innovations, because of the characteristics of the technology and the flexibility and adaptability of microenterprises and SMEs, the opposite has been found. For example, empirical studies have shown that SMEs were more suitable and more inclined to adopt cloud computing technologies (Clohessy et al. 2017; Van de Weerd et al. 2016). Consequently, further empirical research is necessary to establish a consistent relationship between organisational size and blockchain adoption.

Implications

Practitioner and academic interest in the evolving phenomenon of blockchain is intense. Although this review cannot claim to be exhaustive, our study has outlined the benefits of blockchain technologies, provided an overview of potential business use cases and most significantly coalesced salient technological, organisational and environmental considerations which impact the adoption of blockchain technologies. Furthermore, we have provided an overview of how three of the main organisational considerations relate to the adoption of blockchain technologies. Our study can provide a useful quality reference source for practitioners and academics with an interest in blockchain and suggestions for future lines of research that will have strong implications for the practitioner community.

Limitations

It is worth highlighting some limitations and areas which may represent fruitful direction for additional research. First, we discussed three specific organisational considerations which influence a company's decision to adopt blockchain. As highlighted in Table 2.2, we also identified environmental, technological and other organisation considerations which also merit further investigation. We envisage that future research which investigates these categories of considerations might result in a more comprehensive analysis of blockchain adoption. Second, blockchain is a relatively young concept, and there are few well-established theoretical frameworks or unified discourses. While it is felt that the sample of publications is representative of the blockchain adoption literature, there may be some bias associated with the narrow focus of the research resources under review. Additionally, there are potential research resources that investigate similar phenomena but discuss it with different terms, and thus, were difficult to find. We found throughout our survey of the literature that the only consistency pertaining to the concept of blockchain adoption is inconsistency. This fluid state of the blockchain field, in conjunction with the subjective nature of the literature review filtering process—necessary due to the inconsistent use of the term across disciplines/fields—limits this work. However, at the same time, it seems that increasing the focus would not change the general conclusions or provide additional insights. Finally, we would also like to acknowledge the potential for researcher bias. Nevertheless, from the initial research design, through to the development of the methodology and the reporting of the findings, our research made use of an audit trail and audit process (Schwandt et al. 2007). This ensured that our research was underpinned by rigour, authenticity and neutrality.

Conclusion

Using innovation theory (e.g., TOE framework), which has been extensively used to examine the adoption of IT in organisations, our research identified salient technological, organisational and environmental considerations which influence the adoption of blockchain by organisations. We also provided an overview of the blockchain concept and outlined the advantages and potential use cases that organisations contemplating adopting the technology can leverage. Every organisation is unique and has a different structure, culture, industry sectors, number of employees and so on. The combination of these factors affects an organisation's approach to blockchain adoption. We hope that our research endeavours in this article to coalesce the significant blockchain adoption considerations will ignite the spark for both researchers and organisations to investigate these considerations further. Having "stood on the shoulders of giants" by reviewing the extant research on blockchain adoption, like many scholars and IT analysts, we strongly believe that the blockchain concept has the potential to become the new frontier of competitive differentiation. Janus was the roman god of beginnings and endings. We believe that blockchain also encapsulates that duality. It will put an end to traditional ways of doing things and usher in a new era for business and for the world at large. It will be divisive, pervasive and transformational all at the same time. It is time that organisations look ahead.

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3

Blockchain-Based Decentralized Business Models in the Sharing Economy: A Technology Adoption Perspective

Andranik Tumasjan and Theodor Beutel

Introduction: Blockchain Technology and Business Models

Blockchain technology has recently gained strong attention in the media and in business practice (Gupta 2017). In a recent survey of US corporate executives, 61% claimed knowledge about blockchain technology ranging from broad to expert, and among those with knowledge about blockchain, 42% believed that it will “disrupt” their industry (Deloitte 2017). Moreover, in this group, 21% have already bought into blockchain production, while 25% plan to do so in the next year (Deloitte 2017). In addition, beyond corporate blockchain applications (that are mainly

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implementing private or federated blockchain solutions, also referred to as "distributed ledger technologies" (DLTs); BlockchainHub 2017; Tumasjan 2018), we currently witness an emerging landscape of startups using blockchain technology and creating entirely new business models. In this vein, a recent study of blockchain startups found that worldwide more than 1,500 startups were building new products, services, and business models based on blockchain technology and that more than 1.5 billion US dollars of venture capital were already invested in these startups (Friedlmaier et al. 2018).

Notably, based on Satoshi Nakamoto's idea of a "decentralized"[1] digital currency (i.e., Bitcoin; Nakamoto 2008), many of these startups are explicitly building "decentralized" business models as an alternative to extant "centralized" business models. The idea is often formulated as "cutting out the middleman" and creating a peer-to-peer network where a transaction is done directly between two parties as in the case of Bitcoin (Dutra et al., 2018). Transferring this idea to online platforms, several startups aim at creating an alternative to "sharing economy" platforms (e.g., Uber and AirBnB) instead of creating peer-to-peer business models where customers and suppliers make transactions directly using blockchain technology. The goal in these cases is to build "true" sharing economy business models in which users can make peer-to-peer transactions rather than providing their data to and making transactions on centralized platforms entailing relatively high transaction fees. These decentralized blockchain-based sharing economy business models[2] (BSEBM) are then presented as an alternative to traditional, centralized sharing economy platforms (e.g., Uber, AirBnB, Upwork, and Facebook) with the goal of decentralized data storage and saving money on transaction fees (Tapscott and Tapscott 2016a). One example of such a BSEBM is OpenBazaar, a decentralized e-commerce marketplace based on an open-source software where people can buy and sell goods via a peer-to-peer network. Whereas its "centralized

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[1] Whereas Bitcoin was conceptualized as a decentralized digital currency by Nakamoto, we acknowledge that recent research has found that Bitcoin and Ethereum are in fact much less decentralized than usually assumed (Gencer et al. 2018).

[2] For reasons of brevity, we refer to these as blockchain-based sharing economy business models (abbreviated as BSEBM) in contrast to "traditional" sharing economy business models (abbreviated as SEBM).

counterparts" eBay or Amazon store data in a central database, charge fees, and use fiat currency payment, users on OpenBazaar distribute data across the network, do not charge fees, and use cryptocurrencies as a payment method (Patterson 2016). Similar concepts include, for example, La'Zooz (a decentralized ridesharing solution), Filecoin (a decentralized data storage solution), and LaborX (a decentralized labor hire marketplace).[3]

While such BSEBM may be intriguing and worthwhile alternatives to their extant centralized sharing economy business models (SEBM), many challenges remain before BSEBM may reach mass-market adoption. Among the main challenges are product/service usability and actual value added in the mass market. In other words, why should customers use decentralized solutions that may exhibit much lower levels of usability, worse user experience, and possibly occasional technical problems, when they can likewise use extremely convenient services such as Amazon, eBay, or Upwork? Illustrating this point, a co-developer of OpenBazaar stated that "[e]xisting centralized marketplaces like Amazon and eBay have had decades to build up an impressive suite of features for their users. Our first release has the advantage of 0% fees and using Bitcoin, but it will be a long time before we are as feature-rich as the big platforms" (Patterson 2016). Moreover, among other challenges, legal and regulatory challenges remain (e.g., settling money-back issues, dealing with fraud, taxing issues) as well as questions as to how the infrastructure is maintained, who it belongs to, and which business paradigm changes are required to sustainably run such decentralized business models (Beck et al. 2018; Seidel 2017; Voshmgir 2017).

Overall, our current knowledge of such BSEBM is scant. Aside from position papers, blogs, and popular accounts (e.g., Tapscott and Tapscott 2016a), research has not yet systematically investigated under which conditions such business models may be successful and which parameters influence the adoption of novel BSEBM (for recent notable exceptions, see Beck et al. 2018). Therefore, our chapter addresses this gap in the extant literature. We focus on customer adoption by building on a technology accep-

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[3] In a comprehensive analysis, 74 startups building or operating blockchain-based decentralized sharing economy business models were identified as of 2017 (Schneck et al. 2018).

tance theoretical perspective (Karahanna et al. 1999; Venkatesh et al. 2003) to conceptualize relevant parameters of customer adoption of BSEBM. Based on our conceptualization of relevant parameters, we then derive and theorize on different adoption scenarios that we subsequently explore in a simulation for the short term vs. long term using an agent-based modeling approach (Epstein 1999; Rand and Rust 2011; Treiblmaier 2017).

We make the following major contributions to the literature. First, we advance the current state of the literature by systematically theorizing on relevant parameters of user adoption of BSEBM. We do so by building on extant research on technology acceptance (Dwivedi et al. 2017; Venkatesh et al. 2003) and conceptualizing relevant parameters which we use to derive possible adoption scenarios. Second, we contribute to the literature by exploring how these parameters interact in our adoption scenarios. Whereas prior research has often conceptualized adoption parameters in isolation or in a static fashion, our ABM approach allows us to examine their joint influence in our adoption scenarios over time. Thereby, we explore user adoption in the short term vs. long term to identify potential differential temporal effects of adoption. Third, we contribute to the extant discourse by explicitly focusing on the users' view. While prior research has often emphasized technological and governance issues of blockchain-based business models (Beck et al. 2018; Folkinshteyn et al. 2015; Voshmgir 2017), we advance the field by employing a user adoption perspective. Our approach is based on the rationale that the success of such novel BSEBM will largely be decided by sustainable mass-market adoption, and, hence, understanding the users' perspective is crucial.

Theoretical Conceptualization

In this exploratory study, we draw on several research streams that we will briefly review and integrate into the following sections. Hence, the following paragraphs introduce digital platforms in the sharing economy, followed by blockchain-based business models and theories of technology adoption. Toward the end of this section, we explain how we construct the core parameters of this study and present our research questions, respectively.

The Sharing Economy and Concentration of Power

Digital platforms for reallocating underutilized assets gave rise to SEBM that create value through such reallocation processes and charge a fraction of that value for their service of intermediation. SEBM shook incumbents across industries—from accommodation (e.g., AirBnB, HomeAway), transportation (e.g., BlaBlaCar, Uber), to household work and all kinds of freelance tasks (e.g., TaskRabbit, Upwork). These business models go by many names, including the “sharing economy” and “collaborative consumption” (Botsman and Rogers 2011; Matzler et al. 2015). While there is an ongoing discussion whether and how these and related terms differ, there are two common themes (Belk 2014). First, SEBM coordinate temporary access to utilize goods and services. Second, to facilitate the former, SEBM rely on the Internet and mobile devices (Belk 2014).

Some of these platforms reallocate assets (e.g., AirBnB for apartments), while others distribute labor (e.g., TaskRabbit for everyday services), and some a mix of both assets and labor (e.g., Uber for transportation services). As a rule of thumb, startups may be seen part of the sharing economy if there is a true sense of sharing and collaboration involved (Botsman 2015).

However, not only good comes along with these digital platforms of the sharing economy. Business models of digital platforms are a prime example of winner-takes-all markets where economies of scale and profit maximization foster market structures that are dominated by powerful platform owners (Brynjolfsson and McAfee 2014). Ultimately, platform owners can use their power to establish or even enforce processes which may disadvantage users and the public. Common concerns include privacy issues from irresponsible data usage, not transparent pricing mechanisms, and self-employment practices which unburden a platform owner from paying employee benefits and employment tax (Edelman and Geradin 2016; Malhotra and van Alstyne 2014).

As these problems arise from a centralization of power, BSEBM may contribute to addressing such problematic phenomena in the sharing economy (Abramova and Boehme 2016; Beck et al. 2018). In the following section, we elaborate on the rationale underlying the argument that blockchain technology may be of value for the sharing economy.

Blockchain-Based Business Models in the Sharing Economy

Traditionally, online platform providers are a centralized entity that is, or rather needs to be, trusted by its users. Through concepts such as platform cooperativism with peer-to-peer rather than centralized governance, blockchain technology could provide the infrastructure for decentralized trust (De Filippi 2017). However, different blockchain designs result in fundamentally different governance structures (e.g., hierarchy vs. meritocracy) which require a thorough discourse among all involved stakeholders (Voshmgir 2017). To balance power in sharing economy settings, blockchain technology and the underlying protocols could essentially replace a trusted platform operator in centralized structures with trust in the decentralized technology itself (Jarvenpaa and Teigland 2017). The design of such decentralized technology—and its implications for trust (Seidel 2017)—is highly dependent on the particular blockchain technology in use.

In terms of terminology, the term “blockchain” is criticized for being conceptually ambiguous in public discourse (Jeffries 2018), as there is no such thing as “the blockchain” but a variety of blockchains and blockchain-like architectures (for review, see Yli-Huumo et al. 2016). Generally, blockchain technology may be defined as “a distributed database solution that maintains a continuously growing list of data records that are confirmed by the nodes participating in it” (Yli-Huumo et al. 2016, p. 1).

Blockchains can be private or public (Morabito 2017). So-called federated or consortium blockchains are designed for a set or preselected, trusted participants within a controlled network. These types of blockchains—such as Hyperledger Fabric or R3 Corda—are most common in the financial industry (Valenta and Sandner 2017) and are often termed *private* blockchains. Private and public blockchains are subsumed under the umbrella term “distributed ledger technology”.

If there are no limitations to who can read or write, a blockchain is often termed *public* (Morabito 2017). Public blockchains allow anyone to participate and ensure that unknown (and potentially untrustworthy) individuals can coordinate among each other without requiring a central, trusted unit to coordinate because these blockchains use game theory to disincentive malicious activity (Voshmgir 2017). Since BSEBM typically involve peer-to-peer interaction among individuals who do not necessarily know or trust each other, public blockchains are well equipped to fulfill the requirements of SEBM.

Public blockchains (such as Ethereum and Bitcoin) could fundamentally change how a sharing economy is implemented, once they unleash their potential for decentralized governance. In this vein, so-called decentralized autonomous organizations (DAO) may promise a new type of organization that potentially requires lower levels of transaction costs to organize itself while avoiding the pitfalls and dilemmas of centralized governance (Voshmgir 2017). It is often argued that such DAOs may flatten or entirely remove hierarchical structures in the digital economy by creating digital platforms that are governed and used on a peer-to-peer basis by and for users (Beck et al. 2018). Effectively, BSEBM allow members to remain in control of the platform, which could include rules of privacy and data protection as well as decisions on revenue generation and profit distribution (Tapscott and Tapscott 2016a, b).

Since current SEBM and digital platforms more broadly are highly centralized in nature and subject to a range of shortcomings, could BSEBM give birth to a new, true sharing economy? To date, a variety of challenges and risks remain—including technology maturity, regulatory uncertainties, and potentially still unknown hurdles in designing functioning decentralized systems with effective incentive structures (Tapscott and Tapscott 2016a). Especially such uncertainties in performance and characteristics of a system pose an important challenge since there are no historical data to learn from when it comes to technology adoption and the open question how users would decide when confronted with such a new BSEBM. To better understand and investigate user adoption processes, in the next section, we elaborate on established frameworks for technology adoption on which we base our investigation.

Technology Adoption

Established adoption theories encompass two major perspectives to explaining technology adoption. Macro lens models describe and explain adoption at an interorganizational or societal level, while micro lens models describe and explain intraorganizational or personal adoption (Frambach and Schillewaert 2002; Tarhini et al. 2015).

Macro lens models such as the Bass diffusion model (Bass 1969) and Roger's (2003) diffusion of innovation (DoI) theory describe the spread of a technology in a social system. Macro models, however, assume populations to be relatively homogenous in terms of preferences and connectedness among individuals. In the case of DoI, heterogeneity is reflected to some extent as individual adopters are grouped into five categories—innovators, early adopters, early majority, late majority, and laggards. These five groups of adopters behave differently when confronted with a new technological innovation and shape the adoption rate and spread according to DoI (Rogers 2003). While a macro view helps understanding emergent patterns in technology adoption, for the purpose of modeling adoption and analyzing marketing activity for products and services, micro-level models may be more appropriate. In particular, employing a micro lens is appropriate because this perspective incorporates heterogeneous network structures on a local level, which allows creating models that are more realistic in terms of depicting social network structures (Bohlmann et al. 2010).

A variety of micro-level adoption models have been proposed to differentiate between heterogeneous individuals within a population. Exemplary technology adoption theories that model individuals' behaviors at the micro-level include the theory of planned behavior (TPB; Ajzen 1991), multiple versions of the technology acceptance model (TAM; Davis et al. 1989; Venkatesh and Davis 2000), and two versions of the unified theory of acceptance and use of technology (UTAUT; Venkatesh et al. 2003; Venkatesh et al. Xu 2012).

For our purpose of analyzing BSEBM, we posit that it is appropriate to employ a micro lens and focus on individuals' behavior. BSEBM are often conceptualized as two-sided marketplaces with peer-to-peer interactions of individuals as consumers and suppliers at the individual level (Botsman and Rogers 2011). Therefore, we argue that for our purpose, focusing on the predictors of individual adoption (rather than macro-level adoption) is more appropriate, and we therefore employ a micro lens to our research questions regarding user adoption.

In the following paragraphs, we therefore apply the logic of UTAUT because it is primarily designed for explaining individual adoption (Venkatesh et al. 2003) and has been widely used since it was proposed in the early 2000s (for a review and meta-analysis, see Dwivedi et al. 2017). Thus, UTAUT serves as a conceptual basis for our research by providing important elements for individual adoption modeling. However, we do not attempt to replicate or apply the UTAUT model in its entirety for our research but rather use it as a basis from which we derive some of our major parameters. We do so to preserve conceptual and computational parsimony in our simulation model (see section *Method and research design* below) and to be able to integrate further variables that are not part of the UTAUT model but that are nevertheless important for our modeling of BSEBM. Thus, we build an integrative model that has UTAUT as a basis but also includes other parameters that are important for our purposes.

Hence, from the UTAUT model, we employ the construct *performance expectancy* (*PE*), defined as "the degree to which an individual believes that using the system will help" them to benefit from its service (Venkatesh et al. 2003, p. 447). We also use the construct *effort expectancy* (*EE*), defined as "the degree of ease associated with the use of the system" (Venkatesh et al. 2003, p. 450). However, we do not include the construct of *social influence* because of mixed evidence of its utility and indications that social influence is only significant among young women, older people, or in mandatory settings (Hartwick and Barki 1994; Venkatesh et al. 2003). Moreover, *facilitating conditions* are excluded as they are predominantly conceptualized for individuals in an organizational setting (Venkatesh et al. 2003).

Instead, and in line with TPB (Ajzen 1991), we include *attitude* (*AT*) which is "the user's desirability of his or her using the system" (Malhotra and Galletta 1999, p. 1) and is closely related to the intensity of an individual's value-based and ethical perception of the service (Dwivedi et al. 2017). AT is of central importance in the pre-adoption phase when an individual decides to adopt a product (Karahanna et al. 1999) and is directly related to behavioral intention (Davis et al. 1989). Lastly, we also include *pervasiveness* (*PV*) as an essential construct to reflect external influences from word of mouth and network effects which have been deemed important for the adoption of two-sided digital platforms (Zutshi et al. 2014).

Conceptualization of Adoption Constructs

Drawing on the previous section where we introduce the theoretical constructs of technology adoption that are relevant to our study, we will now elaborate on how we conceptualize these four main constructs for the purpose of our investigation. We explain how the constructs relate to BSEBM and present eight scenarios that logically emerge from our constructs.

Performance Expectancy PE is related to constructs such as perceived usefulness (Davis et al. 1989) and relative advantage (Moore and Benbasat 1991). Across multiple models, PE has been shown to be the strongest predictor of behavioral intention to adopt a technology, which explicitly includes voluntary settings such as our case (Venkatesh et al. 2003). In our context of BSEBM, PE describes how individuals would make up their mind on whether they expect a BSEBM to meet their needs to a sufficiently high degree compared to other SEBM. For simplicity, we model a direct effect of PE on use behavior. To illustrate, it is plausible to assume that if individuals expect a BSEBM to serve their use case only to a small extent, the relative adoption of such a service is lower vis-à-vis other SEBM where the individuals expect to experience greater value (e.g., receiving a quick transportation service from A to B or staying at a local's flat in a city center).

Effort Expectancy Moreover, we include EE that, like PE, applies to voluntary usage contexts (Venkatesh et al. 2003). EE is similar to constructs from other theories describing the ease of use (Davis et al. 1989; Moore and Benbasat 1991) and complexity (Thompson et al. 1991). In their seminal work, Venkatesh et al. (2003) find that EE is a strong mediator of facilitating conditions (e.g., the provision of support services; Thompson et al. 1991) on behavioral use intention. Again, to keep the model reasonably simple, we omit the construct of behavioral use intention and we model a direct effect on use behavior since intentions have been shown to be the strongest predictor of actual behavior (Ajzen 1991). In the present context, EE becomes relevant in the process preceding BSEBM adoption, when individuals evaluate the effort they would have to expend on installing the corresponding software for using the BSEBM and becoming familiar with its user interface to perform the tasks that individuals want to accomplish (e.g., booking a ride or an accommodation). If individuals expect that they would need to make a substantial effort before they could extract value from the BSEBM, a lower relative adoption would result as compared to other SEBM where the expected effort is low.

Attitude The third construct of our model is AT which reflects "the user's desirability of his or her using the system" (Malhotra and Galletta 1999, p. 1). In the adapted version of the UTAUT model (Dwivedi et al. 2017), AT is influenced by *social influence* and by *facilitating conditions*, two constructs that are not part of our model. Whereas AT also has an effect on intention, in their meta-analysis, Dwivedi et al. (2017) found a comparatively stronger and direct effect of AT on use behavior. Including AT in our model is important for our purpose of modeling BSEBM adoption. Since BSEBM can build upon the promises of distribution, immutability, and trustlessness (contrary to conventional business models), a positive AT toward these features will foster BSEBM adoption. Thus, if an individual values distribution (e.g., for increased resilience to avoid the shutdown of services), immutability (e.g., for tamperproof records), or trustlessness (e.g., for substituting trust in a third-party institution by trust in a distributed protocol), then this individual's AT would be substantially stronger toward a BSEBM compared to other systems that do not provide these features.

Pervasiveness Our fourth construct, PV, is a measure of the distributedness of a technology or business model within a population. For this study, we define PV as the result of external and internal forces that influence an individual's technology adoption. For external forces, we refer to network effects and viral spread (Gallagher and West 2009; Zutshi 2015). For internal forces, we include switching cost as the barriers an individual perceives when considering a change from one supplier to another (Farrell and Shapiro 1988). In the context of digital business models, PV is fundamentally affected by network effects and viral spread (Zutshi 2015). In the context of digital platforms, network effects commonly describe a positive relationship between the utility which a single consuming individual perceives and the amount of total consuming individuals of the same product or service (Gallagher and West 2009). For BSEBM (and any SEBM) as two-sided marketplaces, this means that these platforms typically face two-sided network effects where consumers perceive a higher utility if the number of suppliers rises. Similarly, suppliers benefit from an increasing number of consumers. The emergence of such network effects is facilitated by viral spread that occurs through word of mouth among individuals within the reach of the radius of their personal network. At the same time, there is a counteracting force in the form of habits and switching cost, which determines the minimum of additional value an individual must expect before they decide to adopt a BSEBM (Farrell and Shapiro 1988). Likewise, there is a threshold of negative user experience that, if exceeded, encourages an individual to abandon a BSEBM.

From these four parameters, we derive eight (two times four) possible scenarios describing the adoption of BSEBM. In our first scenario analysis, which comprises four scenarios, the "perceived-benefit-matrix" (see upper part of Table 3.1), we juxtapose PE and EE to model the value that users expect to extract from the BSEBM's features and usability. In an "ideal" adoption scenario, BSEBM are highly performant (high PE) and easily usable (high EE), and thus, competitive with other SEBM. In the opposite scenario of low PE and low EE, user adoption would likely suffer. Intermediate combinations would lead to usability or performance issues, with the well-performing parameter potentially offsetting the other low-performing parameter.

In our second scenario analysis, which comprises four scenarios, the "internal/external trigger-matrix" (see lower part of Table 3.1), we juxtapose the combinations of high/low values of AT and high/low values of PV. In an "ideal" scenario, again, we would expect fast-paced and sustainable adoption rates because users would not only initially become aware of the BSEBM from a general "hype" (high PV) but would also stick to the BSEBM due to their favorable AT toward the BSEBM. A low/low combination of AT and PV, however, would negatively impact the viral spread and reduce customers' motivation to use the BSEBM. Similarly, a

Table 3.1 Scenarios of perceived-benefit-matrix and internal/external trigger-matrix

	PE	EE	AT	PV	Scenario	Description
Perceived-benefit-matrix	Low	Low	~	~	Late bloomer	BSEBM struggles because users find it inconvenient and insufficient
	High	Low	~	~	Usability issues	Users expect BSEBM to perform well but struggle with barriers to use it
	Low	High	~	~	Performance issues	Users expect BSEBM to be good enough in usability but experience performance issues
	High	High	~	~	Competitive	BSEBM is widely adopted because users perceive little barriers to adoption and sufficient performance
Internal/external trigger-matrix	~	~	Low	Low	At risk of extinction	Users are not keen to use the BSEBM. Neither do they hear from others nor they talk themselves about the service
	~	~	High	Low	Local or niche adoption	Users find the BSEBM appealing, but word of mouth has limited reach
	~	~	Low	High	Temporary buzz	BSEBM lands a viral hit but fails to convince for permanent usage
	~	~	High	High	Sustainable mass adoption	Users are intrinsically motivated by the BSEBM's distinct features and willingly spread the word

local or niche adoption describes a situation where there is low virality but a smaller community of people who are sufficiently motivated by their AT toward the BSEBM. On the other hand, a temporary buzz may also occur resulting from a constellation of high interest initially but no intention for individuals to permanently adopt the BSEBM due to negative AT toward the value of BSEBM. Table 3.1 summarizes the scenarios emerging from the combinations of PE and EE, and AT and PV, respectively.

Research Questions

Above, we have argued that BSEBM could have relative advantages over centralized platforms and, thus, may potentially become widely adopted. To explore the eight adoption scenarios that we have derived above in more detail, we model the underlying parameters using agent-based modeling. We do so by addressing the following three research questions.

First, we have derived four parameters from the extant literatures on SEBM, blockchain technology, and user adoption of technology and study the influence of the parameters as reflected in the following research question:

RQ1: *How are the adoption parameters performance expectancy, effort expectancy, attitude, and pervasiveness related to the adoption of BSEBM?*

Second, we derived eight scenarios based on scenario analyses of our four parameters, respectively, resulting in the following research question:

RQ2: *Which adoption patterns result for the scenarios, and how do the patterns differ across the eight scenarios?*

Third, to investigate sustainable adoption in the long term, we explore how these eight scenarios evolve in the short term vs. the long term as reflected in the following research question:

RQ3: *How does the model predict adoption within the same scenarios in the short term* vs. *the long term?*

In the next section, we operationalize our theoretical approach and introduce our methodology.

Methods and Research Design

We conduct a simulation study to explore the complex interdependencies in our variables. As discussed in the previous section, traditional frameworks investigate adoption patterns typically through macro and micro lenses. Both lenses can provide useful methods to gather and analyze data on the adoption of technology. On the one hand, macro-level frameworks such as Rogers' (2003) diffusion of innovation model help understanding market saturation. On the other hand, micro-level frameworks such as UTAUT (Venkatesh and Davis 2000; Venkatesh et al. 2003) provide sophisticated ways to investigate the motivation of individuals and their intentions. We intend to contribute to bridging this gap between micro and macro lenses by agent-based modeling (ABM). Various studies have shown that ABM can significantly enhance theories for technology adoption which are often inherently static, such as UTAUT (Bohlmann et al. 2010; Treiblmaier 2017).

Agent-Based Modeling

ABM is a "category of computational models invoking the dynamic actions, reactions and intercommunication protocols among the agents in a shared environment, in order to evaluate their design and performance and derive insights on their emerging behavior and properties" (Abar et al. 2017, p. 14). In the past 20 years, ABM has evolved into a widely accepted methodology in the social sciences, and in research on innovation diffusion in particular (Garcia and Jager 2011), yet it remains arguably underused (Axelrod 1997; Epstein 2012).

By modeling interdependencies between individuals rather than aggregating independently conceptualized intentions of individuals, we take into account contingent behavior. Thereby, we consider how each individual's behavior develops independently over time and model the macro lens accordingly (Bruch and Atwell 2015). Especially in an environment potentially coined by peer-to-peer interaction rather than centralized governance, as indicated in the previous section, the result of reciprocal interaction among individuals is of considerable importance. Such a context indicates that using ABM is appropriate since the methodology is considered beneficial if research aims at investigating phenomena emerging from interactive entities (Rand and Rust 2011). Doing so is particularly relevant in our case modeling diffusion and adoption of technology as these entities are autonomous and heterogeneous in nature.

As of today, the blockchain ecosystem is still in its fluid phase of technological experimentation and has yet to shift from experimentation to optimization (Iansiti and Lakhani 2017). Moreover, peers are naturally diverse in this context (i.e., potential adopters of this new technology across all groups of a society). Due to these heterogeneous characteristics not only among agents but also among blockchain technologies, it is challenging to model the adoption of BSEBM. ABM generally allows for taking such heterogeneity into account (Bohlmann et al. 2010).

Rand and Rust (2011) propose six key indicators for evaluating the appropriateness of an ABM approach: medium numbers, local and potentially complex interactions, heterogeneity, rich environments, temporal aspects, and adaptive agents.

First, medium numbers indicate that ABM is neither ideal for a very small number of agents where game theory is superior nor a very large number where statistical regression is typically more efficient. A medium-sized population is typically facing a few, yet important interactions among individual agents (Casti 1996). This criterion applies to our case, which indicates the appropriateness of ABM. Second, local and complex interaction patterns are common to consumer adoption (Rand and Rust 2011) and characterize the case at hand particularly well as the sharing economy relies heavily on local network effects (Malhotra and van Alstyne 2014). Third, the characteristics of agents are indicative of using ABM if they are highly heterogeneous. In our model, we describe local networks with a high degree of individuality due to randomly allocated preferences and continuous word of mouth among agents. Therefore, heterogeneity applies, too. Fourth, rich or dynamic environments describe a complex interaction between an agent and its surroundings, which, again, is warranted by assuming continuous word of mouth among agents. Fifth, temporality is the only necessary factor and describes the need for investigating processes over time rather than at a static point in time. With technology adoption, time and rate of adoption play a major role, for instance, when "crossing the chasm" (Moore 2014). Sixth, the indicator of adaptive agents describes individuals who may change their behavior dynamically based on new information. In the case at hand, we assume agents to act upon influence from their network and change their behavior once they adopt a product and are therefore adaptive. Thus, overall, ABM can be considered appropriate for our study. In the following paragraphs, we describe the design of our model.

Design of the Model

ABM consists of three components: *agents*, *interactions* (or *relationships*), and an *environment* (Epstein 2012; Rand and Rust 2011). By running the model for a certain amount of time units (also referred to as "steps" or "ticks"), agents execute their behavior and engage in interactions with every time unit. Thus, ABM is based on discrete events from activities over a certain amount of time units in which the agents interact with each other in a given environment (Macal and North 2010). In the present case, we model the adoption of a BSEBM over a time of 100 time units vs. 1,000 time units and compare the impact of multiple parameters.

We constructed our model using NetLogo (Wilensky 1999)—an ABM environment with sophisticated capabilities to implement and run agent-based simulations and one of the most widely used tools for ABM (Railsback et al. 2006). NetLogo is considered suitable due to the software's proven track record in the social sciences and beyond, its comprehensive documentation and online support, and its feature-rich yet simple programming language (Railsback et al. 2006). The models were constructed and run in NetLogo version 6.0.2.

To explore our research questions, we employ an existing NetLogo model, DYNAMOD[4] (Zutshi 2015), as a basis. DYNAMOD is specifically designed to model the adoption of technologies and can be readily

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[4] We sincerely thank Aneesh Zutshi for providing the DYNAMOD model code for our research.

modified and extended (Zutshi 2015; Zutshi et al. 2013, 2014). We find DYNAMOD particularly useful as it focuses on digital business models such as multisided marketplaces and includes functionalities for modeling network effects and viral spread. Moreover, DYNAMOD provides a useful construct of influence and satisfaction values among agents to model adoption and rejection of a product.

Our model includes two groups of agents, *blockchainers* and *non-blockchainers*, describing their status as a user of a BSEBM. Following the original DYNAMOD model, we set the total population to 2,400 agents (*max-agents*). Out of the total population, 1% are assumed to be *initial-blockchainer* (i.e., users) from the beginning (i.e., early adopters). In each group, a variable percentage of agents (*moving-agents*) are assumed to be extraordinarily well connected to the whole population. We model these individuals by moving their agent to another, randomly determined location with every time unit within the reach of their network (*radius*).

Together, *moving-agents* and *radius* reflect the viral spread and word-of-mouth component of PV, a core parameter as described in the previous section. As a second component, *minimum-satisfaction* and *minimum-influence* model the responsiveness of an agent toward the formerly described word-of-mouth component. All agents that are *non-blockchainers* are subject to *influence* by their peers and by general network effects. If an agent's *minimum-influence* threshold is surpassed, then adoption would take place. The agent then becomes a *blockchainer* and subsequently receives a satisfaction score. If that score is lower than the *minimum-satisfaction* threshold, the agent abandons the BSEBM and adoption is reversed.

Varying the parameter *moving-agents* and *radius* therefore affects the environment, whereas the parameters *minimum-satisfaction* and *minimum-influence* determine the extent to which agents act on such influence.

Modeling Performance Expectancy and Effort Expectancy As described in the previous section, we model agents' PE and EE regarding BSEBM. Comparing these two parameters allows revealing how favorably potential users perceive the service. An agent may expect a BSEBM to perform well, but high usability barriers may keep the agent from adopting it. Likewise, a BSEBM with good usability would ultimately fail in delivering value if the agents expect low-class performance.

Modeling Pervasiveness and Attitude Moreover, we juxtapose the two constructs of AT and PV. A direct comparison of AT and PV reveals the impact of both on emerging patterns in user adoption. The reasoning is to differentiate between external and internal drives toward adoption. Whereas PV reflects an external influence on an agent, AT reflects the agent's own beliefs.

All our parameters PE, EE, AT, and PV are modeled with values ranging from 0 to 100, except *radius* which is scaled in whole numbers ranging from 0 and 20 (Zutshi 2015). For PE, EE, AT, and PV, a higher value implies a stronger impact on adoption. It is important to note that a higher parameter value of EE, therefore, reflects low (i.e., feasible) expected effort.

Model Construction

For the previously described construct of PV, we utilize DYNAMOD's (Zutshi 2015) capabilities of simulating network effects. A *network-effect-coefficient* is introduced which varies between −0.5 (*network-effect-lower*) and 0.5 (*network-effect-higher*) depending on the number of adopters within the *radius* of an agent. The *network-effect-coefficient* is multiplied by a *network-effect-constant* and added to the *influence* that is continuously assigned to each agent at every time unit.

Adapted from DYNAMOD, we construct *influence* from an *influence-constant* and five other factors (*pe-influence*, *ee-influence*, *at-influence*, *nb-influence*, and *gl-influence*). These five factors are dynamically changed with every time unit and are the product of their corresponding parameter with a k-value to weigh their impact (Zutshi 2015).

The last two factors, *gl-influence* and *nb-influence*, describe PV through a viral spread within the global context (gl) and within an agent's neighborhood (nb). Their corresponding parameter for *gl-influence* is the average influence of all other agents; for *nb-influence*, it is the average influence of other agents within the *radius*.

The parameters of the former three factors—*performance-expectancy* for *pe-influence*, *effort-expectancy* for *ee-influence*, and *attitude* for *at-influence*—are part of the scenario analyses, as described earlier.

The k-values for PV (nb, gl) originate from DYNAMOD (Zutshi 2015). The remaining k-values for PE, EE, and AT stem from a UTAUT meta-analysis (Dwivedi et al. 2017) and underwent standardization. By multiplying Dwivedi et al.'s (2017) five-point Likert-scale values with 25 and subtracting 25, we transformed the Likert scale to values between 0 and 1. This scale, ranging from 0 to 1 with three decimals, is already available in Zutshi (2015) and used in our model too.

The parameter *avg-satisfaction* is a key element of the DYNAMOD model as it plays an important role in the decision-making process of an individual agent to be or not to be a user, depending on their *satisfaction* and the *minimum-satisfaction* threshold.

The initial value of *satisfaction* has a major impact on the course of a model run and therefore requires rigorous testing. Adapted from DYNAMOD, the average satisfaction *avg-satisfaction* ranges from −1 to 1 with a standard deviation *sd-satisfaction* of 0.2. Its absolute value is closely connected to the absolute value of *minimum-satisfaction*, as the difference between these two parameters is equivalent to the amount to which each individual's satisfaction level needs to rise for that particular individual to adopt the technology. Since varying the parameter *minimum-satisfaction* is part of a scenario-analysis, the parameter *avg-satisfaction* undergoes a robustness test. Using NetLogo's BehaviorSpace, the parameter *avg-satisfaction* is tested for the values −0.2 (default), −0.1 (higher), and −0.3 (lower). At the end of the next section, we elaborate on robustness tests.

Overall, our model aims at exploring various potential scenarios. The context in question—business models for the sharing economy that are based on blockchain technology—is currently emerging and therefore does not yet provide robust empirical data to build on. Therefore, we base our parameters on previous related empirical research on technology adoption and digital business models (Dwivedi et al. 2017; Venkatesh et al. 2003; Zutshi 2015) with the limitation that we thereby can only approximate our parameter values. Therefore, we employ an explicitly exploratory and preliminary approach in our analyses.

Results

To address our three research questions, we simulated the eight scenarios of our matrices (Fig. 3.1). The first matrix (perceived-benefit-matrix) reflects the combination of PE and EE. The second matrix (internal/external trigger-matrix) relates AT to PV.

In the following two sections, we describe the results for both matrices in detail.

The Perceived-Benefit-Matrix

When deciding to adopt the BSEBM, agents evaluate their expected performance and effort. The relationship between the two parameters is summarized in Fig. 3.1. In an "ideal" case of high expectations on both performance and effort, the BSEBM may be competitive against "traditional" SEBM which are mostly of good usability and performance.

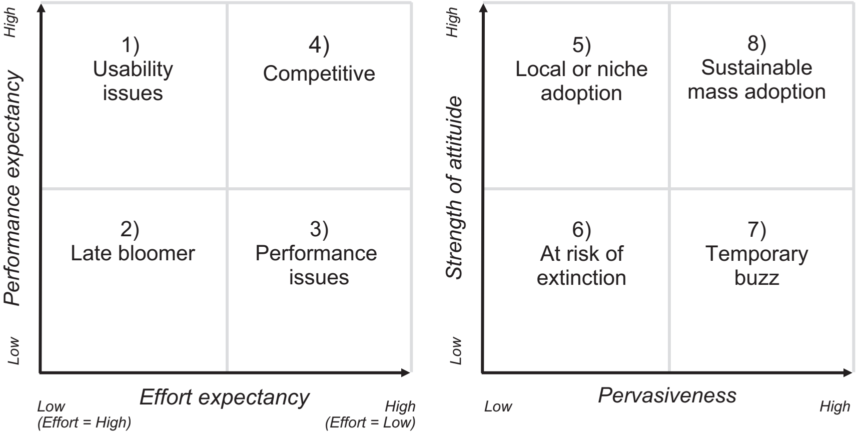

Fig. 3.1 Perceived-benefit-matrix (left) and internal/external trigger-matrix (right)

However, problems in usability and/or performance could diminish the relative adoption and even result in failure.

Figures 2 and 3 show how the parameter values of PE, EE, AT, and PV, as described in our four scenarios (Fig. 3.1), are related to adoption patterns of BSEBM.

For each scenario, we repeated the simulation for the long term. While Fig. 3.2 presents the short term (100 time units), Fig. 3.3 illustrates the long term (1,000 time units).

Table 3.2 displays relative adoption in the short term (100 time units) and in the long term (1,000 time units) at a glance. Each of the four cells presents a distinct percentage value describing the relative adoption of BSEBM in each scenario in the short term and in the long term, respectively. The remaining percentage values to 100% describe the total adoption of other SEBM for each scenario and duration. The numerical results of each scenario in Table 3.2 are mean values from 50 repetitions and,

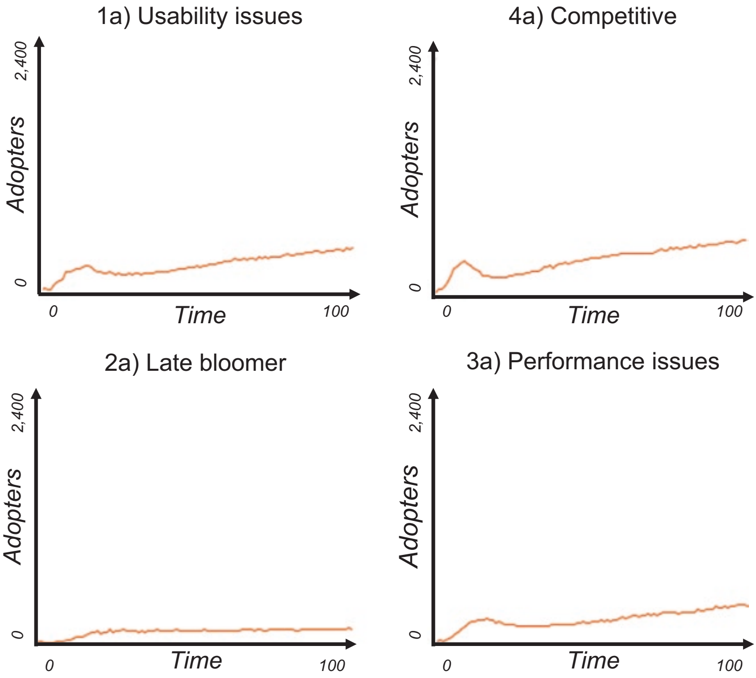

Fig. 3.2 Short-term scenarios of perceived-benefit-matrix (100 time units)

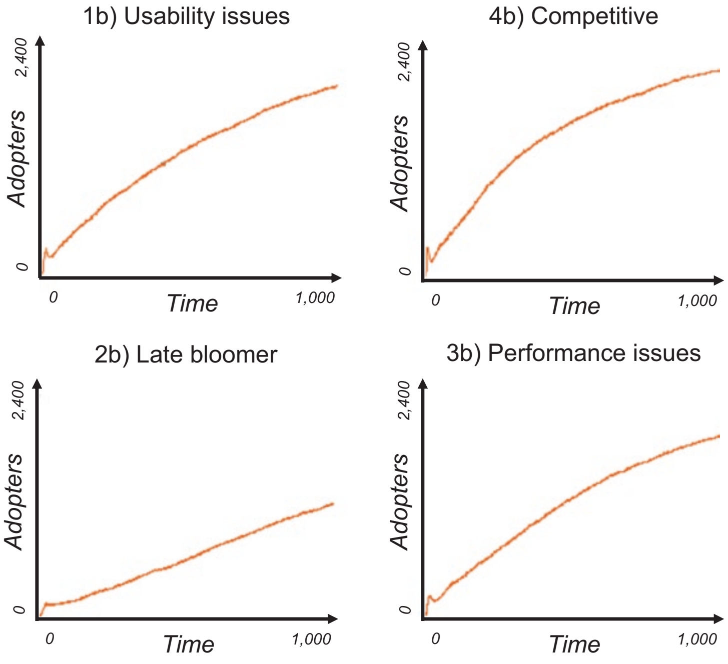

Fig. 3.3 Long-term scenarios of perceived-benefit-matrix (1,000 time units)

Table 3.2 Perceived-benefit-matrix by market share of BSEBM (in %)

		Effort expectancy	
		Low	High
Performance expectancy	High	Short term: 16.8% Long term: 84.4%	Short term: 23.2% Long term: 92.3%
	Low	Short term: 7.2% Long term: 51.2%	Short term: 15.0% Long term: 80.3%

hence, may slightly diverge from the exemplary curves in Figures 2 and 3 which display a single run out of 50 runs.

In the following sections, we elaborate on these adoption patterns in each scenario in the short term and in the long term.

Usability Issues If the expected performance is low but the expected effort is ideal, as shown in cell 1a in Fig. 3.2, the BSEBM fails to reach a majority of users. After 100 time units, only 16.8% of the agents choose to use a BSEBM. Therefore, this constellation of parameters has a rather small impact on short-term relative adoption. Initially, agents seem optimistic about the BSEBM and create notable growth in adoption (Fig. 3.2). However, the initial growth is soon to be corrected and is subsequently transformed into a tiny, yet positive growth rate, indicating performance issues.

However, with 84.4% of the agents being users after 1,000 time units, the model indicates that this constellation of parameters may lead to substantial adoption in the long term (see cell 1b in Fig. 3.3) and surpasses the "late bloomer" scenario.

Late Bloomer The next scenario, which we coin "late bloomer", is illustrated in cell 2a in Fig. 3.2. After 100 time units, 7.2% of the agents choose to use a BSEBM. Therefore, this constellation reveals a lack of substantial traction among the agents to adopt the BSEBM in the short term. In the present case of low levels of both PE and EE, a picture of stagnation emerges. An initial rise which is not an uncontrolled peak may seem to indicate a rise toward sustainability at first but quickly flattens out and leads to near-zero growth until the 100th time unit. Expecting neither a feasible effort nor a valuable performance, the agents see no reason for adopting the BSEBM.

However, the model indicates that this constellation of parameters may change fundamentally in the long term and may eventually lead to substantial adoption among a majority of the agents (see cell 2b in Fig. 3.3). After 1,000 time units, 51.2% of the agents have adopted the solution.

Performance Issues With a higher PE but poor EE, as shown in cell 3a in Fig. 3.2, relative adoption remains poor. After 100 time units, 15.0% of the agents choose to use a BSEBM. Therefore, this constellation of parameters has a similarly small impact on short-term relative adoption as the previously introduced set of parameter values. Like in the previous scenario, an initial rise in relative adoption is not maintained and subsequently flattens to a minor yet nonzero growth rate, as Fig. 3.2 shows.

The result of usability issues, therefore, has a significant effect on relative adoption but still allows for growth.

Yet again, like before, with 80.3% of the agents being users after 1,000 time units, the model indicates continuous growth which eventually flattens out but only due to potential market saturation, as indicated by cell 3b in Fig. 3.3. With the present set of assumptions, neither performance issues nor usability issues seem to persist in the long term.

Competitive The combination of high degrees of both PE and EE results in a striking degree of adoption with 23.2% of the agents having adopted a BSEBM after only 100 time units. A minor initial peak and immediate plunge in adoption do not stop subsequent growth in relative adoption (Fig. 3.2, cell 4a). With a solid number of users after already 100 time units, the BSEBM is considered competitive if it satisfies the agents with both convenient usability and effective performance.

Moreover, with 92.3% of the agents being a user after 1,000 time units, the model indicates that these parameters continue the path of the short-term prediction and eventually lead to market saturation (Fig. 3.3, cell 4b).

The Internal/External Trigger-Matrix

Our second approach to modeling relative adoption of BSEBM entails contrasting internal (AT) and external (PV) forces. On the one hand, agents are influenced by PV through viral spread and network effects. On the other hand, their inner strength of AT also impacts their adoption behavior. Only a combination of both high levels of AT and high levels of PV may be capable of reaching sustainable mass adoption. Merely having high levels of PV may result in lacking sustainability, whereas low levels of PV may merely lead to niche adoption or even extinction.

As can be seen in Figures 4 and 5, relative adoption varies considerably both across the four scenarios and also between the short term (100 time units) and the long term (1,000 time units).

For an overview, Table 3.3 summarizes these results in a numerical format reflecting the relative adoption. Like before in Table 3.2, all percentage values show how popular a BSEBM is in terms of adoption. The remaining percentage values to 100% reflect the total adoption including other SEBM. Like with Table 3.2, the following numerical results in Table 3.3 show the mean value of 50 repetitions and may represent a slightly different pattern than the exemplary model runs shown in Figures 4 and 5.

In the following sections, we elaborate on the results of each scenario.

Local or Niche Adoption High AT but low PV, as shown in cell 5a in Fig. 3.4, leads to an adoption of 8.3% after 100 time units. This constellation of parameters, therefore, has a minor impact on short-term relative adoption that also does not reach a mainstream of agents. As illustrated in cell 5a Fig. 3.4, a pattern of local or niche adoption emerges. The growth in adoption is tiny yet almost continuously positive. This means that there is a group of interested users who see value in the BSEBM, but widespread adoption is not materializing due to low overall PV (e.g., minor viral spread).

Intriguingly, however, the long-term analysis after 1,000 time units with 39.5% of the agents reveals that this set of parameters may eventually lead to substantial adoption (Fig. 3.5, cell 5b).

At Risk of Extinction As shown in Fig. 3.4 in cell 6a, users are not at all motivated to adopt the BSEBM. After 100 time units, only 3.2% of the agents choose to use a BSEBM, representing a low adoption over 100

Table 3.3 Internal/external trigger-matrix by market share of BSEBM

		Pervasiveness	
		Low	High
Strength of attitude	High	Short term: 8.3% Long term: 39.5%	Short term: 16.9% Long term: 95.0%
	Low	Short term: 3.2% Long term: 6.4%	Short term: 6.0% Long term: 6.3%

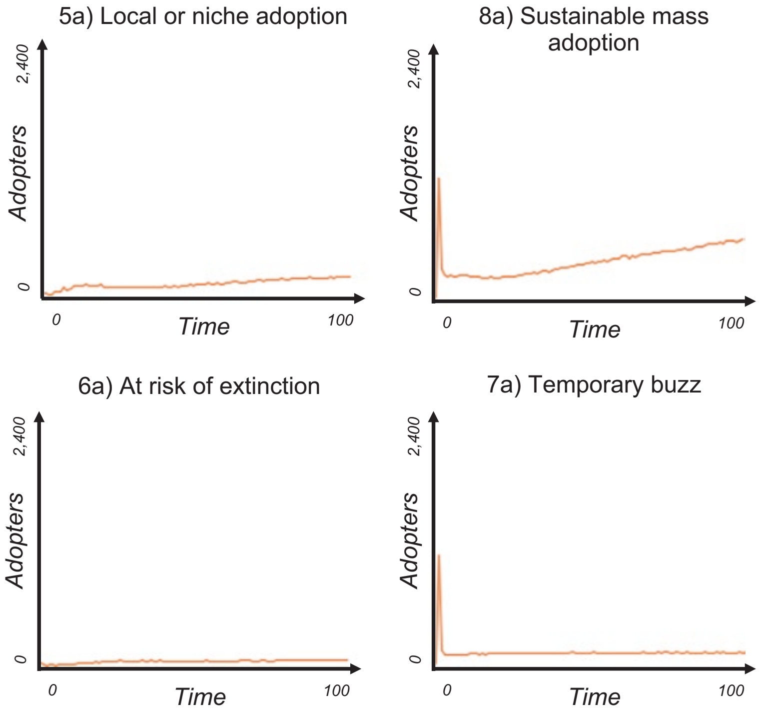

Fig. 3.4 Short-term scenarios of internal/external trigger-matrix (100 time units)

time units. Thus, as expected, in the case of minor strength of AT and low overall PV, the BSEBM is not adopted by a significant number of users. Potential users are neither motivated due to their own attitudes or values, nor are they triggered by their environment. The graph clearly indicates that adoption is stagnant and does not peak at any given moment (Fig. 3.4, cell 6a).

Even more intriguing, with 6.4% of the agents being users after 1,000 time units, the model continues to grow at a near-zero rate. Notably, as shown in Fig. 3.5 in cell 6b, the model does not result in extinction after 1,000 time units, yet the relative adoption is even farther away from total adoption.

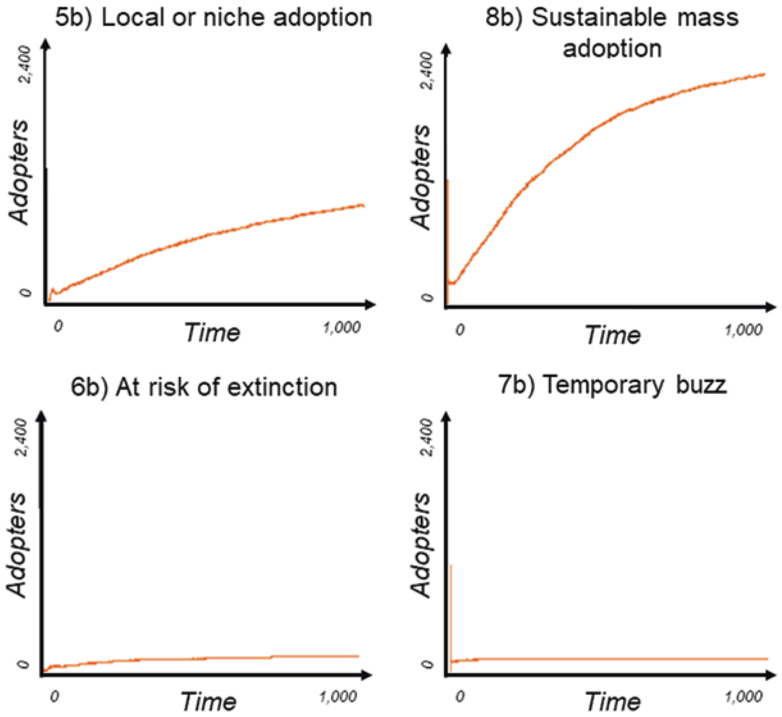

Fig. 3.5 Long-term scenarios of internal/external trigger-matrix (1,000 time units)

Temporary Buzz With low AT and high PV (Fig. 3.4, cell 7a), the resulting relative adoption is also neglectable. After 100 time units, 6.0% of the agents choose to use a BSEBM.

As shown in Fig. 3.4 the initial peak remains to have almost no long-term effect as the growth rate of users after the peak remains almost perfectly steady at a value near zero. Initially, a large share of agents is prone to adopt the BSEBM due to external influence from word of mouth and viral spread so that a large proportion of agents chooses to try the service. However, due to their low internal strength of AT, the time as a user is extremely short-lived for many agents who abandon the BSEBM immediately and never return.

With 6.3% of the agents being users after 1,000 time units (Fig. 3.5, cell 7b), the model stagnates over the remaining 900 time units and does not show any sign of growth or long-term potential.

Sustainable Mass Adoption The fourth scenario, as expected, describes sustainable mass adoption. As illustrated in cell 8a in Fig. 3.4 after 100 time units, 16.9% of the agents choose to use a BSEBM. Therefore, this constellation of parameters has a positive yet medium impact on short-term adoption. With high AT as well as high PV, a distinct pattern results that appears to illustrate organic growth. Even though, at first, the initial peak reminds of a hype as it is followed by a strong decline in user count immediately after the peak. After the drop, however, the BSEBM keeps growing continuously and reaches a remarkably steady user base.

Moreover, as shown in cell 8b in Fig. 3.5, with 95.0% of the agents being users after 1,000 time units, the model indicates that this constellation of parameters may lead to a potential saturation of the market in the long term.

In the next section, we explore the robustness of our model and the previously presented results.

Robustness of the Model

Using NetLogo's BehaviorSpace feature, we conducted thorough robustness checks of our model (following Wilensky and Rand 2015; see also Alden et al. 2014 and Groenhuijzen and Verhagen 2016). BehaviorSpace is a batch experiment tool in NetLogo to run a model multiple times with different settings (Wilensky and Rand 2015), allowing for repeated model runs with identical parameters and further repetitions with varied parameters. In the following sections, we refer to our original model with default values of both k-values and *avg-satisfaction* as the "standard model".

Random Seed NetLogo simulations include an integer *random seed* which by default is generated pseudo-randomly from the current date and time and thus is generated deterministically (Wilensky and Rand 2015). The exact date and time will always lead to the same random seed. However, depending on the random seed, results can vary dramatically. This intentionally enriches the data to reflect on “unknown unknowns” that are exogenous to this model. To preserve reproducibility of this model, an average was taken of each simulation after running the model for 50 times with 50 different random seeds.

By taking the average result across 50 model runs with 50 different deterministically generated random seed integers, our model, thus, ensures reproducibility while preserving randomness.

Robustness of k-Values We also evaluated how robust our model is to variations of the k-value corresponding with each parameter by testing each scenario for lower (50%) and higher (100%) k-values.

In the perceived-benefit-matrix with 100 time units, reducing the k-values to 50% of the standard model results in an adoption between 48% and 93% compared to the standard model. The adoption rates in cells 1, 3, and 4 are similarly low (54%, 48%, and 62%, respectively), indicating a change that is roughly proportionate to the standard model. Cell 2, however, stands out with an adoption rate of 93% compared to the standard model, indicating that the combination of low/low PE and EE is barely affected by changed k-values and does not respond proportionally, whereas the three other cells with low/high or high/high combinations of PE and EE do vary.

Raising k-values to 200% compared to the standard model equally preserves their overall shape and leads to a more pronounced initial peak. All cells 1, 2, 3, and 4 are similarly affected (188%, 179%, 172%, and 181%, respectively) compared to the adoption rates in the standard model, indicating proportional change across the board.

In the internal/external trigger-matrix, after 100 time units, with reduced k-values of 50% of the standard model, adoption rates range between 56% and 69% compared to the standard model. Thus, the cells 5, 6, 7, and 8 are all similarly affected by reduced k-values.

In the case of increased k-values of 200% compared to the standard model, the adoption rates after 100 time units are between 96% and

180%. Cells 5, 6, and 8 are all affected at the upper end of the range (180%, 176%, 161%), indicating that any combination of low/high or high/high of AT and PV values changes the adoption rate roughly proportionate to the increase of the k-values. The adoption rate in cell 7, however, amounts to 96% compared to the standard model, showing that the combination of low AT and high PV values is barely affected by higher k-values and does not change proportionally.

From these analyses, we conclude that variations of the k-values keep the overall form of the curves in place and reveal an impact on adoption rates that is mostly proportional to the change of the k-value. Hence, we consider the model robust to changed k-values.

Robustness of Satisfaction As with the k-values, we tested our model for robustness to changed values of the parameter *avg-satisfaction*. The following paragraphs present the results of changing *avg-satisfaction* from −0.2 in the standard model to a lower (−0.3) and a higher (−0.1). These values are closely related to *minimum-satisfaction*.

In the perceived-benefit-matrix after 100 time units, a lower *avg-satisfaction* of −0.3 results in a graph of similar shape with an equally significant initial peak. The adoption rate after 100 time units is between 29% and 45% compared to the standard model. Cell 2 with a low/low combination of the parameters PE and EE is most affected with 45%. Cells 1, 3, and 4 are affected with 29%, 31%, and 36%, respectively, showing that any combination of the parameters PE and EE other than low/low is less affected by lower satisfaction levels.

Moreover, a higher *avg-satisfaction* of −0.1 leads to adoption rates between 226% and 377% compared to the standard model, showing how sensitive the model responds to the *avg-satisfaction* parameter. However, as before, the curves are similarly shaped. Cell 2 is most affected by 377%, indicating that low/low combinations of PE and EE are highly affected by higher satisfaction levels. Compared to cell 2, the adoption rates in cells 1, 3, and 4 are less affected (246%, 226%, and 229%, respectively). These results show that low/high or high/high combinations of PE and EE are highly affected by adoption rates but not as much as the low/low combination.

In the internal/external trigger-matrix, again after 100 time units, both reducing and increasing *avg-satisfaction* result in a similarly shaped graph with a comparably considerable initial peak in adoption rates. Tests with the lower value (−0.3) of *avg-satisfaction* show that cells 5 and 6 result in adoption rates of 46% and 47%, respectively, compared to the standard model. However, cells 7 and 8 with higher levels of PV result in adoption rates of 19% and 29% of the standard model, respectively, indicating that scenarios with lower levels of PV are less affected by lower satisfaction levels than scenarios with higher levels of PV.

Furthermore, increasing *avg-satisfaction* to −0.1 results in adoption rates between 226% and 394% in comparison to the standard model. Cells 6 and 7 are most affected (329% and 394%, respectively), indicating that the low/low and the low/high combinations of AT and PV values are more affected by higher satisfaction levels than cells 5 and 8. The latter are less affected than cells 6 and 7, but with adoption rates of 237% and 226%, respectively, the cells 5 and 8 are still highly affected in comparison to the standard model.

As expected, we conclude that our robustness tests show that all eight scenarios are sensitive to varying values of the parameter *avg-satisfaction*. However, the overall form of all eight curves remains intact. Moreover, varying values of *avg-satisfaction* are not always resulting in uniform changes among adoption rates (e.g., for a higher value of *avg-satisfaction* with the internal/external trigger-matrix, the adoption rates range relatively widely from 226% and 394% as compared to the standard model).

Discussion

Summary of Results

We set out to examine the emerging phenomenon of blockchain, a technology that may give rise to novel decentralized business models in the sharing economy (Beck et al. 2018; Voshmgir 2017; Tapscott and Tapscott 2016a, b). In this vein, the objective of our chapter was to explore the adoption of such decentralized blockchain-based sharing economy business models (BSEBM). More specifically, we investigated how BSEBM adoption is impacted by the parameters PE, EE, AT, and PV that we derived from prior research (Dwivedi et al. 2017, Zutshi 2015). We demonstrated that the adoption of BSEBM is dependent on users' expectations on BSEBM performance, expected effort and usability, a user's attitude and value-based perception of BSEBM, and the overall pervasiveness of a BSEBM (e.g., in terms of network effects and switching barriers). Notably, the personal attitude of users toward BSEBM has a profound effect on whether adoption is sustainable or remains temporary (e.g., in the form of a trend or hype). In other words, we found that even strong pervasiveness is not sufficient for BSEBM to be permanently adopted if a user's value-based perception is not favorable to a particular BSEBM.

Moreover, our results show that time (i.e., short term vs. long term) has a profound impact on some but not all scenarios. For instance, whereas a combination of low PE and low EE leads to negligible and stagnant relative adoption in the short term, the same combination does eventually reach significant adoption in the long term. On the other hand, low AT prevents adoption even when PV is high and even in the long term.

Implications for Research

Our chapter demonstrates the importance of taking a user adoption perspective to BSEBM. While the extant discourse often centers on technological and governance issues, we posit that for BSEBM the user perspective needs to be taken into account to a much larger extent. Our perspective is consistent with current approaches (e.g., UTAUT; Venkatesh et al. 2003) and earlier accounts of user adoption (e.g., technology diffusion theory; Rogers, 2003) in highlighting the pivotal role of users' attitudes and behaviors as a prerequisite for potential mass-market technology adoption. Whereas prior research has conceptually examined to what extent blockchain technology already meets central attributes of innovation diffusion (Friedlmaier et al. 2018), we extend this research stream by theoretically deriving possible adoption scenarios and simulating these scenarios in the short term vs. long term. While our results are congruent with prior studies in pointing to the importance of including time (i.e., short term vs. long term) as a crucial dimension in adoption models, our research makes an exploratory effort, and we need much more fine-grained research to address temporal questions of user adoption (Zutshi 2015; Zutshi et al. 2013, 2014). Moreover, research is needed that includes moderating variables, such as the moderating variables present in the UTAUT model (e.g., gender, age, or experience; Venkatesh et al. 2003). Such research could reveal further adoption patterns among these variables that may otherwise be "averaged out". Moreover, including the UTAUT parameter *social influence* (i.e., "the degree to which an individual perceives that important others believe he or she should use the new system"; Venkatesh et al. 2003, 451) would allow conclusions regarding society-wide values and norms. It would be interesting to test whether social influence (external and value-driven) significantly differs from AT (internal and value-driven) and PV (external and non-value-driven). Finally, we encourage further studies using variables from UTAUT2 (Venkatesh et al. 2012) and including its three novel constructs of *hedonic motivation*, *price value*, and *habit* to theorize on their influence in BSEBM.

Our chapter also advances the current debate on BSEBM by highlighting the importance of usability variables vis-à-vis users' positive AT toward BSEBM. We maintain that for mass-market adoption, positive user attitudes toward BSEBM will not be sufficient to motivate a considerable number of users to convert to BSEBM but that rather usability and accessibility issues are of high importance for considerable adoption beyond a niche. Users will not necessarily appreciate blockchain technology or the concept of decentralization per se unless it is more than or at least as convenient as "traditional" online platforms of the sharing economy. In fact, similar to most current Internet users being unaware of how the Internet actually works, users of BSEBM will not necessarily understand the technical details of blockchain or use it for merely "cognitive" or "ideological" reasons (e.g., decentralization). By pointing to these issues, our chapter lays the groundwork for more research to investigate how customers make trade-off decisions between using decentralized BSEBM vs. centralized SEBM. Since decentralized BSEBM have only recently been made possible by novel technology, we need more theory and empirical research on when (i.e., under which circumstances and in which contexts) decentralization vs. centralization is appropriate and actually desirable. A promising pathway to evaluating decentralized vs. centralized business model designs could be to apply our model to the first decentralized blockchain applications receiving widespread attention across a major population beyond early adopters and technology enthusiasts. Understanding early successful applications that prove the value of blockchain technology for novel business models (i.e., so-called killer applications) may be an opportunity to conceptualize its value proposition.

Implications for Practice

Our findings also have implications for practice both at an infrastructure level and at an application level. In the light of some blockchains such as Bitcoin and Ethereum not being as decentralized as expected (Gencer et al. 2018), users may conclude that a BSEBM may not sufficiently fulfill their attitudes and corresponding values and beliefs. As we showed in this study, the level of AT can have a profound effect on adoption. Moreover, users place a high value on convenience and accessibility when they anticipate the effort and performance of a BSEBM. Therefore, blockchain startups need to ensure superior or at least sufficient usability and user experience among BSEBM when they want to compete against their centralized counterparts.

To act on such suggestions, there need to be sound, well-founded educational resources and initiatives. Building blockchain technology is fundamentally different from traditional software development in some regards, for instance, in terms of testing environments, bug-fixing procedures, or system performance (Porru et al. 2017). Likewise, developing a business model in the blockchain space including a clear idea of how a blockchain-based business model creates value brings up completely new challenges. Thus, we need to build competencies by employing extensive and early on education on blockchain for developers, designers, and business developers alike.

Importantly, new blockchain startups need to clearly communicate where they see the benefit of blockchain technology and explain the concrete value proposition over and above extant solutions in a precise and specific way. There is no point in building blockchain for the sake of blockchain and decentralizing for the sake of decentralization (Tumasjan 2018; Welpe et al. 2015). Instead, doing so requires careful investigation including potential downsides. With blockchain still receiving an inflated degree of expectations according to the Gartner Hype Cycle (Walker 2017), it is important to assess for which use cases blockchain is valuable and for which use cases it does not make sense. Clearly, blockchain is no panacea, and startups should therefore clearly point out how they build better solutions than existing ones.

Limitations

Our study also has several limitations. First, ABM as a methodology is different from "traditional" empirical research. Simulation-based models like ours are inherently limited due to their simplified design and, thus, prone to predicting biased scenarios due to incompleteness (Seidl 2014). Moreover, like other agent-based models, our model faces a trade-off between the number of agents and computational resources (Wilensky and Rand 2015). Since increasing the number of agents requires significantly more computing power and time, we restricted the population to a size of 2,400 agents.

Second, our own model has various inherent limitations. We only focus on four parameters to analyze our adoption scenarios. We evaluated theories of technology adoption and provided a rationale on why we selected the four parameters of PE, EE, AT, and PV. However, the literature on technology adoption provides many other concepts that may likewise contribute to explaining the adoption of BSEBM and which are not part of our early exploratory study.

Third, our model illustrates adoption patterns in terms of their relative and roughly approximated magnitude (rather than precise values) by comparing high and low values of each parameter using scenario analyses. Moreover, our model computes heterogeneous agent parameters by normally distributing each parameter through an inbuilt function in NetLogo. Therefore, the emerging patterns only represent an exploratory starting point and, of course, require further validation.

Future Research

Building on the results of our study, we encourage future research to validate and extend our model. First, empirical research is needed to refine our parameters describing the driving forces in BSEBM adoption. Our four parameters need to be replicated and refined through survey data on actual user data once such significant amounts of empirical data on BSEBM adoption are available. Moreover, other parameters should be considered to enhance our scenarios and modeling of user behavior.

Second, decentralized business models overall require much more research. Many open questions remain and include the following: What are the advantages and disadvantages of BSEBM? What are decisive criteria for users to adopt such decentralized services? When, and in what way, are BSEBM superior to centralized business models? What are common trade-offs that users make between decentralized and centralized business models? With our study, we lay the groundwork for future research reassessing and extending our findings both conceptually and empirically.

Third, the sharing economy, in particular, provides many opportunities for further research on the specifics of the potentially dawning decentralized paradigm of blockchain. What are the conditions for decentralized business models in the sharing economy to materialize? How do BSEBM compete against SEBM from incumbents? Which factors or stakeholders are decisive in fostering change?

Fourth, we encourage scholars from a variety of disciplines beyond computer science and management research—such as design research, law, economics, sociology, psychology, philosophy—to investigate BSEBM to explore their potential implications for economies and societies.

Fifth, we see great potential in ABM applications in the social sciences and follow Epstein's (2012) call for further experimentation and applications. To improve our model, we would initially propose to include more parameters and data of actual BSEBM use. Moreover, we propose to extend our scenario analysis through temporal analysis in order to explore new patterns and replicate existing results.

Conclusion

The emergence of blockchain as a peer-to-peer technology poses the question of how blockchain technology and BSEBM may be adopted depending on individuals' attitudes and their environment. We analyzed adoption patterns across eight scenarios in the short term and in the long term. We found that users' expectations and attitudes play a crucial role for the adoption of BSEBM and that adoption patterns vary considerably for the short term vs. the long term. We hope that future research will build on our results to further advance our knowledge on the increasingly important topic of blockchain-based business models.

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4

Blockchain as a Platform

Florian Glaser, Florian Hawlitschek, and Benedikt Notheisen

Introduction

Digitalization is a ubiquitous term and refers to the digitization of processes and information alongside improvements, innovations, and reinventions that are enabled by increasingly powerful information technology. Today, nearly every industry sector is affected by digitalization and is facing threats and opportunities through new possibilities. With the rise of the digitalization, the platform approach has become the dominant strategy for large companies to operate an extensible, digital medium of exchange for products, information, and services. A large share of companies with the highest market capitalization based their business on platforms (e.g., Apple, Alphabet, Amazon). The earlier evolutionary stages of today's digital platforms were two-sided markets, where two groups of users exchanged goods and every internet user could take the role of either a buyer or a seller (e.g., eBay). Over the last decades,

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it became a common decision to open up a platform to third-party service developers who could reuse the platform's core functionality to build complementary components. This opening up of platforms is referred to as "permissionless innovation" (de Reuver et al. 2017). A digital platform is defined as "a system that can be programmed and therefore customized by outside developers users and in that way, adapted to countless needs and niches that the platforms original developers could not have possibly contemplated" (Parker and Van Alstyne 2017).

Given the definition above, we can derive features that distinguish a platform from a two-sided market: the openness to innovation through third-party developers. That is, platforms provide application programming interfaces (APIs) which grant developers access to core functionalities provided by the platform for integration of extended functionality, external services, or platforms. A recently emerging type of digital platforms is blockchain systems. Although they can be considered platforms according to the discussed definition, they fundamentally differ with respect to the provision of their core functionality.

A blockchain is a distributed, immutable, append-only database without a central authority that orders and validates transactions to keep data consistent across multiple nodes. In public blockchain systems, every internet user can operate a node and access core functionalities by simply downloading and running a client software. In public blockchain systems, the core functionality is transacting system-inherent tokens. For the Bitcoin platform, sending a (fraction of a) Bitcoin (token) represents the core functionality of the system. The term 'distributed ledger technology' (DLT) is often used interchangeably but extends the notion of a blockchain to a system type that comprises systems under centralized control (permissioned/private systems) of a single organization or a small group of organizations and might apply differing mechanisms to validate transactions and to retain consistency of data. Besides, the term 'blockchain' is often used interchangeably to refer to the underlying data structure, a specific type of decentralized database system, or the network as a whole including users and smart contracts. In contrast, DLT is neutral regarding technical peculiarities and always refers to the distributed system that tracks changes to data and ensures its consistency through a consensus mechanism among group of users with potentially conflicting interests.

Smart contracts are a second core functionality of most blockchain systems. They are small code snippets that are published in the blockchain system by a participant and can subsequently be used by other participants or contracts. Smart contracts are triggered through a transaction that is sent either by a user or by another smart contract during that other contract execution. This interaction of contracts enables complex systems of interacting services that are implemented in the form of smart contracts. The functionality programmed into a contract can range from performing additional checks regarding a token transaction (for instance, to enable conditional payments) or represent a whole service logic, for example, an escrow mechanism or an asset registration service. The control over a contract and hence also the control of the implemented service is defined by the creator of the contract. Control can be left to its creator, another user in the system, or no specific entity at all. The latter setup, autonomy of control, renders the contract an autonomous entity or agent in the system who acts according to its programmed logic, no matter who interacts with it. This last possibility enables a new kind of autonomous service system that can enforce programmed logic, free of any third party's influence, and allegedly requires no trust in a third party to actually execute the service.

These briefly outlined properties render blockchains a potential infrastructure for various (novel) business models in today's digital platform economy, ranging from P2P sharing and P2P lending, over autonomous asset registries, to completely crowd-based financing and investing. Although blockchain technology has been around for nearly a decade (Nakamoto 2008), few sociotechnical challenges have been sufficiently researched and few best practices to address key challenges have been developed. The goal of this chapter is to arrange blockchain technology within the concept of institutions and explain and discuss two resulting key challenges—governance and trust—of such decentralized and potentially autonomous service systems, by drawing upon research on incumbent digital platform models.

Blockchain Systems as Open Digital Platforms

Conceptualization and Sociotechnical Challenges

From an abstract perspective, blockchain systems can be analyzed on two distinct layers: the fabric layer and the decentralized application layer (dapp or application layer) according to Glaser (2017). The fabric layer comprises the P2P communication, consensus, and database management components. The application layer includes all services and features implemented in the form of smart contracts and is relying upon the functionalities provided by the fabric layer. Application layer services can be (re)used by other users in the same blockchain system. A smart contract-based service, for example, can require services of other smart contracts or might require token transactions on the underlying level for performing its service (Fig. 4.1).

A visualization of the technical layers is depicted in Glaser (2017). Both layers of a blockchain system are providing core functionalities that

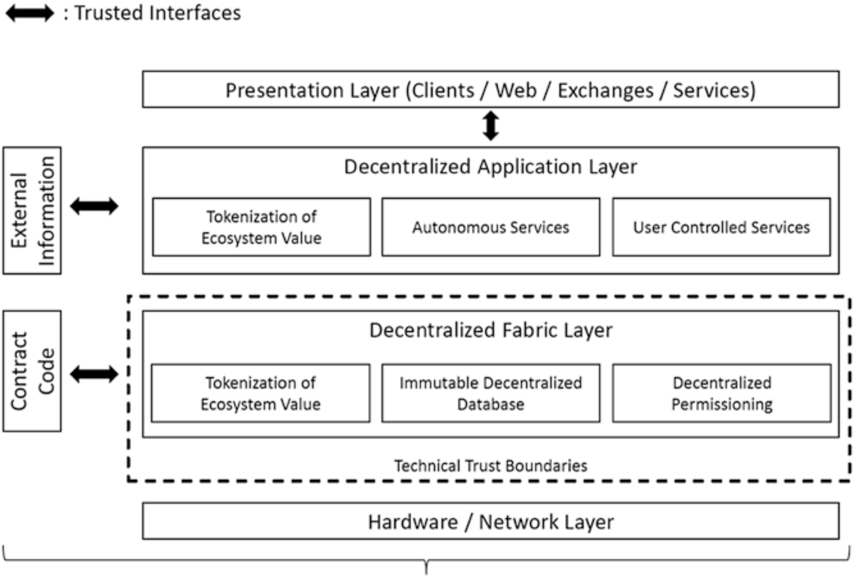

Fig. 4.1 Technical layers of a blockchain system, based on Glaser (2017)

are open to be used or extended by users of the system. Hence, blockchains are open platforms, and therefore research on and knowledge about digital platforms and blockchain share a common ground.

A crucial difference to digital platforms is, however, that blockchains do not provide a common application programming interface (API) to interact with service interfaces, but the possibility to deploy code onto the platform's fabric layer which is shared by all users. To set up a smart contract, a user has to attach code to a transaction and send the transaction into the network. Other nodes in the system receive the transaction, attach it to the blockchain of transactions according to the consensus mechanism, and can thereafter retrieve the code of the contract from the blockchain database. Thus, once a smart contract is deployed in the blockchain, its code is available at every node for execution whenever a user calls the contract. Put differently, the functionality of the entire platform can be extended by any user through deployment of smart contracts onto the fabric layer.

Incumbent digital platforms are usually governed by larger corporations or organizations that have full control over additional features provided for the platform. The governing company is in control of the technical APIs of its platform or in control of the extensions that are available and published for the platform. For example, Google governs its android platform's Playstore, and Apple is in control of iOS' App Store, while Facebook is in control of its platform's APIs.

In summary, blockchains' core functionalities are solely developed and operated by a multitude of open-source developers (that develop the fabric layer) and participants ('miners' that validate transactions) in a globally distributed system with extending functionality provided by users (on the application layer). There does not have to be a single organization or corporation that is coordinating the development or overseeing the operations of the fabric layer. Although, in practice, a crowd/privately funded organization is often in charge of coordinating the selection and implementation of future features of a fabric layer.

While this holds for the fabric layer, smart contracts can be written by any participant who might be a single user, a nonprofit organization, or a corporation. These properties render a blockchain system a decentralized, open digital platform that provides a set of core functionalities for others to build upon, which is, however, changing over time through contributions of arbitrary other users. This allows blockchain-based platforms to function as a decentralized institution that enables and implements new forms of governance mechanisms. However, the distributed nature of such systems also requires a new form of governance mechanisms as neither the fabric layer nor the application layer has a central authority that can deliberately impose binding processes. Given the inherently distributed nature of public blockchain systems, previous approaches might apply to some degree but are challenged by these new and pervasive sociotechnical interaction mechanisms.

The openness of public blockchain systems further implies that smart contract code can be developed and deployed by any participant. Relying upon services provided by publicly available smart contracts requires trust. On the one hand, the user has to trust in the correctness of the code. This requires the user to trust the developer of the code and the code that it performs exactly the way the user expects it to do. The alignment of expectations and reality regarding performed functionality of code might be possible for simple contracts but becomes nearly impossible for complex service networks that are composed of a multitude of interacting contracts.

If these trust requirements are fulfilled, the actual execution of the code in its unchanged version is comparably reliable, that is, ‘trust-free’, as the code is deployed into a large distributed system and once deployed cannot easily be manipulated or changed. This resembles the actual meaning of a stipulated enforcement of a ‘smart contract’ as by proposed by Szabo (1997).

However, this trust-free property is limited to the consensus regarding smart contract code execution and data that is generated within the blockchain system (i.e., trust in system information about token transactions between users). As soon as external data might be required for a smart contract to execute (e.g., sensor data, financial time series data, or any other data describing the state of the physical world), additional trust in the externally provided data is needed.

These two issues induce two severe sociotechnical challenges, governance and trust, if blockchains are to become ubiquitous and utility-bearing parts of our future digital economies and societies. The remainder of this chapter discusses these two challenges in more detail and in explicit sociotechnical and socioeconomic contexts.

Institutional Characteristics and Governance Implications of Blockchain-Based Platforms

Institutions form the core of any governance mechanism. To create a rudimentary understanding of institutions and how they work, this section gives a brief introduction to the field of institutional economics, builds on this foundation to arrange blockchain technology within the concept of institutions, and discusses the resulting governance implications.

The Role of Institutions

To provide a common starting point, we follow North (1991) and define institutions as "[…] humanly devised constraints that structure political, economic, and social interaction" (North 1991, p. 1). As such, they consist of both formal and informal rules that take the behavior of individuals into account. These behavioral factors comprise the impact of agency costs (Jensen and Meckling 1976), the consequences of separation of ownership and control (Fama and Jensen 1983), the relevance of property rights associated with interactions (Demsetz 2000), the social costs generated by external effects (Coase 2013), and the impact of transaction and coordination costs on organizational structures (Williamson 1979).

The purpose of institutions is to structure interactions and organize human behavior by constraining action spaces, attributing a set of possible reactions to possible actions, and collectively assigning a function to objects. We can formalize this perception by the saying X counts as Y in C

$$\mathrm{X} \rightarrow \mathrm{Y}, \text{in } \mathrm{C}, \tag{4.1}$$

where X stands for the domain of physical and nonphysical objects that are allowed by the institution (i.e., the action spaces), while Y is the function assigned to them. C represents the institutional environment that defines the manifestation of X and Y and the relationship between them. It restricts the available set of actions in X by specifying which objects belong to X and assigns a possible set of functions Y to these objects. These enabling rules are embedded in the transformation function and allow individuals to act within a specific spectrum. Both restricting and enabling rules are equally important as they depend on each other.

This way, institutions impose consistency on human activities, which allow interacting parties to "[…] create stable expectations about the behavior of others" (Hodgson 2006). The resulting order of social life and interactions reduces transaction costs as institutions prescribe the behavior of individuals to reduce the need for costly information and enforcement activities (Coase 1937; Jensen and Meckling 1976; Williamson 1979).

As highlighted before, institutions can be formal or informal, and thus do not require an explicit representation in order to exist and be relevant (Hodgson 2006). In addition, they form either directly or indirectly as a result of the combined effort of a society and its individuals (Tuomela 1995). Formal institutions are written rules that prescribe specific behavior and provide a basis to enforce it. In case of violations, they also specify sanctions that allow a (centralized or decentralized) authority to enforce the previously agreed arrangement. Informal institutions, on the other hand, are usually not available in an explicit form and manifest on the basis of reciprocity as individuals implicitly agree on them by behaving accordingly. In addition, enforcement is not specified in advance, and instead violators are punished by spontaneous feedback of the society (e.g., by exclusion). Independent of their formal or informal nature, institutions can form either spontaneously, which is when their existence leads to an improvement for a society as a whole (Foss 1996), or as a result of a conscious design (Smith 2003). In the case of a conscious design, the individual agents that form a society negotiate rules to govern interactions in their social and economic life in order to reach some superordinate goal. Figure 4.2 summarizes the dimensions of institutions and illustrates their assorted characteristics. It is important to note that

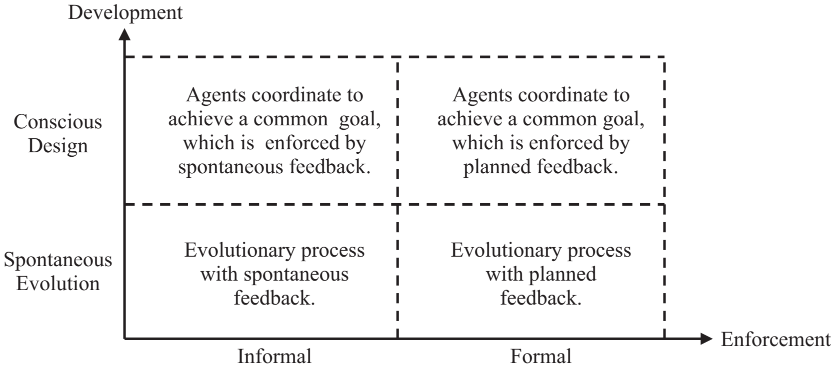

Fig. 4.2 The dimensions of institutions

institutions—irrespective of their level of formalization and their origin—are not fixed and are subject to change as societies evolve over time (Ostrom 1986):

$$X(t) \rightarrow Y(t), \text{in } C \tag{4.2}$$

To ensure that they adapt accordingly, rules have to be renegotiated or adapt implicitly, as the sociotechnical and economic environment evolves continuously and interacting individuals change their behavior.

The Blockchain as an Institution

Based on the understanding of the role, characteristics, and key components of institutions developed in this section, we apply this understanding to blockchain-based platforms.

First, we will take a look at the key components, namely, restricting and enabling rules that span the governing scope and define the fashion of order an institution establishes. Transferring this concept to blockchain systems, the fabric layer restricts the action spaces of its users by setting the boundaries of the technical infrastructure, thus constraining the scope of possible application scenarios. As highlighted in the section

'Conceptualization and Sociotechnical Challenges' and Glaser (2017), the fabric layer specifies the characteristics of a blockchain system and thus determines its application domain and scope of governance. Building on the fabric layer, the application layer empowers individuals to shape the way they interact with each other. It enables users to assign a function to the generalized IT artifact defined by the fabric layer and engage in concrete interactions, by allowing users to tokenize values, provide and use services, and conduct transactions.

The fabric layer of the Bitcoin blockchain, for instance, is specified to conduct transactions between pseudonymous counterparties without a central intermediary while allowing only a highly limited incorporation of program/software logic via opcodes. In consequence, the action space is constrained to actions related to transferring some number values between users. However, this limited functionality enables its users to use Bitcoin as a peer-to-peer payment system. In other words, it allows the users of Bitcoin to act within a given spectrum and provides a common understanding of the Bitcoin system as an electronic cash system.

In contrast, the Ethereum blockchain goes beyond the concept of a pure cryptocurrency and incorporates a shared global infrastructure that allows the implementation of smart contracts by intentional design. As a result, it enables a variety of assigned functions that range from the simple functionality of a cryptocurrency known as Ether, over transaction systems (Notheisen et al. 2017a), to decentralized autonomous organizations (Jentzsch 2016) and marketplaces (Notheisen et al. 2017b). This functional scope has multiple advantages, such as the automation of governance, but also impedes the development of a common understanding of its assigned function(s).

Second, we arrange the blockchain protocol, which includes fabric and the application layer, as well as adjacent processes such as protocol development and maintenance within the institutional dimensions introduced (see Fig. 4.2), in order to highlight and understand the multifaceted nature of blockchain-based platforms.

The fabric layer, which forms the technological foundation of each blockchain system, is usually the result of a conscious design of a small group of core developers that coordinates to achieve a common goal, such as providing a fully decentralized electronic cash system in the case of Bitcoin. The resulting system aims to contribute to a collectively determined goal of society by reducing the coordination efforts of individual agents required to achieve this goal. With respect to blockchain technology, such a goal could be the transfer of assets between interacting parties without relying on a central authority. However, whether a specific blockchain fabric becomes widespread standard or fails to establish in the institutional landscape cannot be enforced by the protocol itself but is rather determined implicitly by its actual use.

If a user does not agree with the proposed protocol, he or she can provide an update to the system to which other users can switch if they prefer the proposed update. As a result, the compliance with a specific blockchain fabric is enforced via network effects based on the implicit vote of users by joining a proposed protocol or protocol update or sticking with the incumbent system version.

In addition, blockchain fabrics that have the reputation of not functioning well or giving unfair advantages to a specific group of users are also punished by social feedback (i.e., a bad reputation), which in turn leads to an absence of users.

In most cases, the fabric layer is maintained and updated by an open-source community or an organization that is based on an open-source community (examples include Bitcoin Foundation or the Ethereum Foundation). These maintenance mechanisms form as a result of an evolutionary cultural process within the specific communities and often build on the altruistic aspiration to improve the underlying protocols. Compliance with specific rules, customs, and manners within these communities is usually enforced by social feedback.

The application layer, which embeds payment services, smart contracts, and other functionalities, results from the conscious design of the fabric layer, which enforces the compliance of interacting agents with their previous commitments based on technical specification of the blockchain system (Beck et al. 2018). More specifically, individual agents can only engage in a transaction with assets for which they can provide a verifiable proof of ownership (e.g., by referencing to received transactions stored in older blocks), and the settlement of a transaction takes place as a direct consequence of the consensus mechanism. The same logic applies for contractual agreements implemented in smart contracts and nonmonetary transactions within more complex smart contract-based platforms.

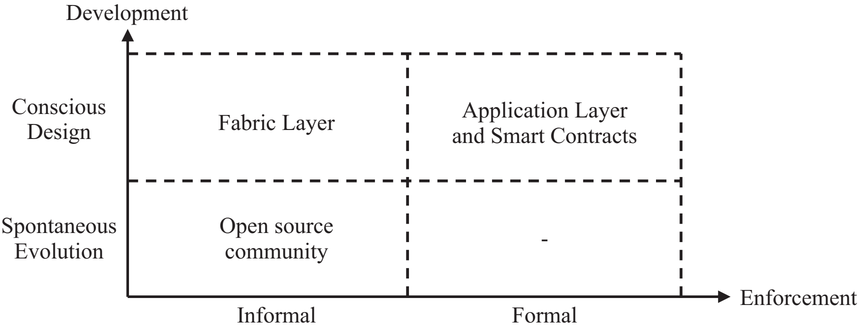

Fig. 4.3 The institutional dimensions of blockchain-based platforms

Figure 4.3 summarizes and illustrates the arrangement of the blockchain's institutional characteristics within the dimension of institutions introduced in the section 'The Role of Institutions.' In total, this illustrates how blockchain systems resemble the key components of institutions and highlights the enforcement channels that blockchain technology utilizes in order to govern the interactions of individual users of an open platform.

Implications for Platform Governance

As a result, of its institutional and technological features, blockchain technology has the potential to reshape the way platforms, in general, are governed. The following section highlights a potential path of such a transformation along the core value propositions of blockchain technology—the improvement in transparency resulting from the current and complete record, the decentralization of consensus authority, and the automation of enforcement. Eventually, we illustrate how platform governance might change in the future.

First, the more current and more complete information about ownership structures (Yermack 2017) facilitates the dissemination of information among platform users in real time and allows them to make more informed decisions. The resulting technical establishment of the accountability of individual users (Beck et al. 2018) leads to a reduction of the uncertainties that interacting parties face under asymmetric information

(Notheisen et al. 2017a). Further, it mitigates free-rider problems (Yermack 2017) that arise in economically and socially opaque environments. In addition, the historical record of interactions reveals entanglements among individuals thereby disclosing potential conflicts of interest (Yermack 2017) that might impede platform efficiency. However, the increase in transparency also raises some issues with respect to the incentives of users to contribute to the consensual agreement, as the disclosure of formerly private information reduces the rents individuals were able to generate from this informational monopoly. Furthermore, the visibility of unique identifiers and related transactional histories raises privacy concerns (Beck et al. 2018; Böhme et al. 2015) that need be considered when designing blockchain-based platforms.

Second, the decentralization of consensus facilitates the decentralization of decision rights (Beck et al. 2018) and enables the resolution of disagreements and conflicts without the involvement of a centralized arbitrator (Beck et al. 2018). As a result of this diffusion of authority, individuals themselves, supported by the scrutiny and wisdom of the crowd, become the sources of authenticity (Morabito 2017). In combination with the irreversibility of transactions, this shift ensures the correctness of the stored record and ensures the provision of a tamper-free database to the provider and the users of a platform alike. In addition, the reliability and quality of the stored information do not depend on the judgment and ability of costly auditors, and data integrity becomes independent of the integrity of individuals (Yermack 2017). However, the absence of a central authority and the resulting transmission of decision rights and consensus authority to the heterogeneous crowd of individual platform users require an effective alignment of individual incentives and collective interests (Beck et al. 2018). When the incentives to participate in the costly consensus process are not properly aligned with the users' individual interests and motivations, their contributions may be insufficient or even malicious, which eventually threatens the integrity of the entire platform (Beck et al. 2018).

Third, as highlighted in the section 'Conceptualization and Sociotechnical Challenges,' blockchain technology automates the enforcement of agreements between interacting parties. These agreements can range from simple monetary transactions at a single point in time, such as in the Bitcoin system, to a contractual nexus of multiple interactions between multiple parties at multiple points in time. Smart contracts provide a tool to govern such complex interaction patterns by autonomously enforcing the rules defined by the ecosystem of the platform and the agreements specified in multilateral negotiations and encoded in the smart contract itself (Beck et al. 2018). The resulting automation of enforcement enables leaner and simpler contracts (e.g., fewer covenants in debt contracts, see Yermack (2017)), reduces opportunistic behavior of individuals, such as balance sheet fraud, and alleviates the scope of manipulative actions (Yermack 2017). In addition, it facilitates the replacement of (government) entities that manage property rights of physical and digital assets by blockchain-based equivalents (Morabito 2017).

However, it is important to keep in mind that blockchain technology and smart contracts will not be able to replace the negotiation of agreements. Instead, lawyers will no longer draft extensive paper documents but rather encode the results of their negotiation in self-executing legal documents based on smart contracts (Morabito 2017). So while the blockchain may be able to reduce coordination costs, this negotiation of process might entail a substantial amount of new coordination costs (Beck et al. 2018).

An important prerequisite for these new coordination costs is some sort of common language that allows lawyers and developers a joint understanding of the concluded agreement (Al Khalil et al. 2017). In addition, the finality of the data stored on the blockchain leaves no chance to correct undesired outcomes or to react to unexpected events. The resulting immediateness of transactions and triggered agreements increases transaction risks (Böhme et al. 2015) and can cause hazardous feedback loops (Paech 2017) as smart contracts cannot be breached (Morabito 2017).

Besides the potentially beneficial impact of blockchains on the governance of platforms, maintaining and updating the underlying blockchain infrastructure, especially on the level of the fabric layer, raises new governance problems itself (Yermack 2017). One way to maintain a blockchain system is to utilize the open-source community as a governance institution (see Fig. 4.3). In such a governance system, a change in the source code of the fabric layer can be initiated by every user, and system-wide adoption requires a majority of nodes to implement the update on their device. This passive process of adoption puts powerful individuals in a dominating position and makes blockchain-based platforms vulnerable to sabotage by malicious users that distribute updates that favor themselves by exploiting collective action problems (Yermack 2017).

The distribution of such asymmetrically favorable updates might be detrimental to other, less powerful users and is pronounced in systems with more heterogeneous user bases (Paech 2017) and on platforms, where individuals show more distinct collusive tendencies. The empirical findings of Wang et al. (2017) reflect this imbalance and indicate that while individuals value decentralization within the application layer, they do not value decentralization with respect to the governance of a fabric layer (Wang et al. (2017).

In consequence, it remains necessary to delegate the responsibility for maintaining the network and to ensure compliance with the socioeconomic and legal environment a platform operates in to some governing entity (Paech 2017). Although the increase in transparency, the decentralization of authority, and the automation of enforcement shift trust toward a more technical, algorithmic notion (Lustig and Nardi 2015), the trust of users in the governing entity still plays a crucial role in order to ensure the efficacy and efficiency of blockchain-based platforms.

Trust in Blockchain Systems

Many of the governance features highlighted in the previous section build the 'trust-free' nature of blockchain technology. The term trust-free refers to the ability of blockchain technology to create an immutable, consensually agreed, and publicly available record of past transactions that is governed by the whole system (Hawlitschek et al. 2018) and therefore should be considered a mainly technological feature in the first place. In addition, the section 'Implications for Platform Governance' highlights that trust still plays an important role with respect to the governance of the system. This section builds on these presumptions, elaborates the trust-free property, and discusses which trust relationships prevail or even gain importance in blockchain-based platforms.

Blockchain systems are increasingly taken into consideration to form the basis of different types of digital platforms. Given the characteristics of blockchain technology, it is possible to assume that as long as the platform remains a closed-up, purely technical ecosystem, it can be in fact considered trust-free (Glaser 2017). However, such purely technical platforms do rarely exist in the real world. Instead they form the basis for a variety of whole microeconomies that need to be managed by platform providers (Parker and Van Alstyne 2017). This shifts the purely technical view on blockchain-based platforms to a sociotechnical perspective (de Reuver et al. 2017). As a result, the notion of a trust-free blockchain system as underlying infrastructure for platforms should be critically assessed and discussed.

Leaving the realm of blockchain systems as purely technical concepts, it is viable to revise the notions of trust and trust-freeness in greater detail. Across disciplines, trust is usually considered as a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another (Rousseau et al. 1998). Therefore, trust-freeness is a property that is hard, if not impossible, to achieve for a platform (notwithstanding the use of blockchain systems as a technological basis). From the perspective of information systems (IS) research, different trust relationships matter for users. For example, users need to trust the IS, the provider of the IS, the internet (as an enabler for using an IS), and the community of internet users (Söllner et al. 2016). We propose that the same holds true for platform users.

In fact, the trust relationships in a platform microeconomy can even be more complex, especially for the case of two-sided markets. The notion of blockchain-based platforms for peer-to-peer sharing is not only in the center of the (popular) scientific discussion (Hawlitschek et al. 2018), it has already begun to enter the global market. The Universal Sharing Network (USN) of the German company Slock.it, for example, can be considered as a digital platform with an extensible codebase (de Reuver et al. 2017). In contrast to most posterchild examples of the sharing economy, such as Airbnb or BlaBlaCar, the USN is based on an open-source infrastructure on which blockchain application modules can be deployed, enabling third parties to on-board any object to the USN[1].

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[1] https://slock.it/usn.html

In the following we will outline which trust relationships matter for blockchain-based platforms. We guide and exemplify these considerations based on an example of a peer-to-peer sharing economy platform and—in doing so—illustrate why even blockchain systems require trust.

The engineering of two-sided markets is a particularly difficult task, since markets need to attract participants that take both the roles of consumers and providers in order to facilitate market growth and stability (Teubner and Hawlitschek et al. 2018). Therefore, a set of different user perspectives has to be taken into account to understand the different trust relationships in two-sided blockchain-based markets in detail (see Fig. 4.4). In contrast to ISs with a rather homogeneous user base, at least two different user types need to be distinguished, that is, consumers and providers. Since two-sided platforms may well benefit from a possible dual role of users acting as both consumer and provider (Stummer et al. 2018), it is also worthwhile to extend this categorization by a third type: the prosumers (Ritzer et al. 2012).

Obviously, the segmentation of the user role in at least two subtypes is accompanied by a need for trust between these roles. Especially in the context of peer-to-peer sharing, interpersonal trust plays a significant role (Hawlitschek et al. 2018; ter Huurne et al. 2017). In particular, sharing economy platform users need to believe in each other's ability, benevolence,

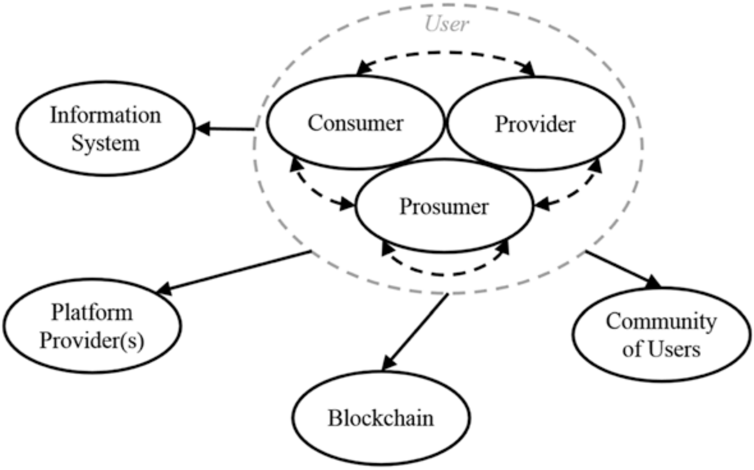

Fig. 4.4 Prevalent trust targets in two-sided markets from a blockchain IS users' point of view, based on Söllner et al. (2016)

and integrity to develop transaction intentions (Hawlitschek et al. 2016). Furthermore, following the work of Söllner et al. (2016), a set of further trust targets is relevant to understand the use of information systems. For blockchain-based information systems, we adapt and summarize these targets as the information system itself, the platform provider(s), the platform's blockchain infrastructure, and the community of users.

Trust in the information system includes both layers of the blockchain system that are the application layer and the fabric layer. Therefore trust in the IS is a rather broad concept comprising multiple aspects, such as the tokenization of the ecosystem value, the immutable decentralized database, the decentralized permissioning, as well as autonomous and user-controlled services. Importantly, the perception of the trustworthiness of the different layers and corresponding components will largely depend on the user type. While inexperienced and less tech-savvy users may perceive the IS mainly through the presentation layer, expert users may have the ability to dig deeper into layers and evaluate the blockchain system's components.

Blockchain systems and their components are operated by both open-source developers (developing the fabric layer) and participants in a globally distributed system (developing on the application layer). Consequently the community of open-source developers can be considered as the blockchain platform providers. Trust in the platform provider(s) is therefore necessary to prevent an absence of users (e.g., due to the perception of unfair or fraudulent implementation). In the same way, the participants in a globally distributed system can be considered as the community of users. Following Söllner et al. (2016), we argue that blockchain systems can provide effective support to their users only if the community of users offers valuable services or information. Thus, trust in the community of users describes an individual's belief that the community of users provides services and information reliably, benevolently, and with integrity.

Finally, users of a blockchain system need to trust the underlying technology itself—that is, the blockchain. Trust in the blockchain becomes necessary due to the high complexity of the technology. Since in most cases users will not be able to fully understand the mechanics of the underlying blockchain technology, they will need to trust in its reliability. This is comparable to the more established institution-based trust in the internet (Söllner et al. 2016).

Summary and Conclusion

The institutional characteristics of blockchain technology help to structure and organize the interactions on these platforms by facilitating a common understanding of a platform's functionalities and imposing consistency to individual users' behavior. In this context, the fabric layer, which usually results from the conscious design of an informal group of developers and is maintained by spontaneously evolving open-source communities, sets the boundaries for interactions of users and the scope of application domains. The concrete manifestation of the fabric layer, and thus the characteristics of a platform, is determined implicitly by the informal feedback of user adoption. Building on the fabric layer, the application layer enables individual users to implement various features based on smart contracts. The services and applications resulting from this conscious design reshape governance mechanisms within platforms and redefine how users interact with each other. Their transparent, autonomous, and distributed nature has the potential to reduce the negative effects of information asymmetries, democratize decision processes, secure property rights, simplify contracting and enforcement, and limit opportunistic behavior. However, these features also increase transaction risks and raise privacy concerns. In combination with the governance of a blockchain-based platform, mastering these challenges requires a new notion of trust. The core dimensions of this new notion of trust are the trust in the information system and the deployed algorithms, trust in the providers of the platform infrastructure (i.e., the blockchain providers), and trust in the community of users. It is this user and developer base that maintains and secures the fabric layer which fuels the variety of applications and services built atop the application layer. This trust remains a central facilitator of the adoption of blockchain-based platforms, in particular when it comes to intersections with the real world and the governance of the system itself.

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5

Blockchain Technology: The Autonomy and Self-Organisation of Cyber-Physical Systems

Ben van Lier

Introduction

In Heidegger's view, technology is a phenomenon where we constantly have to ask ourselves what the essence of a new manifestation of technology is. Answering the question of technology's being also creates, according to Heidegger, meaning in terms of what this current being of technology can mean for us as humans in our relationship with this technology. According to Heidegger (1968), the essence of technology is not human, but certainly not purely technological either. In his view, the essence of technology lies "in what from the beginning and before all else gives food for thought. It might then be advisable, at least for the time being, to talk and write less about technology, and give more thought to where its essence lies, so that we might first find a way to it. The essence

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of technology pervades our existence in a way which we have barely noticed so far" (p. 22). As long as we humans are not interested in the essence of technology or it is merely a passing thought, we will never learn to understand what technological applications really are or what they really mean for us as humans. As long as we fail to address the essence of the technology we use, we will, Heidegger claims, "never experience our relationship to the essence of technology so long as we merely conceive and push forward the technological, put up with it, or evade it. Everywhere we remain unfree and chained to technology whether we passionately affirm or deny it. But we are delivered over to it in the worst possible way when we regard it as something neutral; for this conception of it, to which today we particularly like to pay homage makes us utterly blind to the essence of technology" (p. 4). Heidegger's views on technology are based on, among other things, his previous work in which he concluded that objects or systems that we humans encounter are always part of what he calls equipment or a structure that makes the object what it is to us. According to Heidegger, an object never stands alone but is always part of a whole of contextually connected equipment. The equipment takes care of interconnectedness between the object and its environment while also determining how we perceive the object in this environment. The whole of equipment between the human being and the object determines the way in which we, as human beings, can or want to use the object within the whole in which it is interconnected. An object is consequently never a stand-alone object, Heidegger claimed, but is simultaneously part of multiple forms of equipment that are also interconnected. Each specific combination of an object connected in its equipment, and our approach to the resulting whole, makes that the specific object acquires a certain manifestation to us, which is what Heidegger calls enframing (*Gestell* in German). As humans, we assign a specific purpose or meaning to this enframing or whole, which allows us to perform actions or activities together with the object or allows the object to perform actions or activities with a certain level of autonomy. According to Heidegger, the whole of that which we experience or perceive of the functioning of the object thus reveals itself as a whole that stands alone, which he referred to as a phenomenon. Technology and interconnected technological applications make up the phenomenon of our time, and we, as human beings, connect to networked objects such as smartphones, smart TVs, electrical vehicles, or personal assistants such as Apple's Siri (via various devices), Amazon Alexa (via Amazon Echo), or Google Assistant (via Google Home), which reveal themselves to us as stand-alone objects. Although the separate objects reveal themselves in their physical and stand-alone manifestation, which we then go on to use or apply, the physical component that is present in our environment is extended by new features through the addition of combinations of algorithms and software. The algorithms and software in the object enable the object to connect to other objects in networks, as well as to communicate and interact with other connected objects in these networks. Communication and interaction between objects through the exchange and sharing of data and information makes new functionality of the individual object perceivable on the one hand and creates a new whole on the other hand, whereby this whole has more capabilities than the sum of its constituent parts. Exchanging and sharing data and information through networks thus not only creates new functionality of the individual object but also creates new functional features for the whole of jointly operating objects. Although the use of algorithms and software does not change the manifestation of the object itself, it does change the functionality and autonomy of the traditional object as used and perceived by humans. The whole of mutual connections, communications, and interaction between people and objects increases the object's possibilities for autonomous execution of activities and actions. The increasing interconnectedness in networks, or the enframing as Heidegger called it, where people operate in conjunction with objects, algorithms, software, and information, changes not only the functionality of the object but also our relationship with an object or with multiple objects jointly, as well as the way in which we perceive the functioning of these enframed objects. As the autonomy of objects within a specific context continues to grow, the mutual relationship between humans and the autonomous object within that same context will change ever more drastically. For Arthur (2011), all forms of technology, no matter how simple or advanced, are "dressed up versions of some effect—or more usually of several effects" (p. 47). He adds, however, that the main manifestations of technology are those manifestations that create a new domain for themselves, or in his words, "They are the expressing of a given purpose in a different set of components" (p. 51). Such a new phenomenon that is enabled by technology is precisely what the manifestation of the blockchain seems to be. As a phenomenon, the blockchain resembles what Arthur refers to as a new domain made up of different interconnected components. The new domain of the blockchain is based on global peer-to-peer networks, such as the Internet. Within these networks, new possibilities are created based on the available software, enabling peers to perform secure information transactions among themselves. This new domain is generally believed to originate from an article by Nakomoto (2008). While it is undeniable that this article was the first to provide a broad description of the functionality of a global financial blockchain in the form of the cryptocurrency bitcoin, it is also clear that technological possibilities that were available at the time were being combined to form a new whole. Six years later blockchain technology shifted to a new domain, the domain of the Internet of Things. As van Lier states (2018), Samsung Electronics and IBM developed a proof of concept (ADEPT) that focused on increasing the autonomy of devices or machines that operate in a decentralised manner within the (industrial) Internet of Things. For their pilot, they used a Samsung washing machine (W9000). According to Samsung and IBM, these kinds of consumer appliances will increasingly be hooked up to networks such as the Internet of Things and will perform information transactions in electronic marketplaces and other environments in an increasingly autonomous and self-managed fashion. The information transactions performed by these devices can, for example, consist in them autonomously ordering detergent or spare parts, negotiating with the electricity company about power supply, or showing adverts on the washing machine's display. To enable devices to do these kinds of things, the project focused on peer-to-peer messaging, distributed file sharing, and autonomous device coordination. These protocols were needed for the project to, among other things, be able to register and authenticate the various devices in the network, as well as for the agreements and checklists between the devices and the consensus-based rules of engagement. The ADEPT project has led to a pilot of a blockchain of devices, where devices work together autonomously and make decisions about tasks or orders, and so on. The approach of linking these devices using blockchain technology also further increases these devices' level of autonomy. To some extent, this project is shifting the focus of the blockchain technology mindset from the domain of the financial industry and cryptocurrencies to developments in the domain of interconnected and autonomously operating systems. According to the chairman of the World Economic Forum Klaus Schwab (2016), we are currently on the verge of the fourth industrial revolution, one that he thinks may be marked by the omnipresence of networks such as the (mobile) Internet. Besides people, more and more (industrial) objects are also interconnected in these networks, objects such as sensors, machines, factories, and so on, gradually creating a global industrial Internet of Things, which Schwab describes as follows: "in its simplest forms it can be described as a relationship between things (products, services, places, etc.) and people that is made possible by connected technologies and various platforms" (p. 18). The fourth industrial revolution will create new ways for people, machines, and organisations to be interconnected in networks, communicate with each other by exchanging and sharing information, and interact based on this information. One of these new technological possibilities is, according to Schwab, blockchain technology. Swan (2015) describes blockchain technology as follows: "the decentralized transaction ledger that is a part of a larger computer infrastructure that must also include many other functions such as storage, communication, file serving and archiving" (p. 20). This chapter will focus on the question whether, and if so how, such blockchain or fault-tolerant distributed ledger technology combined with voting and consensus algorithms can play a role in the developing autonomy of cyber-physical system-of-systems. After addressing the interconnection of separate and autonomous systems in cyber-physical system-of-systems such as the industrial Internet of Things, the chapter will present basic principles that should, in theory, enable the exchange and sharing of information, that is, the interoperability of information, within system-of-systems. Bearing these basic principles in mind, the next section of the chapter will take a closer look at the technical possibilities offered by distributed computing and distributed ledgers. The final section of the chapter will go into the question whether the whole of blockchain technology can contribute to the autonomy and self-organisation of interconnected cyber-physical systems in system-of-systems. Finally, the chapter will present several conclusions.

Cyber-Physical System-of-Systems

Physical objects, such as cars, lorries, planes, solar panels, wind turbines, MRI scans, drones, and even television sets and washing machines, are increasingly integrated and interconnected in networks. Interconnecting devices in networks enables such objects to communicate and interact by exchanging and sharing information. The physical and stand-alone object is slowly but surely evolving into a networked cyber-physical system. In the view of Baheti and Gill (2011), a cyber-physical system refers to a new generation of systems with "integrated computational and physical capabilities that can interact with humans through many new modalities. The ability to interact with, and expand the capabilities of, the physical world through computation, communication and control is a key enabler for future technology developments" (p. 1). According to the US National Institute of Standards and Technology (NIST) (2015), these new and interconnected and integrated systems can fill new social needs "to improve quality of life and enable technological advances in critical areas, such as personalized healthcare, emergency response, traffic flow management, smart manufacturing, defense homeland security, and energy" (p. xii). According to the NIST, a system-of-systems exists when it has at least three of the following four characteristics: "operational and managerial independence, geographic distribution, emergent behaviour, and evolutionary development" (p. 17). Cyber-physical system-of-systems are, in the NIST's definition, characterised by interaction with their environment, which generally also includes people. The Trans-Atlantic Research and Education Agenda (2013) defines a system-of-systems as "an integration of a finite number of constituent systems which are independent and operable, and which are networked together for a period of time to achieve a certain higher goal" (p. 11). A roadmap (2015) compiled by the European cyber-physical system-of-systems project defines these CPSoS as follows: "The concept of Systems of Systems (SoS) has been developed to characterize large, distributed systems that consist of interacting and networked, but partially autonomous, elements and can show emergent behaviour" (p. 5). Together, the variety of components that make up CPSoS fulfil a specific need, provide a specific service, or produce specific products. The functioning of a system-of-systems as a whole thus depends on the orchestration of the individual components. The authors of the roadmap also claim that "physical size or geographic distribution of the system are not essential factors to make it a system of systems, but rather is its complexity" (p. 7). It is this complexity that impedes centralised running or controlling of cyber-physical system-of-systems made up of autonomous components, such as people or cyber-physical systems, as they perform their time-independent and location-independent actions or activities. The European roadmap considers autonomy to be the presence of local conditions or priorities that cannot be executed or controlled from the system as a whole. "Rather, incentives or constraints are given to the subsystem control in order to make it contribute to the global system targets" (p. 8). In the opinion of the roadmap authors, this kind of autonomy can lead to self-organising systems. Dressler (2006) describes self-organisation as a process "in which pattern at the global level of a system emerges solely from numerous interactions among the lower level of a system" (p. 2).

Interoperability of Information

The required communication and interaction between random systems and entities comes about through the exchange and sharing of data and information between these systems. When a recipient system is able to take in and process data and information from its environment, this system can then assign meaning to this information and data. The meaning assigned forms the basis for things such as the system's behaviour, actions, or feedback to other systems. The continuous cycle of communication, feedback, and interaction between a diversity of cyber-physical systems drives the development of a cyber-physical system-of-systems as a whole in time and space. This development is similar to that of ecosystems, where organisms are interconnected and interact, causing the ecosystem as a whole to be in a constant state of evolution. Due to this evolution of the ecosystem as a whole, the constituent organisms need to have the ability to constantly adapt to new circumstances. A cyber-physical system-of-systems can also be considered as a complex ecosystem made up of people and a wide range of different technological applications that is, as a whole, constantly evolving. One example of a cyber-physical system-of-systems is according to van Lier (2015b) the industrial Internet of Things. The development of global networking of sensors, machines, production processes, and factories will inevitably lead to new, digitised and global industrial system-of-systems. Based on the interconnectedness of machines, production processes, and supply chains, a new and complex sociotechnical industrial whole is developing through the exchange and sharing of data and information. The capability to exchange and share data and information between a diversity of systems and entities based on a relationship of equality and trust is therefore the main condition for the development of this new industrial and sociotechnical whole. In the words of van Lier (2015b): “by using the opportunity to digitize machinery, factories and entire supply chains, and to exchange and share data and information within them in networks, increasingly large and growing volumes of data and significant information will be created. Enabling access to and analysis of these new collections of data and information will enable industrial production companies to generate new knowledge about the various phases of production and their associated supply chains, from design to distribution including supply chain management, production processes and marketing” (p. 2). The possibility of exchanging and sharing information between distributed and random systems and entities is also referred to as interoperability of information, which van Lier and Hardjono (2010) define as follows: “the realization of mutual connections between two or more systems or entities to enable systems and entities to exchange and share information in order to further act, function or produce on the principles of that information” (p. 67). For a separate and autonomous cyber-physical system to be able to function within a system-of-systems, interoperability of information is an essential precondition, which, when fulfilled, will also enable the development of the cyber-physical system-of-systems as a whole. For the concept of system, this paper uses Luhmann’s (1995) definition: “the concept of system refers to something that is in reality a system and thereby incurs the responsibility of testing its statements against reality” (p. 12). This description of a system or combination of systems, such as a cyber-physical system-of-systems, also lets us consider this whole as an independent entity. Figure 5.1 is based on the assumption of two autonomous systems that, in themselves, are equally equipped to be part of cyber-physical system-of-systems and can therefore be interconnected with other systems.

To accomplish interoperability of information between these separate systems and entities, van Lier and Hardjono (2011) claim that these systems need to be interconnected in networks (technology) and must be able to process similar symbols as a processing language (semantics) and place the information received in a context that is shared with other systems. van Lier (2015a) defines context as "a temporary and cohesive whole, a non-material entity, that is formed and perceived in an arbitrary connection between people, between objects, and between arbitrary combinations of people and objects. Context as a temporary whole is thus more than the experience of each of the mutually connected yet distinguishable parts. Context as a temporary whole or entity is not a reality that can be objectively observed or a material whole" (p. 61). Within a specific context, systems will jointly perform operations, conduct actions, or produce new things aimed at achieving a specific goal. Interactions between the systems involved are mutually aligned through the exchange and sharing of data and information and as the systems involved assign meaning to this data and information. To make the exchange and sharing of data and information within a system-of-systems possible in an effective way, van Lier (2013) argues that four basic principles have to be adopted. First of all, a system needs to be capable of some kind of self-reference to be able to exchange and share information. Self-reference will enable an independent and autonomous system to differentiate between the connections and communication elements it needs

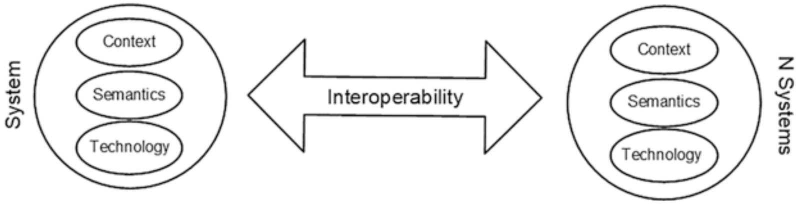

Fig. 5.1 Interoperability of information—I

for its own internal functioning and the communication elements the system produces for systems in its environment or that emerge from its environment. van Lier (2013) puts it as follows: “Self-production of elements enables self-referential and autonomous systems to set up relations with themselves and to differentiate these relations from relations with their environment” (p. 75). Self-reference hence marks the boundary between the system and its environment. This boundary closes the system off from the outside world, albeit that it is still able to take in new information from its environment. Taking in information from the environment and assigning meaning to this information enables the system to learn and develop and hence adapt to changes in its environment.

Figure 5.2 presents self-reference as the open arrow that points back at itself. In Luhmann’s (1995) view, the concept of self-reference is inextricably connected with the concept of autopoiesis, where “auto” means “self” and “poiesis” “creation”. Assuming that a system is separate from its environment, each system creates its own information based on selections from its interior, transferring this information selection across its boundary into its environment. The second principle is Luhmann’s theorem of double contingency, which van Lier and Hardjono (2011) describe as follows: “In order to be able to tackle the issue of how a self-referential, autopoietic and autonomous system can interact and communicate with one or several systems, Luhmann was forced to shift the focus of his analysis from: ‘the orientation of a single given actor to the consideration of two or more interacting actors as a system” (p. 485). In the context of cyber-physical system-of-systems, this theorem forces us to look not only at the possibilities offered by a single cyber-physical system but also

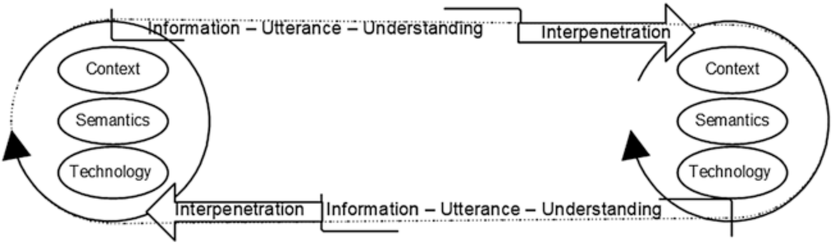

Fig. 5.2 Interoperability of information and interpenetration

at a temporary whole of interconnections, intercommunications, and interactions between the various cyber-physical systems. This temporary whole of interconnections forms a new and stand-alone system. In Fig. 5.2, the idea of double contingency is depicted as a dotted line between the two systems. The area encompassed by the dotted line is consequently a new and stand-alone whole that is more than the sum of the separate systems.

The third principle is that a connection established between two or multiple systems is not, and cannot be, the same as merely sending and receiving messages between a sender and a receiver, as formulated by Shannon. The metaphor of sending and receiving messages covers, according to Luhmann (1995), only the manifestation of the sending and/or receiving of these messages. This specific manifestation is what Luhmann calls utterance, which, in his view, is merely a manifestation of a selection of information. Following Luhmann, communication connections between systems can therefore be considered not just a selection process of information in which only two elements are involved, namely, the sender and the receiver, but they should be considered to be a three-part selection process. According to him, the synthesis that arises from the unity of the three elements of "selection of information", the "utterance of information", and the possible "understanding" of the selected information that is included in the communication connection should be assumed for the communication connection between two or more systems. This synthesis of a selection of information, the utterance, and the understanding of this information is reflected in Fig. 5.2 between the two parentheses originating from the sending system. Following on from this, the fourth and final principle concerns the receiving and processing of the synthesis of information-utterance-understanding. In principle, we have to assume that the receiving system can either reject or accept each communication unit when receiving the synthesis. Whenever random systems trust the communicative element and are willing and able to accept it across their system boundary is what Luhmann (1995) considers to be a form of interpenetration. In Luhmann's words, "interpenetrating systems converge in individual elements—that is they use the same ones—but they give each of them a different selectivity and connectivity, different past and futures" (p. 215). Luhmann uses the concept of interpenetration to make it clear that systems that are interconnected and exchange and process communication units mutually contribute to the development of other systems in their environment. This means that interpenetration of communication units is more than a general relationship between the system and its environment. Instead, it should, van Lier (2013) claims, be seen as an intersystem relationship between two or more systems that create a temporary but shared environment. In this shared environment, the sending system makes its complexity available for the development of other systems in its environment. In the words of van Lier: "The concept of interpenetration is Luhmann's answer to the question of how double contingency between different systems is enabled, and a new system based on communication comes into being with sufficient frequency and density. Making connections between two or more systems leads to the evolutionary creation of a new and higher form of system formation. This new system formation consists of interlinked autonomous and self-referential systems, and is basically a higher form of interlinked systems that only manifests itself as it comes into being, i.e. as it enters into and maintains a communicative association" (p. 78). The communicative link makes the evolution of a cyber-physical system-of-systems possible through mutual interpenetration of data and information between systems, creating what systems theory refers to as a circular communication process that shapes itself in reality.

Blockchain Technology

In the previous section, four basic principles are described for interoperability of information between random and autonomous systems, as presented in a diagram in Fig. 5.2. Based on these basic principles, we can conclude that acceptance and processing of a synthesis of information, utterance, and understanding by a receiving system can be equated with a transfer of information between two random and autonomous systems. The *Merriam-Webster Dictionary* defines autonomy as "the quality or state of being self-governing". Autonomy creates the possibility to be, function, or operate independently of others and without external control or support. To be autonomous is therefore also a form of freedom to, independently or together with others, perform tasks or achieve formulated goals. In this section, the focus will be on shaping a system of information transfer or information transactions between random and autonomous systems that together make up a system-of-systems. Information transactions between autonomous and separate systems that are interconnected in a system-of-systems are presented in diagram form in Fig. 5.3.

Any reliable communication system that is developed to facilitate information transactions between separate, autonomous, and distributed

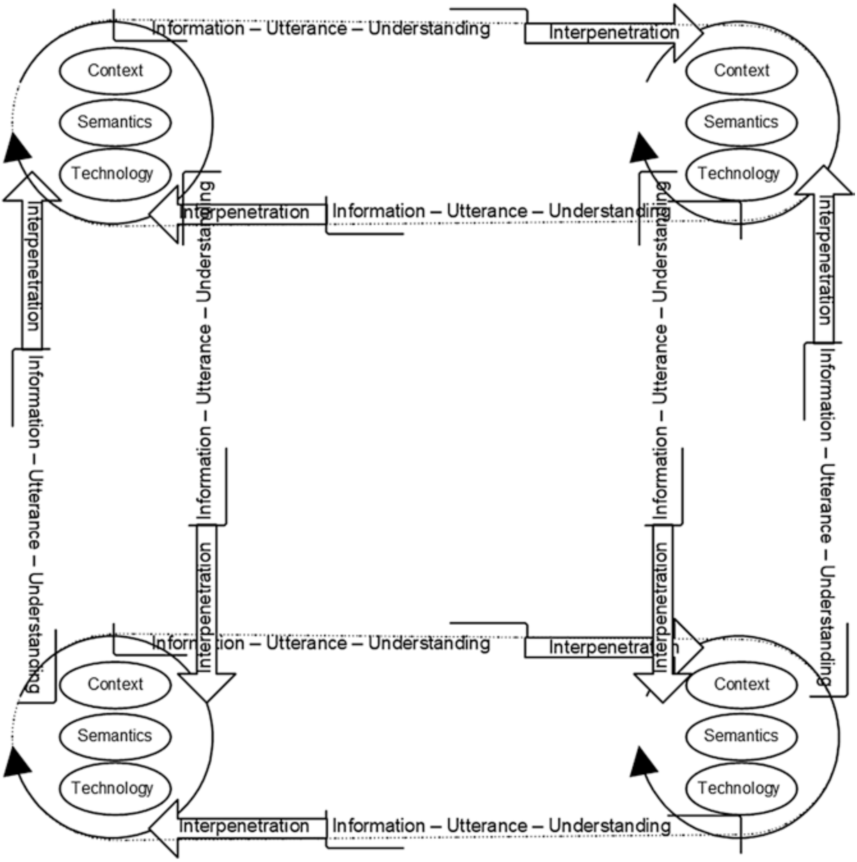

Fig. 5.3 Interoperability and system-of-systems

systems will have to meet a number of general conditions. The system will have to be robust or fault tolerant, meaning that the system must always be able to keep running and keep enabling information transactions between systems in a reliable manner. When distributed systems want to conduct direct transactions with each other, consensus will have to be reached between the systems involved on whether they can jointly accept and process a reliable transaction based on the information received from the environment. It must be possible for every autonomous and distributed system to record every agreed transaction so that the origins of the information transaction can always be traced without having the information available in a central location. Finally, there needs to be a protocol in place that specifies all conditionalities for consensus on decisions and for the distributed recording of these decisions. In the following, these four aspects will be worked out based on research by Lamport. Lamport (1978a) defines a distributed system as "a collection of distinct processes which are spatially separated and which communicate with each another by exchanging messages" (p. 558). A process, in turn, is defined by Lamport as a system of events with a predefined order, whereby "we assume that sending a message is an event in a process" (p. 559). Lamport assumes that every process is capable of sending these messages directly to other processes and of receiving similar messages directly from other processes. The ability to send and receive messages between different processes requires distributed algorithms that ensure that each process follows similar rules for the sending and receiving of messages, meaning that there is no longer a need for centralised synchronisation or storage of these messages. Lamport states that "this approach can be generalized to implement any desired synchronization for such a distributed multiprocess system" (p. 562). With such a direct way of sending and receiving messages between processes, he does, however, specify a further condition that application of distributed algorithms requires all other processes involved to participate actively. Active participation is possible, Lamport explains, when all processes "know all the commands issued by other processes, so that the failure of a single process will make it impossible for any other process to execute State machine commands, thereby halting the system" (p. 562). Communication processes' interconnections with and dependency on random and distributed systems mean that a system-of-systems must be able to keep functioning, without problems in one or multiple separate systems or components of systems leading to the system-of-systems malfunctioning or not functioning at all. This means, in Lamport's view, that we have to think about fault-tolerant systems. He considers the concept of a disruption of one or multiple processes within a system meaningless without a notion of time. He (1978b) therefore states that "we can only tell that a computer system has failed ('crashed') when we have been waiting too long for a response" (p. 96). Another condition required to make fault-tolerant systems possible is that "each machine must maintain its own copy of the user machine state" (p. 109). In Lamport's view, communication between systems that function as part of a whole can be considered secure when it is impossible, or at least difficult, to disrupt the required communication between the systems through, for example, unauthorised activity, or by spreading information that has not been approved beforehand. For a combination of distributed systems to ultimately be able to jointly form a fault-tolerant system, Pease et al. (1980) claim that what is needed is an ability to absorb the effects of faulty functioning or non-functioning of distributed systems by using "voting schemes involving more than one round of information exchange; such schemes might force faulty processors to reveal themselves as faulty or at least to behave consistently enough with respect to the non-faulty processors to allow the latter to reach an exact agreement" (p. 234). Pease, Shostak, and Lamport assume that distributed systems will have to be able to reach consensus on transactions unaided when distributed algorithms can be developed that can regulate the consistency of these voting schemes. One of the basic conditions for these kinds of algorithms is that they must work on the basis of at least four systems, as reflected in Fig. 5.3. In their opinion, the ability to continuously maintain an interactive form of consistency between separate systems is a fundamental precondition for the design and development of distributed systems, where executive control is also distributed. To be able to solve the problem of interactive consistency, they elaborate a solution to what is known as the Byzantine generals' problem (BGP). According to Lamport (1983), a solution to the BGP implies "obtaining agreement among a collection of processes, some of which may be faulty" (p. 668). A distributed algorithm that is intended to solve the BGP will have to take as its starting point the signed and therefore reliable messages that systems can send to each other, the contents of which are based on the contents of previously received messages. An algorithm that intends to solve the BGP will be functional when the principle of at least four machines is combined with the principle that a minimum of five messages are used to reach consensus between parts of the system as a whole on the activities or transactions they are to perform jointly. Once consensus has been reached on the execution of activities or transactions, the components involved in the decision-making will themselves record this decision in their own, and therefore distributed, ledger. In 1990, Lamport (1998) submitted a research article to the Association for Computing Machinery (ACM). The article, entitled "The Part-Time Parliament", which sat there for eight years before finally being approved for publication, centres around what is considered one of the more obscure algorithms in distributed computing. In this article, Lamport describes the workings of a parliament in an ancient civilisation, using this description as the basis for a decision-making algorithm that is focused on reaching consensus between the part-time members of this parliament who are not all able to attend parliamentary meetings at the same time to take part in decision-making procedures. Lamport uses the story of this parliament and its members as a metaphor for the consensus random parts of a system must reach in joint decision-making. He describes in great detail how such a protocol for consensus and decision-making would have to be designed. He captures this protocol in a detailed algorithm, with which the consensus, decision-making, and transaction recording that need to be carried out can be accomplished between the entities. The key requirements behind this algorithm are, firstly, fundamental trust between the entities involved and, secondly, consistency where "each Paxon legislator maintained a ledger in which he recorded the numbered sequence of decrees that were passed" (p. 2). Key conditions for the use of these individual ledgers used by individual systems are described in what is known as the Paxos protocol, including the condition that each decision be recorded using indelible ink so that recorded decisions cannot be changed at a later stage. The Paxos protocol focuses primarily on achieving consistency in recording decisions in the respective distributed ledgers to prevent saving of contradictory information. The

Paxos protocol also contains, among other things, rules to ensure that decision-making procedures are initiated and ballots are conducted; rules on quorums for these ballots; and how to reach consensus between separate systems on decisions to be made. Furthermore, the protocol provides rules on the manner in which the decision made is to be recorded in the respective ledgers. Once a decision has been recorded by all involved in their own distributed ledger and can no longer be changed, this decision can be considered to be a shared block that appears in all distributed ledgers. This block is the basis for subsequent decision-making procedures and connected decisions on whether blocks can be considered to be a chain of decisions, that is, a blockchain. The Paxos protocol therefore seems to provide nearly all characteristics needed for fault-tolerant and distributed exchanging and sharing of information between separate systems, as it functions on the basis of a mutually agreed joint protocol for consensus and decision-making. In a cyber-physical system-of-systems, consensus would then enable decision-making on joint activities or transactions by random systems. Decisions made are recorded securely in distributed ledgers. The total of distributed ledgers consequently offers every individual component an up-to-date overview of joint decisions, meaning that these components no longer need to rely on centralised storage of decisions by a trusted third party.

Self-organisation

When, as set out above, systems are enabled by mutual communication and voting and consensus algorithms to jointly make decisions within a blockchain, this will boost not only the autonomy of the individual components but also the self-organisation of the new and interconnected whole. Ashby (1962) states that when conditionality is inherent in, for instance, communication, voting, and consensus algorithms between the parts, then we can speak within the concept of organisation of "a whole composed of parts". The appearance of being self-organising, Ashby states, "can be given only by the machine S being coupled to another machine (of one part) for instance α. Then the part S can be self-organizing within the whole S+α (p. 117)". According to Dressler: "in computer networks, selforganization is especially important in ad-hoc networking because of the spontaneous interaction of multiple heterogenous components" (p. 1). According to Holland (1999), in essence, "emergence" is a product arising from mutually linked interactions within a specific context. Holland believes that the behaviour of the whole which arises from the communication and interaction between, for example, people, organisations, and cyber-physical systems present together at a specific place and time cannot only be explained by summarising it as the behaviour of its constituent parts. According to Fromm (2005), a characteristic of a system can be qualified as emergent "if it is not the property of any fundamental element and emergence is the appearance of emergent properties and structures on a higher level of organisation or complexity" (p. 3). Gershenson and Heylighen (2004) notes that one of the products generated from the communication and interactions between people, organisations, and cyber-physical systems is a new and cohesive whole. This new and self-developing whole, says Gershenson (2007), is not present in the individual components and "cannot be reduced to them". The new whole in turn brings about influence over the individual elements. The higher-level characteristics of the new whole cannot be observed or perceived at the level of the separate components of the system but do, however, arise as a separate product of the communication and interaction between the individual elements. This separate product can then be regarded as the whole that is greater than the sum of its components. This product or the characteristics of this whole are also designated as emergent, says Gershenson (2007), but he believes we are in fact dealing with an ontological problem. He therefore suggests, "According to classical thought, there is only one 'true description' of reality. In this case, a system cannot be at the same time a set of elements and a whole with emergent properties. But by introducing the ontological distinction between absolute being and relative being, we can clarify the issue" (p. 6). In the view of Mathews et al. (1999), the theory of self-organising systems can help us to learn to understand how "complicated rules or spatially complex systems with many interacting components produce complex, but organised and patterned behaviours, and to explain the apparent paradox of how large-scale structures function when their constituent elements are swimming in a sea of chaos" (p. 447).

The origins of this theory of self-organisation can be found with Ashby. For Ashby, a machine is a composition of parts and the way in which these parts can be brought into cohesion. This cohesion can be named as the structure of the machine. By introducing feedback loops (positive-negative) between the individual components of the system or between the system and its environment, Ashby (1952) believes that the specific characteristics of such a system can only be explained by referring to the characteristics of the specific feedback loops which are used. Ashby (1962) believes that a fundamental characteristic of these machines is that they can be interconnected. Two or more interconnected machines make up a joint and new entity. Only when the relationship between these two entities has become a conditional stipulation for the new entity does Ashby believes that a necessary condition of organisation of the whole arises. He says of this conditionality: "Thus the theory of organisation is partly co-extensive with the theory of functions of more than one variable" (p. 104). The mutual connections and the required combination of systems necessarily yield new limitations and correlations for the new whole. According to Ashby, the presence of a form of organisation is "equivalent to the existence of a constraint in the product-space of the possibilities" (p. 105). The new whole of interconnected machines, says Ashby, can be qualified as self-organising if the entity can independently and automatically change a positive feedback loop into a negative feedback, as a result of which "the whole would have changed from a bad organisation to a good" (p. 115). In Ashby's belief, every dynamic system or cohesion of dynamic systems generates its own form of intelligence and exhibits this intelligence by means of its self-organisation capabilities. For De Wolf and Holvoet (2005), one of the characteristics of such self-organising systems is that the system is autonomous and can use this autonomy to determine independently how to respond to changes in its environment. Gershenson and Heylighen (2007) state that self-organisation in a system or part of a system or a cohesion of systems can be regarded as the structure or function of this system which arises autonomously (emerges) between the elements within the system or between the system and its environment. The advantage of self-organising systems is that their autonomy enables them to search independently for solutions without any external management or intervention from an engineer being required. Self-organising systems are intrinsically open, because they can communicate and interact with their environments, making them flexible and adaptive. When changes occur in the system's environment, they can adapt more quickly and effectively in the absence of central controls. Because the organisation of self-organising systems is distributed across a number of participating elements and the connections present which jointly shape it into a whole, this whole can be qualified as robust if "it can survive destruction of any part of its components without too much damage, as the other components make up for the lost functions" (p. 54), note Gershenson and Heylighen (2004).

Conclusions

Interconnecting cyber-physical systems in networks automatically leads to the creation of cyber-physical system-of-systems. A cyber-physical system-of-systems will further evolve and develop through communication and interaction between random separate and autonomous cyber-physical systems. Communication and interaction between separate and individual cyber-physical systems comes about through the exchange and sharing of information, which is referred to here as interoperability of information. Acceptance and processing of information emerging from a system's environment lead to an information transaction between systems. When it comes to developing a fault-tolerant transaction and decision system between cyber-physical systems, the Paxos algorithm seems to offer realistic possibilities. Practical applications can, however, only be created when such distributed algorithms are incorporated into software. The possibilities offered by the software used also determine whether independent and autonomous distributed systems are empowered to learn. Learning seems to enable the further development of cyber-physical systems' capacity for self-organisation to take shape. There is, however, as yet little experience with large-scale developments and application of distributed systems, such as cyber-physical systems, and distributed algorithms that will connect and allow them within system-of-systems to communicate which each other and make decisions by themselves based on this communication. Further development of distributed systems and distributed algorithms will have to factor in what are known as emergent properties. The development of the new technology we call blockchain thus creates a new and as yet unfathomable reality of interconnected and autonomous systems that have the ability to make decisions about or for us as human beings. We can conclude that we, as human beings, are not yet able to sufficiently grasp and control the essence of this new technology. Thinking and speaking about the essence of this technology in its connection with other technological developments have therefore become a necessity, because as Heidegger (1977) said: "we are delivered over to it in the worst possible way when we regard it as something neutral" (p. 4).

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Part II

Finance

6

Bitcoin and Investment Portfolios

Karl Weinmayer, Stephan Gasser, and Alexander Eisl

This chapter explores the question whether Bitcoin as an unregulated cryptocurrency can have a positive effect on already well-diversified investment portfolios. Bitcoin was originally introduced in 2008 in a paper titled “Bitcoin: A Peer-to-Peer Electronic Cash System”.[1] Since then, Bitcoin has seen increasing trading volumes (as well as major capital gains and losses) in a high-volatility environment while also experiencing

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[1] The paper was written by an anonymous programmer/a group of programmers only known by the pseudonym of Satoshi Nakamoto.

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growing attention by regulators, academics, the media and the general public. At the same time, more and more online and offline businesses worldwide started to adopt Bitcoin as an alternative means of payment, even though Bitcoin does not have legal tender status. Today, Bitcoin is still the most popular unregulated cryptocurrency. Bitcoin's share of the total market capitalization of all cryptocurrencies currently amounts to just under 45% according to Coinmarketcap (2018), and Bitcoin is also the top-searched cryptocurrency of the top five cryptocurrencies in terms of market capitalization (Google Trends 2018). This is largely due to the fact that Bitcoin was the first cryptocurrency based on a decentralized peer-to-peer network (to confirm transactions and generate a limited amount of new Bitcoins in doing so) and functioning without the backing of a central bank or any other monitoring authority. For the general public and most media outlets, Bitcoin is still seen as the leading cryptocurrency.

Interestingly, an analysis of Bitcoin returns shows remarkably low correlations[2] with traditional investment assets such as other currencies, stocks, bonds or commodities such as gold or oil. In this chapter, we analyze properties of Bitcoin as an asset by shedding light on the impact an investment in Bitcoin would have had on an already well-diversified investment portfolio over the time period from 2010 to early 2018. More specifically, we ask the question whether Bitcoin, given its historical return distribution, should have been included in efficient portfolios and to what extent. Due to the non-normal nature of Bitcoin returns, we do not propose the classic mean-variance approach but analyze the tail of the return distribution by adopting the Conditional Value-at-Risk (CVaR) as asymmetrical risk measure. This should be better suited to capture the risk involved with a Bitcoin investment and also ensures coherence of the risk measure compared to other alternatives. For a sample period from 2010 to early 2018, we find that Bitcoin can contribute to the risk-return profile of well-diversified portfolios. Nevertheless, an investment in Bitcoin can have substantial risk (e.g. regulatory) that might not be adequately captured using historical Bitcoin prices.

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[2] See, for example, Brière et al. (2015) and our own analysis in Table 6.3, section "Results".

Literature Overview

In the academic world, Bitcoin has drawn significant attention from researchers from a broad variety of fields. A number of papers have been published focusing, for example, on law and computer science aspects of Bitcoin, for example, on a descriptive analysis of the Bitcoin network (Ron and Shamir 2013), the potential risk of double-spending (Karame et al. 2012), the implications of the availability of a public ledger containing all Bitcoin transaction ever made (Meiklejohn et al. 2013), security issues of high-rate transaction processing (Sompolinsky and Zohar 2015) or Bitcoin's challenges for financial regulators (Sotiropoulou and Guégan 2017). In addition, Bitcoin has also been analyzed from a financial economics point of view in several recent studies. One of the most important questions in this regard is the issue of what Bitcoin actually is; that is, should Bitcoin be seen and analyzed as a currency or a commodity? According to most macroeconomic textbooks, a currency necessarily fulfills three functions: it needs to act as a medium of exchange, a unit of account and a store of value. Right now, according to a number of papers and regulatory reports focusing on this subject, Bitcoin has its deficits with regard to these functions (e.g. as of now it is not a generally accepted medium of exchange, and its high volatility prevents it from being a proper store of value), which is why both the scientific community and regulators currently regard Bitcoin as a commodity and not as a currency (Internal Revenue Service (IRS) 2014; Mittal 2012). Yermack (2013, p. 2) concurs and argues that, even though Bitcoin has several characteristics usually associated with currencies, it does not behave like one and concludes that the high volatility of Bitcoin makes it look more like a "speculative investment similar to the Internet stocks of the late 1990s".

However, it is interesting to note that several papers analyzing the underlying technology of Bitcoin are also emphasizing that Bitcoin has the technological potential to fulfill the abovementioned functions of a currency and to improve current payment systems in a number of areas (Plassaras 2013). Luther and Olson (2013) agree and interpret the Bitcoin peer-to-peer network and its decentralized ledger (the "Blockchain") tracking all transactions and every single Bitcoin over time as Bitcoin's most valuable feature, as this system provides for a cheap and extremely fail-proof way to save, store and retrieve data (i.e. a store of value). The Congressional Research Service also supports this view and highlights Bitcoin's low transaction costs[3] (no third-party intermediary is needed to process payments), its increased privacy and its potentially low inflation risk (as soon as regulatory uncertainties are eliminated), due to the maximum number of Bitcoins being limited (Congressional Research Service (CRS) 2015).

Investing in Bitcoins

As already mentioned above, an analysis of historic Bitcoin returns shows remarkably low correlation with traditional investment assets such as stocks, bonds, currencies or with commodities such as gold or oil, thus making it a potentially interesting asset for portfolio diversification purposes. Looking at the Bitcoin price from this perspective might give interesting insights on how the return distribution of Bitcoin is related to other asset classes.

In the last few years, several papers have looked at Bitcoin from a portfolio optimization and risk management perspective. For example, Brière et al. (2015) use mean-variance-based spanning tests and find diversification benefits using data from 2010 to 2013. Liew and Hewlett (2017) also look at portfolio diversification effects using a mean-variance approach. Trimborn et al. (2017) take the illiquidity of Bitcoin into account and find that Bitcoin can still add value to a portfolio. In general, in line with our results, these papers find evidence for potential diversification benefits of Bitcoin. Dyhrberg (2016) analyzes the hedging possibilities in a GARCH framework and shows that Bitcoin can be used as a hedge against the Financial Times Stock Exchange Index and, to some extent, the USD. Glaser et al. (2014) find evidence that especially uninformed users regard Bitcoin as an investment vehicle and not as a means

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[3] During 2017 and until January 2018, Bitcoin transaction costs dramatically increased due to the increase in the number of transactions handled by the network and the resulting network congestion, and only recently new technological developments helped in counteracting this development.

of payment. Elendner et al. (2016) study cryptocurrencies as alternative investment assets and investigate the relation between Bitcoin and other cryptocurrencies.

Due to the non-normal nature of Bitcoin returns, that is, with the Bitcoin return distribution showing large excess kurtosis and positive skewness, we do not propose the classic mean-variance approach, for example, as applied by Brière et al. (2015), but adopt a CVaR framework as CVaR is a risk measure that does have better properties when asset returns are not normally distributed (Rockafellar and Uryasev 2000). In addition, rather than picking just one single point in time for our portfolio optimization, we apply a portfolio backtesting technique, tracking and evaluating the out-of-sample monthly and total portfolio performance over an investment horizon of more than 6.5 years while rebalancing the portfolio weights on a monthly basis. Considering the abovementioned future potential of Bitcoin to serve as a currency and improve the payment systems currently in place, we think that it is fair to assume that Bitcoins should not be interpreted as a martingale but that they indeed do have a positive expected value and that our considerations in this chapter are thus warranted.

Methodology

In this chapter, we focus our analysis on the diversification effect of Bitcoin in an otherwise well-diversified portfolio. In other words, we analyze the effect that adding Bitcoin to the set of available assets has on the efficient frontier and the risk-return structure of that portfolio, and we show how the asset allocation changes and the share of Bitcoin develops over time. The benefits of additional asset classes on portfolio diversification have been analyzed in previous studies. For example, in a related paper, Belousova and Dorfleitner (2012) show that adding different types of commodities to a portfolio can have a beneficial impact.

As already mentioned, Bitcoin has recently experienced an increasing amount of attention, also by the investment community, at least partly due to the fact that Bitcoin has shown a significant price increase with exceptionally high returns, especially since mid-2013. From a portfolio management perspective, however, we are not solely interested in the impact Bitcoin might have on an already well-diversified investment portfolio but mostly in its effect on that portfolio's return-risk ratio. Of course, the sharp increase in Bitcoin price over the last few years could be the result of a Bitcoin price bubble. Thus, historical averages of returns might not be good estimates of the expected return of Bitcoin for future time periods even though our data set also includes various extended periods of negative performance like the sharp decline during the first quarter of 2018. It must also be noted that several important risk factors that investors should be aware of are not necessarily reflected in historical market prices. For example, regulators all over the world are still discussing how to effectively regulate markets for cryptocurrencies.

Therefore, our research questions can be summarized as follows:

1. How does the inclusion of Bitcoin affect the asset allocation of an already well-diversified portfolio?
2. Is the weight of Bitcoin in an already well-diversified portfolio robust with regard to the different optimization model specifications used?
3. Can Bitcoin improve the risk-return profile of an already well-diversified portfolio?

The details of our approach are explained in the following subsections. As Bitcoin's return distribution exhibits large deviations from a normal distribution, we choose a more robust risk measure based on CVaR.

In the context of the standard capital asset pricing model, a mean-variance approach is used to calculate Sharpe ratios and to determine the optimal portfolio given a number of risky assets. However, the mean-variance analysis requires that returns follow a normal distribution in order to allow for the use of variance as a risk measure. Otherwise, the variance is likely to underestimate the potential loss resulting from additional tail risk and, hence, can lead to suboptimal portfolio decisions (see, e.g. Jorion (2001) and McNeil et al. (2005)).

In such a case, a risk measure better reflecting the downside risk is more favorable. One possible measure proposed in the literature is Value-at-Risk (VaR), which is the loss that will not be exceeded over a given time horizon at a given confidence level. This measure has received a lot of attention due to its inclusion in financial regulation (see, for instance, Jorion (1996) and Campbell et al. (2001)). Despite its popularity, VaR suffers from various shortcomings, such as instability and difficult numerical estimation, when losses are not normally distributed.

Additionally, VaR does not further quantify the amount by which this quantile can be exceeded (Rockafellar and Uryasev 2002). Moreover, Artzner et al. (1999) show that VaR is not a coherent risk measure, since it does not satisfy the property of sub-additivity.

In order to ensure coherence of our risk measure, we follow Rockafellar and Uryasev (2000) and adopt a different approach using the CVaR as risk measure. We try to adhere to their notation to make the definitions comparable.

Define the cumulative distribution function $\Psi(\omega, \zeta)$ of a loss $z = f(\omega,y)$ as

$$\Psi(\omega,\zeta) = \mathrm{P}\{\mathrm{y} \mid \mathrm{f}(\omega,\mathrm{y}) \le \zeta\}, \tag{6.1}$$

where

ω = decision vector (i.e. portfolio weights),
ζ = a specific loss,
y = uncertainties (e.g. market variables) that affect the loss.

Then the VaR for a given confidence level α (ζ_α) is defined as

$$\zeta_\alpha = \min\{\zeta \mid \Psi(\omega,\zeta) \ge \alpha\}. \tag{6.2}$$

The Conditional Value-at-Risk ($CVaR_\alpha$) is now the expected value of the loss, given that the loss is weakly exceeding the VaR $\zeta_\alpha(\omega)$[4]:

$$CVaR_\alpha(\omega) = \frac{1}{1-\alpha} \int_{f(\omega,y) \ge \zeta_\alpha(\omega)} f(\omega,y)\, p(y)\, dy. \tag{6.3}$$

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[4] Rockafellar and Uryasev (2002) also refer to this as $CVaR^-$ or Tail VaR. In case of a continuous distribution, this coincides with the expected shortfall.

We then form optimal portfolios by minimizing CVaR$_\alpha$:

$$\min_{\omega} CVaR_{\alpha}(\omega) \tag{6.4}$$
$$s.t.$$
$$\omega^T \hat{y} = \bar{r}$$
$$\omega^T 1 = 1$$

where

$\hat{y}$ = vector of expected asset returns,
$\bar{r}$ = expected total return of the portfolio.

On the basis of the CVaR$_\alpha$ as defined in Eq. 6.3, we calculate a return-risk ratio *S* similar to Campbell et al. (2001), which can be used as a performance indicator to evaluate the return-risk efficiency of portfolios in the same way as the Sharpe ratio. For our analysis we choose a confidence level α of 95%, and the optimal combination of assets is then found, when the return-risk ratio *S* is maximized.

Portfolio Strategy

In order to evaluate the diversification effect of including Bitcoin into portfolios based on the described mean-CVaR approach, we adopt the view of a US investor and construct well-diversified portfolios including various broad indices for equity, fixed-income, money market, commodity, real estate and alternative investment opportunities. We then apply a backtesting technique to assess the performance of these portfolio strategies using historical data.[5] We calculate monthly out-of-sample portfolio returns based on the optimal weights w_i of each asset i given the maximized risk-return ratio estimated using 12-month rolling horizons. We use the first 12 months of data from our sample period as a "burn-in"

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[5] We use the R-package fPortfolio to construct the well-diversified portfolios and apply the backtesting technique.

period for the initial weights estimation. We apply this methodology for all 12-month rolling horizons to estimate portfolio weights throughout our sample period. This allows us to calculate out-of-sample expected monthly returns as well as CVaRs for the investment period, that is, the sample period without the burn-in phase. Afterward we explore the effect of adding Bitcoin by comparing the risk-return ratios of the optimal portfolios. The weight optimization process for each optimal portfolio is thereby subject to various parameters defined in four different portfolio optimization frameworks described below. Additionally, in three out of four strategies, three-month weight smoothing is applied based on an exponentially weighted moving average (EWMA). Hence we end up with eight portfolios in total, four of which include Bitcoin.

The *unconstrained portfolio framework* does not apply any weight-related constraints to the optimization process and should therefore yield optimal portfolios with the highest risk-return ratios of all portfolio frameworks. The results from this strategy show the unbiased effect of adding a new asset to the portfolio mix. However, the risk-return maximization process might lead to both fairly large asset weights and extremely high weight rebalancing over time and render an implementation of such a strategy unfeasible. Due to the first 12 months of the total sample period being used to calculate the initial weights estimations, the investment period is 12 months shorter than the total sample period.

The *constrained portfolio framework* allows for asset weights to shift between +100% and −100%. Compared to the unconstrained portfolio optimization framework, we expect to see smoother weight rebalancing, which makes this strategy more interesting in terms of feasibility. Here, the first 12 months of data are again used to compute the initial portfolio weights, reducing the investment period to a time frame that is 12 months shorter than the total sample period.

The *long-only portfolio framework* imposes as short-selling constraint in order to reflect possible restrictions involved with short-selling certain assets that are included in each portfolio, thus effectively limiting both the sum of all asset weights and the weight of each asset in a portfolio to 100%. As of now, it is also not clear whether or not a short position in

Bitcoin is actually feasible. Again, the first 12 months of data are not part of the investment period, since they are used for the initial estimation of portfolio weights.

The *equally weighted portfolio framework* represents a passive portfolio strategy in which the portfolios consist of equally weighted assets, with the weights being constant over time. Therefore, no optimization process is applied. We include this strategy based on the findings of DeMiguel et al. (2009), who show that an equally weighted portfolio leads to comparable or even higher Sharpe ratios in comparison to various portfolio optimization techniques, due to the poor predictive capacity of many commonly used risk and return measures. By including this approach, we acknowledge the prediction risks involved with the risk and return measures we apply in this chapter (and consequently any resulting bias in our findings) and provide a possible solution with this framework not depending on estimating risk and return measures. As the portfolio weights are held constant over time, also no smoothing is here applied. Again, the first 12 months of data are not part of the investment period; however, since of course no initial portfolio weights estimation is necessary here, this is done solely in order to ensure comparability with the other three portfolio optimization frameworks.

Data

For Bitcoin price data, we use the CoinDesk Bitcoin USD Price Index, a simple average of global Bitcoin/USD exchange prices.[6] It is expressed as the midpoint of the bid/ask spread across a number of global exchanges meeting certain minimum criteria with regard to minimum trade size, trading volume and others.[7] Since historical price data on Bitcoin becomes available starting on July 18, 2010, on CoinDesk.com, the sample period

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[6] As noted, for example, by Brière et al. (2015) and Brandvold et al. (2015), Bitcoin prices can vary between individual exchanges.

[7] See http://www.coindesk.com/price/bitcoin-price-index/ for more detailed information.

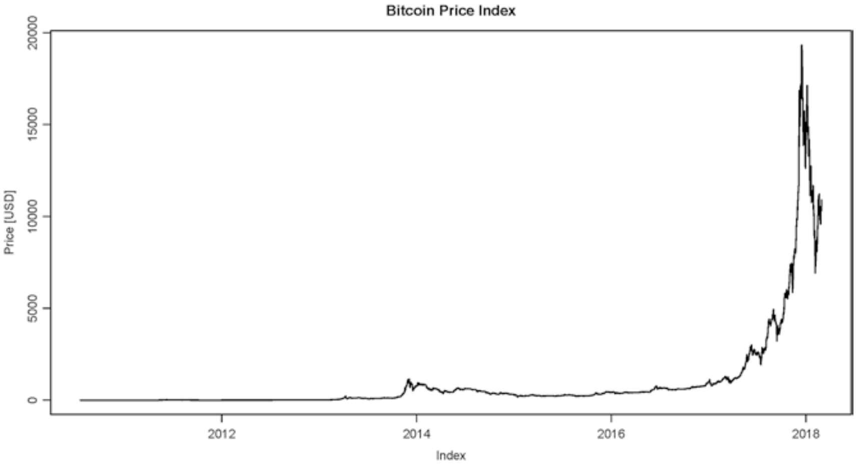

Fig. 6.1 The historical development of the Bitcoin price in USD from July 18, 2010, until March 01, 2018. We use the Bitcoin USD Price Index created by CoinDesk as a market-wide representation of the Bitcoin price. The index represents the average of the Bitcoin price quoted in USD across a number of exchanges that fulfill basic data requirements

covers just under 93 months until March 01, 2018. Figure 6.1 depicts the historical development of the Bitcoin price quoted in USD starting on July 18, 2010.

For the portfolio optimization process, we assume the position of a US investor. In order to allow for a well-diversified and international portfolio, we include a broad range of asset classes in our sample. Our asset class lineup therefore covers equity, fixed-income, money market, commodity, real estate and alternative investment opportunities, each represented by at least one or a number of broad and liquid financial indices. All assets are required to be quoted in USD, and data is gathered using Thomson Reuters Datastream and Bloomberg. See Table 6.1 for a detailed overview of all sample assets.[8]

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[8] For the risk free rate, we assume a value of 0%, since interest rates on US one-month Treasury bills have been floating in the range 0–0.1% in recent years.

Table 6.1 Details on the investment assets included in the sample

Name	Abbrev.	Asset class
CoinDesk Bitcoin Price Index (BTC)	coindeskBPI	–
MSCI World Index	msciworld	Equity
MSCI Emerging Markets Index	msciem	Equity
MSCI Frontier Markets Index	mscifm	Equity
Bloomberg Global Developed Sovereign Bond Index five to seven years	bgsv	Fixed income
Bloomberg Barclays Emerging Markets Sovereign TR Index Value Unhedged USD	blcsv	Fixed income
Bloomberg Barclays US Corporate Investment Grade (USD) TR Index Unhedged USD	bcor	Fixed income
Bloomberg Barclays Global High Yield Corporate Total Return Index Unhedged USD	bhyc	Fixed income
iShares TIPS Bond ETF (US only)	tipus	Fixed income
MSCI EAFE Currency Index (USD)	mxea	Money market
S&P World Commodity Index	spwici	Commodities
FTSE EPRA/NAREIT Developed Real Estate Index	engl	Real estate
Global Hedge Fund Index	hfrxgl	Alternative

The abbreviation column gives the abbreviations used in tables and figures later on, while the asset class column indicates each asset's respective asset class. The sample period over which data is gathered starts on July 18, 2010, and ends on March 01, 2018

Results

Table 6.2 shows descriptive statistics on all assets used in our portfolio optimization frameworks. As already mentioned, the Bitcoin return distribution exhibits large excess kurtosis (6.49) and is positively skewed (1.63). Table 6.3 shows pairwise correlation coefficients and corresponding p-values for the null hypothesis of correlation coefficients of zero.

While many of the other assets are significantly correlated, the results indicate that the Bitcoin correlation coefficients are small and not significantly different from zero. Our findings in this regard are thus largely in line with the results of Brière et al. (2015), which indicates that these findings still hold when analyzing an extended data set of 93 months.

Table 6.4 presents an overview of the main results of our empirical analysis. For all four portfolio optimization frameworks introduced above

Table 6.2 Descriptive statistics for the monthly returns of the assets included in our portfolios for the sample period from July 18, 2010, to March 01, 2018

	coindeskBPI	bcor	bgsv	bhyc	blcsv	engl	hfrxgl	msciem	mscifm	msciworld	mxea	spwici	tipus
Mean	1.58	0.09	0.10	0.07	0.04	0.04	0.06	0.17	−0.01	0.01	0.07	0.04	0.11
Median	0.67	0.10	0.08	0.10	0.05	−0.01	0.04	0.18	0.07	−0.08	0.01	0.01	0.09
Maximum	30.28	0.83	0.93	0.77	0.64	3.33	0.49	3.38	0.86	3.94	3.62	5.58	1.16
Minimum	−10.30	−0.35	−0.77	−0.97	−0.63	−1.62	−0.48	−1.80	−1.89	−2.94	−3.58	−6.75	−0.61
Volatility	5.67	0.22	0.31	0.23	0.23	0.80	0.18	0.96	0.49	0.91	0.98	1.52	0.30
Skewness	1.63	0.58	0.19	−0.85	−0.28	1.02	−0.01	0.55	−1.14	0.87	0.45	−0.01	0.57
Kurtosis	6.49	1.11	0.77	4.80	0.60	3.00	0.29	0.75	1.92	4.54	3.46	5.25	0.81
Observations	93	93	93	93	93	93	93	93	93	93	93	93	93

Table 6.3 Pairwise correlation coefficients and the corresponding p-values (below) from the significance tests

Correlation matrix – coefficients												
	coindeskBPI	bcor	bgsv	bhyc	blcsv	engl	hfrxgl	msciem	mscifm	msciworld	mxea	spwici
bcor	−0.16											
bgsv	−0.06	0.36										
bhyc	−0.05	−0.10	0.39									
blcsv	−0.12	0.31	0.10	0.47								
engl	−0.10	−0.10	−0.30	0.20	0.39							
hfrxgl	−0.02	−0.10	0.00	0.46	0.43	0.49						
msciem	−0.12	−0.10	0.05	0.59	0.48	0.55	0.56					
mscifm	−0.19	−0.10	0.11	0.29	0.30	0.06	0.28	0.29				
msciworld	0.01	−0.30	0.23	0.71	0.34	0.56	0.69	0.68	0.28			
mxea	−0.01	−0.30	0.36	0.75	0.34	0.44	0.59	0.67	0.24	0.93		
spwici	−0.03	−0.10	0.11	0.35	0.12	−0.10	0.26	0.23	0.16	0.25	0.24	
tipus	−0.03	0.70	0.26	−0.20	0.08	−0.20	−0.06	−0.20	−0.10	−0.29	−0.22	0.05
Correlation matrix – p-values												
	coindeskBPI	bcor	bgsv	bhyc	blcsv	engl	hfrxgl	msciem	mscifm	msciworld	mxea	spwici
bcor	0.12											
bgsv	0.56	0.00										
bhyc	0.64	0.23	0.00									
blcsv	0.26	0.00	0.33	0.00								
engl	0.34	0.39	0.01	0.05	0.00							
hfrxgl	0.87	0.43	0.98	0.00	0.00	0.00						
msciem	0.26	0.33	0.66	0.00	0.00	0.00	0.00					
mscifm	0.07	0.52	0.29	0.00	0.00	0.58	0.01	0.00				
msciworld	0.91	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.01			
mxea	0.9	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00		
spwici	0.79	0.37	0.28	0.00	0.26	0.33	0.01	0.03	0.14	0.02	0.02	
tipus	0.79	0.00	0.01	0.13	0.42	0.14	0.54	0.06	0.34	0.00	0.04	0.61

Correlation coefficients are calculated using monthly returns for the sample period from July 18, 2010, until March 01, 2018

Table 6.4 Main results for each portfolio and every portfolio optimization framework

	Mean monthly BTC weight	Mean monthly return (%)	Mean monthly CVaR (%)	Mean monthly return-risk ratio
Equally weighted BTC	7.69%	1.14	0.90	3.02
Equally weighted no BTC	–	0.26	0.61	1.94
Long-only BTC	7.90%	0.92	1.15	1.88
Long-only no BTC	–	0.33	0.67	1.20
Unconstrained BTC	5.00%	2.80	1.37	3.38
Unconstrained no BTC	–	0.47	0.36	1.90
−100%/+100% BTC	2.30%	0.75	0.58	2.17
−100%/+100% No BTC	–	0.47	0.36	1.90

All data presented are monthly means for the investment period starting July 1, 2011, and ending on March 01, 2018

(see section "Methodology") and over the total 81-month investment period (exception: under the equally weighted framework, the investment period equals the total sample period of 93 months), the table shows the mean portfolio weights of Bitcoin, the mean monthly portfolio returns, the mean monthly portfolio CVaRs at the 95% level and the corresponding mean monthly return-risk ratios of the portfolios. As explained in section "Methodology", all of the results presented in the following are out-of-sample results computed using the portfolio backtesting approach.

Overall, we find that the results for all the portfolio optimization frameworks are rather similar. The mean monthly weight of Bitcoin in the portfolios is relatively low across the board, with values between 2.30% in the −100%/+100% framework and 7.90% in the long-only portfolios. Concerning the mean monthly portfolio returns, an increase is clearly observable across all optimization frameworks when comparing the portfolios excluding Bitcoin to the portfolios including Bitcoin. With an average increase in return being 1.02 percentage points, the effect is most prominent in the unconstrained optimization framework, where the mean monthly return increases by 2.33% from 0.47% to 2.80%. In line with the results reported earlier, our findings confirm that the mean portfolio risk also increases when Bitcoin is added to the asset mix. With mean CVaR in BTC portfolios being 0.50 percentage points higher on average across all frameworks, this effect is again most prominently illustrated by the unconstrained portfolios, with the CVaR increasing from 0.36% to 1.37%, that is, an increase of 1.01 percentage points. Most importantly, as can finally be seen from the return-risk ratios, the higher returns of the portfolios including Bitcoin seem not to be completely offset by the evident increases in risk. In fact, the return-risk ratios improve consistently over all optimization frameworks when adding Bitcoin to the asset mix with an average increase of 0.88. Again, the effect is most pronounced for the unconstrained portfolio. However, even in the equally weighted portfolio framework, the return-risk ratio increases by 1.08 from 1.94 to 3.02, and in the −100%/+100% portfolio, we find an increase of 0.27, up from 1.90 in the portfolio excluding BTC to 2.17 in the portfolio including BTC.

Figure 6.2 depicts the optimal portfolio weights of Bitcoin under all of the four portfolio optimization frameworks we applied in this chapter in more detail over the investment period. With the mean Bitcoin weights lying somewhere between 2.30% and 7.90% as already mentioned above, it is interesting to note that Bitcoin has a positive weight under all frameworks over the whole investment period. Furthermore, while it is obvious that Bitcoin is included under the equally weighted framework at a stable weight of 7.69%, Bitcoin weights are stable most of the time in the three other frameworks, hovering in the area of 1% to 8% across all other optimization frameworks. The two exceptions are the unconstrained portfolio framework in 2012 showing a Bitcoin portfolio weight of 28.87% and the long-only portfolio framework between 2015 and 2017, where the Bitcoin weight reaches 57.82% at its peak.[9] In general, the relatively low and stable BTC weights shown might be beneficial from a liquidity perspective: low and stable Bitcoin portfolio shares (i.e. thus requiring

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[9] The explanation for the increase in BTC weights in the long-only portfolio can be found in the price development of BTC. BTC exhibited a significant decrease in volatility during that time, and the short-selling constraints of the framework do not allow for a more efficient reallocation into other asset classes.

only infrequent rebalancing, which reduces transaction costs) might make Bitcoin investments more feasible for both institutional and private investors.

Following this, we take a more detailed look at the results of one specific optimization framework, the −100%/+100% framework. We present these results as representative examples of all four optimizations, since the results of the other optimization frameworks (i.e. equally weighted, long-only, and unconstrained) are comparable in almost all areas.

The three plots shown in Fig. 6.3 outline the main results of the −100%/+100% portfolio optimization framework. The first plot of Fig. 6.3 depicts the cumulative returns of both the portfolios including Bitcoin and the portfolios excluding Bitcoin on a monthly basis. As can

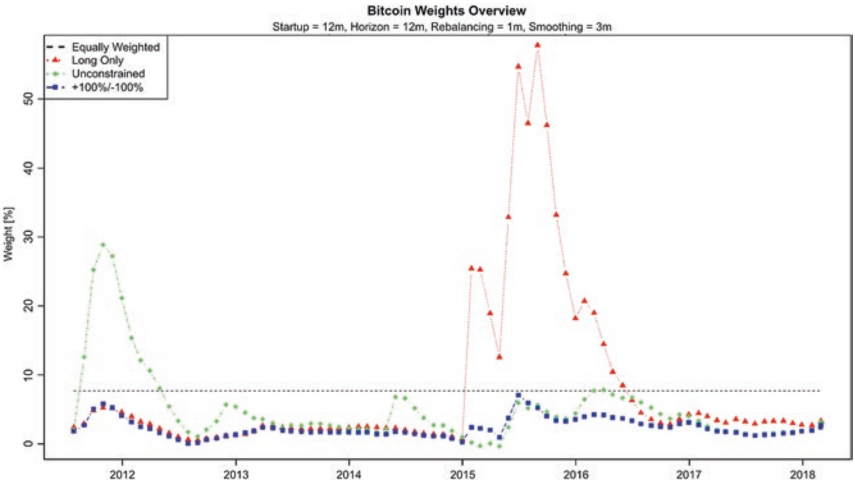

Fig. 6.2 Optimal portfolio weights of Bitcoin under the four different portfolio optimization frameworks (equally weighted, long-only, unconstrained and constrained −100%/+100%) over the investment period. Of the total sample period of 93 months, the first 12 months of data are used for the initial estimation of optimal portfolio weights, thus yielding an 81-month investment period starting July 01, 2011, and ending on March 01, 2018. Furthermore, a rolling 12-month window is used for the optimization throughout the investment period, with monthly portfolio rebalancing and three-month EWMA (equally weighted moving average) smoothing on asset weights. This is true for all optimization frameworks except for the equally weighted framework, where no estimation of optimal portfolio weights takes place and no smoothing is applied

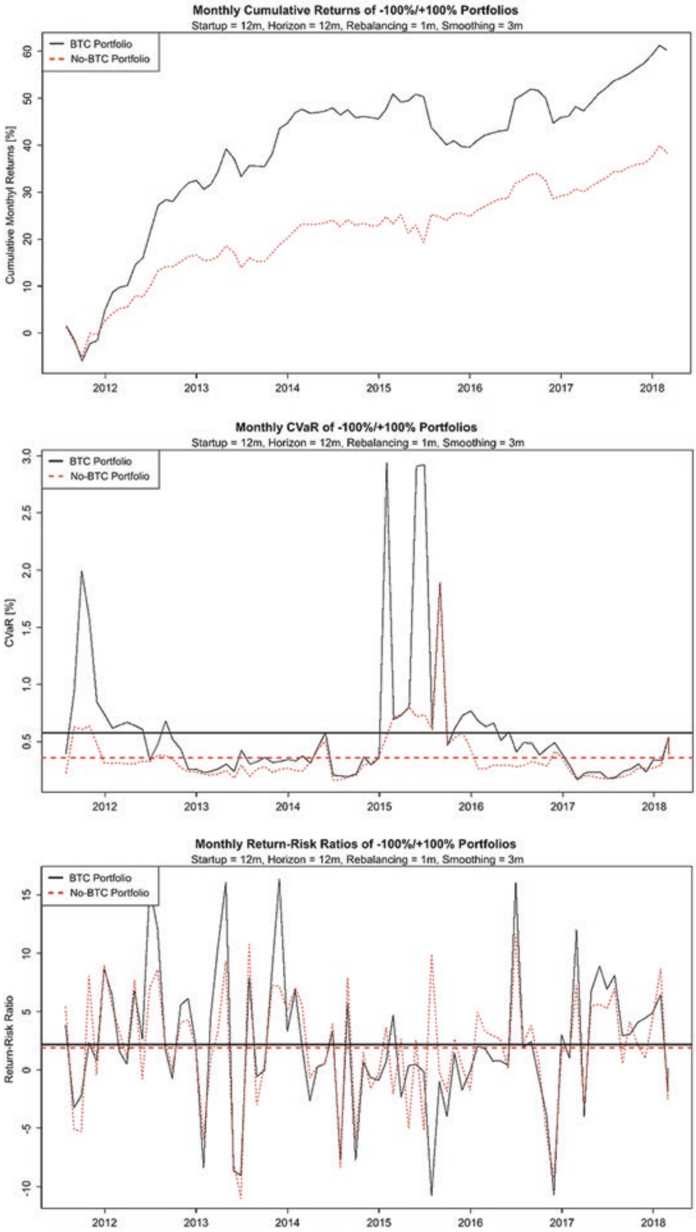

Fig. 6.3 Backtesting results of the portfolios including Bitcoin and the portfolios excluding Bitcoin under the −100%/+100% portfolio optimization framework. First, we plot cumulative monthly returns of the two portfolios, second, we plot

be expected by now, it can clearly be seen that the portfolios including Bitcoin exhibit a higher total cumulative return at the end of the investment period (60.32%) than their counterparts excluding Bitcoin (38.32%). The second plot of Fig. 6.3 details the development of monthly CVaRs of both the BTC and no-BTC portfolios, with the Bitcoin portfolios always having a higher risk exposure. The mean CVaRs of 0.58% (incl. BTC) and 0.36% (excl. BTC) shown in Table 6.4 confirm this as well.

The third plot of Fig. 6.3 graphs the development of the monthly return-risk ratios over the investment period, with the portfolios including Bitcoin constantly having higher return-risk ratios than the portfolios excluding Bitcoin. Again, this is also evidenced by the respective mean return-risk ratio with 2.17% (incl. BTC) and 1.90% (excl. BTC) shown in Table 6.4.

Figure 6.4 finally compares the optimal asset allocation of the portfolio excluding Bitcoin and the portfolios including Bitcoin under the −100%/+100% portfolio optimization framework over the investment period. To allow for easier illustration, we combine the weights of the original investment assets into a number of merged asset classes: equity (stocks), fixed income (government bonds and corporate bond), and various (money market, commodities, real estate and alternative asset). It can clearly be seen that the introduction of Bitcoin into the portfolio optimization process has some impact on the weights of all other included asset classes. Throughout the investment period, the optimal portfolios contain between 0.05% and 7.1% Bitcoin (weights are less than 1% in eight months in total).

At the same time, equity portfolio weights do not change very much as a result of introducing Bitcoin to the asset mix. With respect to government bonds, it can be seen that long positions have been increased when

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the time series of CVaRs of the two portfolios, and third, we plot the time series of return-risk ratios of the two portfolios. Of the total sample of 93 months, the first 12 months of data are used for the initial estimation of optimal portfolio weights, thus yielding an 81-month investment period starting on July 01, 2011, and ending on March 01, 2018. Furthermore, a rolling 12-month window is used for the optimization throughout the investment period, with monthly portfolio rebalancing and three-month EWMA (equally weighted moving average) smoothing on asset weights

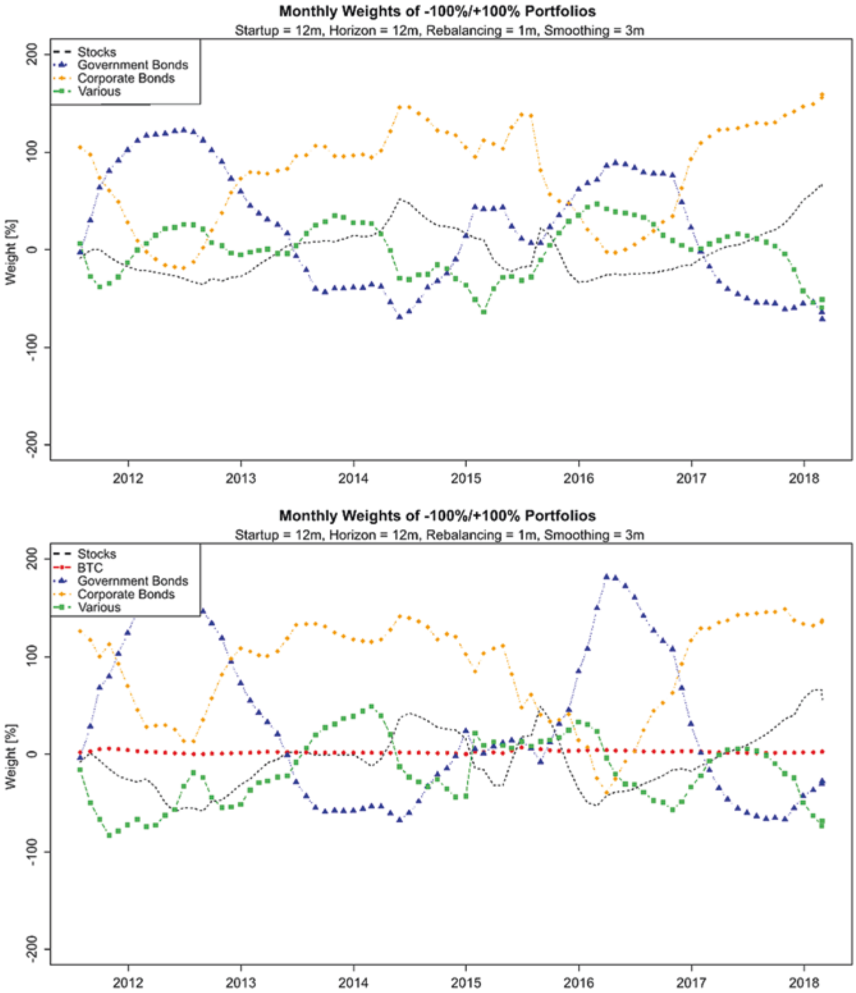

Fig. 6.4 Comparison of the optimal asset allocation of the portfolios including Bitcoin and the portfolios excluding Bitcoin under the −100%/+100% portfolio optimization framework. Using our backtesting approach, we show the optimal weights of individual asset classes over time, combining the money market, commodities, real estate and alternative asset classes into one group name "various", to allow for easier illustration. Of the total sample of 93 months, the first 12 months of data are used for the initial estimation of optimal portfolio weights, thus yielding an 81-month investment period starting on July 01, 2011, and ending on March 01, 2018. Furthermore a rolling 12-month window is used for the optimization throughout the investment period, with monthly portfolio rebalancing and three-month EWMA smoothing on asset weights. Due to the combining of specific assets into asset classes, the weights of specific asset classes can reach values below −100% and above 100% notwithstanding the applied portfolio constraints

Bitcoin is added to the portfolio, in order to counter the increased portfolio risk originating from the Bitcoin investment. The weights of corporate bonds remain mostly unaffected and are on average roughly 10% higher in the portfolios including BTC, while the weights of the group "various" are 20 percentage points lower on average.

Conclusion

Bitcoin is undoubtedly still the most popular unregulated cryptocurrency. Given Bitcoin's interesting characteristics (e.g. the historical development of the Bitcoin price or its surprisingly low correlation with other, more well-known and widely used investment assets), the literature on the subject and the high level of media coverage, we aim to answer three specific research questions on Bitcoin: How does the inclusion of Bitcoin affect the asset allocation of already well-diversified portfolios, is the weight of Bitcoin in an already well-diversified portfolio robust with regard to the optimization procedure used, and does a backtesting approach indicate that Bitcoin might be able to improve the risk-return profile of an already well-diversified portfolio?

To account for Bitcoin's highly non-normal return distribution, we adopt a more robust portfolio optimization approach built on the CVaR approach. We apply a portfolio backtesting technique to calculate monthly out-of-sample returns and return-risk ratios based on the CVaR. As a robustness check, we calculate our results under a number of different portfolio optimization frameworks, including completely unconstrained portfolios, portfolios featuring short-selling constraints and equally weighted portfolios as a naive benchmark.

In answer to our research questions and on the basis of a data set covering all available data on Bitcoin (July 18, 2010, until March 01, 2018), we find that even in already well-diversified portfolios our optimizations lead to Bitcoin being included in efficient portfolios. This result indicates that the characteristics of the Bitcoin price could provide a diversification benefit. Furthermore, the inclusion of Bitcoin in the respective portfolios under the different optimization frameworks also has interesting effects on the weights of government bonds. The portfolios we obtain do not simply have lower weights in all other assets but show in increase in the share of government bonds in comparison to the no-BTC portfolios to counterbalance the increased risk introduced by Bitcoin. The relatively low and stable Bitcoin weights are also beneficial from a liquidity perspective. With market turmoil generally casting doubt on the liquidity of Bitcoin markets, low Bitcoin portfolio shares with infrequent rebalancing requirements might thus make Bitcoin investments more feasible for both institutional and private investors.

Our results furthermore indicate that Bitcoin can contribute to the return-risk ratios of optimal portfolios. For our sample period from 2010 to early 2018, including Bitcoin would have increased both the expected return and the risk of the portfolios. However, according to CVaR-based return-risk ratios, the return contribution seems to outweigh the additional risks faced by the investor. These results are robust with regard to the optimization framework applied.

When thinking about asset allocation and investment decisions, results of portfolio optimization procedures using historical data have to be interpreted with care. As already noted in Black and Litterman (1992), expected returns of assets are very difficult to estimate. Especially given the large price increase of Bitcoin over the recent years, historical means might not be ideal estimates of the expected return of Bitcoin in the future. Moreover, it is an open question how important risk factors (e.g. increased regulation) will impact Bitcoin prices, and it is unclear if this risk is correctly reflected in market prices.

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7

Blockchain in the Payments Industry: Developing a Discussion Agenda Based on Pain Points and Opportunities

Friedrich Holotiuk, Jürgen Moormann,
and Francesco Pisani

Introduction

The rise of blockchain is likely to cause a noticeable disruption across many industries. Currently, blockchain is most famous for its applications in the field of cryptocurrencies such as Bitcoin. However, the broader potential of the technology encompasses business process improvement and the simplification of existing procedures. A variety of blockchain-based applications in the financial services sector are being discussed. Among them are, for example, approaches where blockchain can help reduce financial fraud (Hyvärinen et al. 2017). Another application of blockchain copes with "know-your-customer" processes and aims to improve the verification process of customers for banks while also improving the customer experience (Parra Moyano and Ross 2017). Applications of blockchain are based on the benefits of the technology pertaining to decentralization and transparency (Rückeshäuser 2017). The recent

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advancements of the technology suggest that the financial services sector is perceived to be the primary user of blockchain (Nofer et al. 2017), and a number of beneficial outcomes in this field are already being discussed (Fanning and Centers 2016).

Our chapter aims to develop a better understanding of the impact blockchain might have on the payments industry as a part of the financial services sector. Payments are "a quintessential economic activity, the 'glue' that binds together the gains from trades" (Kahn and Roberds 2009, p. 19). Hence, the payments industry represents a cornerstone of banking and often serves as the central hub for other products and services. Due to the importance of payments and the growing interest in blockchain, we investigate in which areas experts expect the highest potential and the necessity for the application of blockchain. Furthermore, we analyze how important the development around blockchain is for financial institutions. Currently, we see that the discussion is influenced by a strong hype around the topic, while a deep understanding of pain points and opportunities is still missing.

In the next sections, we work out the impact based on statements from experts and structure the statements to allow for a more organized discussion. For this purpose, we conducted a Delphi study with 45 experts from the payments industry. The input from all experts was gathered and enabled us to derive 45 statements representing the impact of blockchain. We analyze the *consensus* among the participants, which was generated in the course of the study, and determine clusters of the statements with high, medium, and low consensus, yielding different levels of unison. Next, we analyze the *ranking* of the statements and derive three groups (top, middle, and bottom) with different levels of importance. Based on these two dimensions of the analysis (consensus and ranking), we identify areas where the dissemination of blockchain faces challenges as well as opportunities in the field of payments. This unique structure of the analysis allows us to provide an agenda on how the discussion about blockchain in the payments industry should proceed and where practitioners and academics should focus.

Based on this agenda, the chapter contributes to the literature by adding structure and overview to the discussion on the adoption of blockchain, as well as providing a better understanding about the impact of blockchain for companies in the financial services sector, the competitive landscape of the payments industry, and the possibility of new entrants into this industry.

The chapter is structured as follows. First, we present a brief background on digital technologies and the payments industry. Second, we introduce the Delphi method and present how we gathered the statements that serve as the basis for our analysis. Third, we analyze the data according to two dimensions (consensus and ranking). Last, we conclude by providing an agenda to structure the discussion on blockchain in payments.

Background

In the past, new technologies have often been the drivers for radical change, creating new opportunities and generating new sources of income. At the same time, new technologies have always posed a threat of falling behind by missing out on using technological advancements (Bower and Christensen 1995).

One of the most recent breakthrough technologies is blockchain, with the financial services sector as one of its most impacted application areas (Beck et al. 2017). This is particularly due to substantial process inefficiencies and a huge cost base issue in this industry (Nofer et al. 2017). The technology's potentially revolutionary enhancement for financial products and services, process improvement, and even process innovation makes it highly interesting for banks, insurance companies, and other financial service providers. Blockchain initiates a progressive shift toward direct transactions between parties without the necessity for intermediaries (Beck et al. 2016).

Applications of blockchain have diversified since its first major implementation, the cryptocurrency Bitcoin. For example, applications have been presented around instant payments and peer-to-peer (P2P) transactions, as well as use cases illustrating how to overcome the existing boundaries of payments (Swan 2015). The implementation of blockchain in the traditional payments industry is presumed to be groundbreaking due to the extraordinary potential attributed to the technology (Swan 2015; Tapscott and Tapscott 2016). Furthermore, due to the technology's complexity major organizational implications are to be expected (Holotiuk and Moormann 2018).

The extant literature on blockchain has mainly focused on identifying possible single applications of the technology (Bott and Milkau 2016; Wörner et al. 2016), placing less emphasis on the overall (and consequently more diverse) impact of blockchain on an entire industry. Often, use cases have been envisioned without relating to the possible implications for the industry and the subsequent change that would follow. Thus, the identification of actual pain points and challenges in an existing industry like the payments field is most promising for blockchain research and the advancement of knowledge on blockchain. Deeply understanding its impact allows the derivation of adequate steps to guide and manage the dissemination of the technology in the payments field.

Blockchain inherently includes many features that are promising for payments. Based on a collective bookkeeping system known as the distributed ledger, blockchain allows for immutable entries of transactions in blocks that are combined in a chain. Furthermore, it builds on identical duplication of the chain of blocks across nodes within a network, which eliminates manipulation of past entries. The data in a blockchain is shared and synchronized across multiple geographic locations, countries, and institutions without centralized administrators (Scardovi 2016). With transparency and permanence as the two main properties of blockchain (Lee and Pilkington 2017), the technology offers security and reliability when it comes to data storage (Crosby et al. 2016). The original intention was to process transactions based on cryptography, providing an alternative to conventional methods of transaction between two parties and eliminating the need for trustworthy intermediaries (Nakamoto 2008).

For payments, blockchain provides a range of applications including real-time transactions between parties, trade of digital assets (e.g., records of ownership), and cross-currency relocations of financial assets. As a result, the interest in blockchain has been further fueled, and a number of scenarios are being discussed. However, changes to the payments industry are potentially harmful to incumbents like current banks or payment service providers. Not only are payments a lucrative source of revenue, but they are a core product for a huge spectrum of other financial services. Furthermore, the payments industry is a major contributor when it comes to customer data. Banks can use the information gathered through payments as a source of knowledge about their clients. Hence, a loss in involvement in payment transactions may have significant consequences for the income generation of banks (Hallowell 1996).

Squeezed between the need for investments in compliance and information technology (IT), the erosion of income from traditional sources, and fierce competition, the business models of many financial institutions are under pressure. Hence, attempts to make the current payment infrastructure obsolete or to pull away payment transactions from financial institutions will contribute to the deterioration of banks' business base. In this regard, blockchain represents a significant threat, especially since it might switch off the third-party function of financial institutions.

At the same time, however, the reduction of costs that could be realized by using blockchain is inducing financial institutions to closely look at, and sometimes actively push forward, its development. The formation of worldwide associations (such as R3, including Citibank, Credit Suisse, and Deutsche Bank) as well as international alliances (e.g., Enterprise Ethereum Alliance, including JP Morgan, UBS, and Accenture) is accelerating the development of blockchain also for payments.

Research Method

The analysis in this chapter is based on a Delphi study conducted among a group of selected experts, all of whom possess knowledge of both blockchain *and* payments. Given the lack of existing research and the exploratory nature of the study, open qualitative interviews were considered as an option. However, the industry still shows a high degree of uncertainty regarding the topic of this study. This necessitated a more formalized and group-oriented, multistage approach. Consequently, the Delphi technique was the method of choice (Rowe and Wright 1999).

The Delphi method is widely accepted in research regarding the forecasting of technology (Adler and Ziglio 1996; Turoff 1971). It is suitable for developing exploratory theories on interdisciplinary issues, with the involvement of future trends (Akkermans et al. 2003; Meredith et al.

1989). The method has been used frequently for the identification and ranking of key issues for management action in the context of information systems research (Schmidt 1997). The structured communication flow of the Delphi method makes possible the discussion of complex issues (Linstone and Turoff 1975).

In order to gain a highly reliable consensus among a group of experts, the method builds on four distinct characteristics as defined by von der Gracht (2012): (1) anonymity, (2) iteration, (3) controlled feedback, and (4) statistical group response.

Panel of Experts

One of the fundamental criteria for selecting the participants of a Delphi study is the individual's expertise on the topic of research (Okoli and Pawlowski 2004). Furthermore, we took the requirements described by Hill and Fowles (1975) into account. Accordingly, we selected experts for our panel based on their practical experience in the payments industry, the role and background of their firm, and their professional position. A necessary precondition was an extensive understanding of blockchain in order to evaluate its impact on payments. In the process of properly identifying and validating the experts for this study, web searches, talks with practitioners, and databases of professional networks (e.g., LinkedIn) were used. As a result, our Delphi panel consisted of 45 participants representing a high-quality mix of experts. Out of the 45 panelists, 16 (35%) came from consulting, 11 (24%) from fintechs, 6 (13%) from banks, 4 (9%) from academia, 3 (7%) from public institutions, 3 (7%) from payment service providers, and 2 (4%) from technology providers. The panel did not change throughout the study, but its size reduced due to minor dropouts (Table 7.1). The stable core of panelists enabled answers to be

Table 7.1 Response rates of the Delphi study

Round 1		Round 2		Round 3	
Sent out	Complete responses	Sent out	Complete responses	Sent out	Complete responses
45	38 (84.4%)	38	36 (94.7%)	36	34 (94.4%)

obtained from a wide spectrum of experts while still being able to guarantee a clearly focused evaluation (Pousttchi et al. 2015).

Data Collection

As suggested by Murry and Hammons (1995), we chose to follow a three-round procedure. Round one (R1) aimed to derive the panelists' insights and opinions. In round two (R2), the panelists evaluated the results of R1. In round three (R3), the panelists were asked to re-evaluate the results in light of the group feedback.

As per Linstone and Turoff (1975), we designed R1 based on an open-ended format, suggesting starting points around blockchain with relevance to the payments industry. The goal was to elicit individual perspectives, judgments, and opinions from each panelist (Schmidt 1997). In R1, we sent out emails to the 45 panelists asking for their individual judgments on how blockchain will impact the payments industry (regarding scenarios, strategy, services, and products, among others) and received 38 responses (84.4% response rate). All answers from the panelists were consolidated and transferred into one document. To this end, the input was reviewed and coded by three independent researchers, while a moderator coordinated the process and facilitated coding between the researchers. Finally, the researchers translated each item of the coding process into a more readable and understandable statement for the subsequent rounds. Through the coding, an initial set of 45 statements was produced, which describes the impact of blockchain in the payments field.

In order to allow for a structured overview and analysis of the statements gathered, the 45 statements were grouped into thematic blocks by the researchers, resulting in a total of seven thematic groups. The development of the thematic groups was inspired by frameworks for analysis of markets and technologies such as Porter's five forces framework (Porter 1980) and the technology-organization-environment framework (Depietro et al. 1990). As blockchain is perceived as a revolutionary technology with the potential to disrupt companies, business models, and entire markets, the thematic groups were chosen with the aim of reflecting the respective areas of impact: (1) innovations in payments and effects of blockchain, (2) market players and competitive landscape, (3) implications for companies and business models, (4) new services based on blockchain, (5) IT challenges and technical concerns, (6) constraints and risks in the development of blockchain, and (7) regulation around blockchain (Fig. 7.1).

In the following we briefly introduce the thematic groups:

- The first thematic group is defined as *innovations in payments and effects of blockchain* (in short: Group Innovation). It consists of six statements summarizing and addressing technological progress within payments due to blockchain and introduces points of reflection on new possibilities that may arise with the new technology.
- *Market players and competitive landscape* (Group Competitors) form the second group consisting of five statements. It compiles assertions which address the disruptive potential of blockchain on the players in the payments industry as well as new entrants. Furthermore, it addresses the composition of players in the industry and their respective behavior toward the development of blockchain.

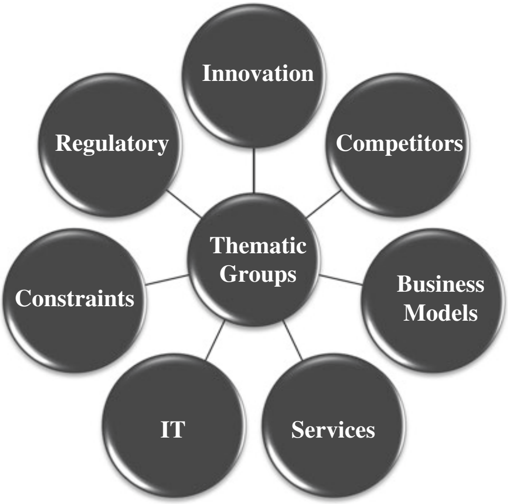

Fig. 7.1 45 Statements grouped in seven thematic groups

- *Implications for firms and business models* (Group Business Models) is the title under which the eight statements of the third group are summarized. It places emphasis on the effects of introducing blockchain to traditional business models. Both the development of new business models (including revenues, incomes, and costs) and the possible replacement or even obsolescence of existing business models are found in this group.
- The new features which blockchain could bring to the payments industry are summarized under *new services based on blockchain* (Group Services), with a total of six statements. These include newly developed processes as well as the replacement of existing processes like the restructuring of trust services, clearing and settlement, reconciliation, as well as both internal and external auditing procedures.
- *IT challenges and technical concerns* (Group IT) contains 9 of the 45 statements and represents the fifth group. It captures the internal implications for companies in the event of blockchain adoption and their internal restructuring. It addresses the importance of change management and the impact on existing backend infrastructure as well as the IT requirements.
- *Constraints and risks in the development of blockchain* (Group Constraints) is the sixth thematic group consisting of eight statements. The main focus lies on technical issues that have to be overcome for a successful dissemination of blockchain, such as cyber-risks, legal and compliance risks, scalability, high robustness, and availability.
- *Regulation around blockchain* (Group Regulatory) is the seventh group and summarizes three statements. It focuses on the necessity for a regulatory framework around blockchain for an industry-wide dissemination, including updates and the development of new regulatory standards.

For the following two rounds (R2 and R3), we were interested in two aspects: first, in the evaluation of the statements and, second, in the ranking of the statements within the seven thematic groups. To make the evaluation and the ranking as easy and convenient as possible, we used an online tool (Qualtrics) to present the statements. This tool allows for the simple selection of an evaluation for each statement by clicking it and, subsequently, ranking the statements via drag-and-drop. The panelists were asked to provide the evaluation of each statement on a six-point Likert scale ranging from “strongly agree” to “strongly disagree”. A range of six points was chosen to promote clear decisions toward agreement or disagreement while at the same time offering enough options for a differentiated evaluation. The number of ranks depended on the number of statements in each group (e.g., seven statements allow for ranks one to seven).

R2 of our study only considered those 38 panelists who completed R1. These experts were presented with all 45 statements generated in R1 and asked for their evaluation and ranking. At the end of R2, the evaluation and rank of each statement were received from 36 out of the 38 panelists.

In R3, the resulting group of 36 experts was presented with the same statements as in R2. The panelists were asked again to provide their evaluation and ranking of the statements. However, now the group evaluations (shown via bar diagrams) and the individual evaluations from R2 were presented for each statement. Moreover, each panelist was presented with the group ranking (shown via the average ranking) and the panelist’s individual ranking from R2 for each statement. By presenting the (group and individual) evaluations and rankings, panelists were able to reconsider their evaluations and rankings. In total, 34 responses were collected as a result of R3. Table 7.1 shows the response rates of each round.

The analysis of our data, as presented in the next two sections, was done according to two dimensions. First, we analyzed the level of consensus of the evaluations for each statement and checked how many consensus criteria the evaluations fulfilled. As a result, we were able to develop four consensus clusters. Second, we analyzed the ranking of each statement, respectively, the rank of R2 and the rank of R3. We checked whether the ranks fell within the top, middle, or bottom sections of the thematic groups.

Analysis of Consensus

The analysis of the evaluations was conducted with a particular focus on the changes between R2 and R3. Any change would signal an increase or decrease in the level of consensus. To examine the consensus, a number of statistical criteria are available for selection. However, when it comes to analyzing Delphi data for consensus, no general constructs or guidelines are available stating which criteria yield the most accurate result for consensus (von der Gracht 2012). As suggested by the literature, those criteria should be chosen which are most suitable for the objectives of the specific study.

In the first step, the original Likert scale ranging from "strongly disagree" to "strongly agree" for each evaluation was transformed into numerical values (ranging from 1 to 6). Subsequently, the statistical values of the variance and standard deviation of the evaluations were calculated and compared with regard to R2 and R3, as a first indicator to determine whether consensus had been achieved. Comparing the values of both rounds, the average variance decreased from 1.23 in R2 to 0.96 in R3. The decline can be seen as an indicator of increased consensus. The average coefficient of variation, which is calculated by dividing the standard deviation by the mean, is considered as a further parameter to confirm consensus. The lower the variation, the larger the convergence toward the mean, thus indicating stronger consensus. In order to interpret the value of variation appropriately, suggestions from the literature were used stating that a variation of 50% or lower is defined as acceptable to confirm consensus (von der Gracht 2012). Observing the development of variation across all statements, a decrease from 47% in R2 to 43% in R3 is visible, indicating the achievement of consensus.

Next, we evaluated the consensus based on three criteria. As a first criterion of consensus, a predefined level of agreement of 75% for each statement with respect to the six-point Likert scale was chosen. This value seemed reasonable in the light of similar research using benchmark percentages between 60% (Tobergte and Curtis 2013) and 80% (Putnam et al. 1995) on a five-point Likert scale. The second criterion meant that statements with a variance higher than 1 were excluded, as suggested by the literature (von der Gracht 2012). In order to fulfill the third criterion, statements had to have a variation lower than 0.5 (50%), following the suggestion by English and Kernan (1976). These three criteria were applied to the evaluations of each statement after the results of R3 were collected. Depending on how many criteria the evaluations fulfilled, the corresponding statements were clustered into four clusters. Evaluations of 17 statements fulfill all three consensus criteria (high-consensus cluster), evaluations of 7 statements fulfill two criteria (medium-consensus cluster), 19 statements and their corresponding evaluations fulfill one criterion (low-consensus cluster), and 2 statements did not achieve consensus (Table 7.2). The resulting consensus clusters (high, medium, and low) will be analyzed in the following section.

The four clusters provide a structure of the numerous topics currently discussed around blockchain (Fig. 7.2). In the following, we focus on those 17 statements captured in the high-consensus cluster.

All direct citations in this section are taken from the answers panelists provided in R1 and are formatted in italic. The number in square brackets indicates the number of the statement in Table 7.2. The statements are not ordered by number but follow the flow of thoughts according to the statements' content.

[9] Panelists stress that the development of blockchain allows new service offerings to be brought to the market. They relate to a number of innovations and the relevance of "*making money out of data intelligence*". The future for market players will be around payment services enhancing the traditional transaction services. Data can be used to offer "*data analytics*" to deliver deeper insight into payments, which contributes to enhanced "*fraud detection and prevention*". Other important services which will be needed are conversion between traditional payments and blockchain-based payments as well as personal financial management.

Three statements delivered by the experts reflect service areas which might play a major role in the future. These services may create new business opportunities and are forerunners of the change to come in payments. [1] Blockchain is expected to make direct transactions possible without any third party acting as "*trust agent*". Hence, a "*transaction can be executed peer-to-peer*" directly between two contractual parties (peers). P2P transactions can occur between parties such as firms or customers. Furthermore, "*transactions without a middleman*" are paving the way for decentralized payment transactions.

[2] Blockchain is thought to improve international transactions in cross-currency and cross-border contexts. The huge potential of these improvements becomes obvious when looking at global trade and the high inefficiency of the current global payment infrastructure. Blockchain

Table 7.2 Statements grouped based on the consensus clusters

No.	Statements	Consensus cluster	Thematic group
1	Blockchain will allow P2P transactions and make direct transactions possible	High	Innovation
2	International transactions in cross-currency and cross-border context will be improved by blockchain	High	Innovation
3	Blockchain will allow a connection of contracts and transactions	High	Innovation
4	Fintechs will positively influence the development of blockchain	High	Competitors
5	With the blockchain new business models in payments will develop	High	Business models
6	Blockchain will make some business models in payments obsolete	High	Business models
7	Due to the blockchain, the income structure in payment transactions will change	High	Business models
8	More practical use cases for blockchain are needed, and less theoretical concepts should be put forward	High	Business models
9	With blockchain, new services in payments will develop	High	Services
10	Blockchain will make some services obsolete	High	Services
11	Blockchain will increase the efficiency in transaction processes	High	Services
12	Blockchain technology allows cost reduction in different types of cost	High	Services
13	Firms are required to adapt new technology more strongly and integrate new blockchain in existing systems	High	IT
14	Standards, unification, and interoperability are needed to boost blockchain	High	IT
15	Blockchain has to provide high availability in terms of no downtime, high robustness, and 24/7 service in order to be used in payments	High	Constraints
16	Low latency is needed to allow short response times and fast acceptance of transactions by blockchain	High	Constraints
17	Closer exchange between all market players is needed to develop further regulatory standards	High	Regulatory

(*continued*)

Table 7.2 (continued)

No.	Statements	Consensus cluster	Thematic group
18	Blockchain will introduce instant and real-time transactions in the payments industry	Medium	Innovation
19	Blockchain will lead to an elimination of intermediaries in the market	Medium	Competitors
20	With the rise of blockchain, fintechs will gain a large market share	Medium	Competitors
21	Banks will remain important with blockchain and positively influence the development	Medium	Competitors
22	Central service providers will provide blockchain service platforms using decentral ledger technology	Medium	IT
23	High scalability has to be ensured by blockchain in payments	Medium	Constraints
24	A general update of regulation due to blockchain is needed	Medium	Regulatory
25	Blockchain will have less influence on customer side	Low	Innovation
26	As the blockchain develops further, banks will lose importance	Low	Competitors
27	Generally, blockchain leads to low margins in payment transactions	Low	Business models
28	The development of blockchain reveals several challenges around human resources	Low	Business models
29	In order to boost blockchain, collaboration and project work are needed	Low	Business models
30	With blockchain the relevance of external and internal audit will decrease	Low	Services
31	A higher speed will be reached in transactions with blockchain	Low	Services
32	Blockchain tremendously changes the existing backend infrastructure, leading to a reduction of traditional infrastructure and an elimination of legacy systems	Low	IT
33	Change management is important and strongly needed to further blockchain	Low	IT
34	With blockchain transactions will be irreversible	Low	IT

(*continued*)

Table 7.2 (continued)

No.	Statements	Consensus cluster	Thematic group
35	More data will be included in transaction records when using blockchain	Low	IT
36	Blockchain raises concerns concerning identification and authentication of transaction partners in addition to higher transparency requirements	Low	IT
37	There are increased requirements for privacy to allow for anonymous transactions with blockchain	Low	IT
38	Legal, compliance, and regulation risks have to be resolved to advance blockchain	Low	Constraints
39	High risks to blockchain are cyber-risks	Low	Constraints
40	With the development of blockchain, no new risks will arise, but existing risks of the payment industry will remain	Low	Constraints
41	Blockchain faces mainly security issues around the system security of the technology	Low	Constraints
42	Main security issues for the blockchain emerge from the end-user side	Low	Constraints
43	Overregulation of blockchain can hinder innovation and needed advancements	Low	Regulatory
44	Micro and nano payments become possible with the blockchain	None	Innovation
45	Good marketing and lobby work for blockchain are important for the further development	None	Business models

will make these payments “*faster and cheaper*”, that is, faster by providing a solid, common infrastructure across borders for transactions and cheaper by removing expensive intermediaries, thus overcoming today’s “*lack of trust*”.

[3] A completely new service that blockchain will allow is the connection between contracts and transactions. Hence, the technology can be used to keep records of “*contracts of purchase and passing of property*” in addition to the actual transaction. Thereby, a contract of purchase can be directly linked to a payment transaction, which is referred to as a smart contract. As a result, blockchain can be used as a “*proof of ownership*” as

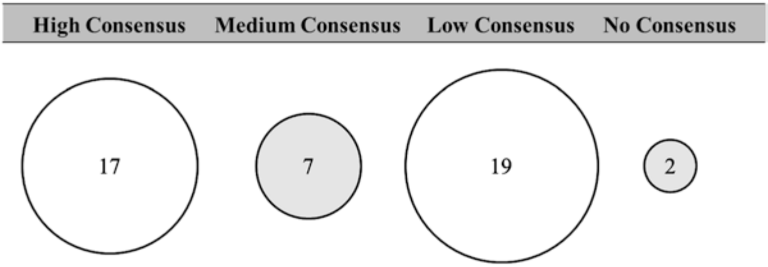

Fig. 7.2 Quantitative representation of consensus clusters

well as a proof of payment. The development of smart contracts will allow the "*automated execution of transactions*". Hence, smart contracts prove to be a critical cornerstone in the current advancements around the Internet of Things.

[10] With the further development of blockchain, current payment services like third-party trust services, clearing and settlement, as well as reconciliation, are expected to become obsolete. As a starting point, most panelists mention that today's processes are "*inefficient and slow*". They particularly refer to the current payment infrastructure (SWIFT and SEPA transactions), which requires a lot of manual steps and, hence, "*transfers at a relatively high cost*". Due to the unified record keeping in the blocks, clearing and settlement services will no longer be needed for payments if based on blockchain, which leads to the implementation of "*fully automated reconciliation*". As a result, the omission of entire process steps is expected to eliminate core services.

[7] The changes in services cause massive implications for the income structure in the payment business, which means that traditional sources of revenue die out, though at the same time new ones emerge. There is consensus that "*payments will be a commodity*", resulting in very low margins. Furthermore, the currently mainly margin-based revenue structure will erode, with transaction fees dropping to "*even less than cents*". Current margins benefit from high complexity and artificially created boundaries between payment networks, which will vanish with blockchain. In the future, income sources have to be shifted away from transaction-based margins toward the provision of "*user-friendly and secure platforms*" and/or the management of smart contracts.

[12] In addition, blockchain allows cost reductions. For example, the replacement of the currently inefficient payment infrastructure will free up capital. Also the costs for processing transactions will drop, making the transfer of money cheaper. "*The opening of formerly closed systems*" provides great potential to reduce costs. Overall, the increase of efficiency will "*address the rising costs*" of regulation and allow more efficient compliance due to increased transparency; for example, "*know-your-customer processes will be streamlined*", which results in decreased costs. In addition, a faster execution of transactions leads to a reduced risk of default and hence lower costs.

[5] We see a strong consensus that with the development of blockchain new business models in payments will emerge. For example, panelists stress the importance of data by emphasizing "*data analytics and further data-related services*". This is in accordance with the observation in our research that payments-related business models will only survive if new services are added like "*payments-extending services and products*", thus enhancing existing business models. Only the creation of "*value-added service*", complementing current business models, will allow financial institutions to keep their customer base stable. For example, panelists point out that future business models will no longer build on account service fees but "*hosting and data security fees*" and will be able to "*monetize interfaces*", not just services.

[6] Contrary to the great potential blockchain offers for payments, we also see an equally strong consensus that some business models will become obsolete. Examples are the traditional margin-based, intermediary, or trusted party business models. The role of a trustworthy broker ("man in the middle") "*will be redundant with blockchains*". Intermediaries face the problem of complete eradication as they are going to be "*extinct because their business model is being replaced with a more efficient mechanism*". Margins cannot provide a source of revenue, as the mere execution of transactions will lose importance with blockchain. Furthermore, it is questionable whether financial institutions can maintain their current function as a trusted party, since blockchain will enable features like direct transactions and equal access to the market for all participants. It is noteworthy that participants compare the "*future role of payment service providers to the letter mail in the age of the internet*".

[4] Next, fintechs will positively influence further blockchain development. Panelists see fintechs as an "*enabler for market infrastructure*" and as "*specialized providers from outside with a catalytic role*". The increasing number of fintechs like Ethereum and Ripple supports this view. Moreover, there are certain structural and technological boundaries in existing financial institutions that make it hard to change the underlying technology the business is running on (e.g., back-office software, interorganizational payment networks, supra-authority infrastructure). In contrast, fintechs have the advantage of being able to opt for a new technology with fewer dependencies and, hence, adopt blockchain considerably more quickly. They will play out their advantage to occupy parts of the value chain and offer services industry-wide, which will force existing players to "*acquire white label blockchain solutions*" from fintechs to stay in the market.

[8] It remains a challenge that more practical use cases for blockchain are needed and less theoretical concepts should be put forward. As mentioned by one of the Delphi participants, "*to be accepted on a wider range, blockchain technology should prove that it can do better than the existing infrastructure in terms of speed, efficiency, and costs*". This perspective is driven by the currently strong focus on applications in theory rather than on actual use cases. One aspect panelists criticize is that "*use cases to date have not tested the scale and configuration of the blockchain*" actually needed in financial services. Hence, further development is hindered, as the extent to which the new technology can fulfill the high requirements of the payments industry is unclear (Tsai et al. 2016). The panelists believe that use cases could trigger a "*positive helix of application*", where even regulators would join the movement since they favor features of blockchain such as transparency and increased control.

[13] Next, firms are required to adapt new technology more strongly and integrate blockchain into existing systems, namely, the legacy systems of financial institutions. The main reason is identified as pertaining to the outdated infrastructure, which makes "*interfacing legacy systems with blockchain an ongoing challenge*". At this stage, there is an open question as to how the "*implementation of blockchain connections to existing IT*" should happen. In effect, applications of blockchain technology have mostly been tested outside the current infrastructure. The panelists agree

that there should be a shift to where "*companies are required to adopt new technology more strongly and integrate new blockchain technology in existing systems*". However, the "*challenge of incorporating blockchain into the existing infrastructure*" remains.

[14] Standards, unification, and interoperability (across companies, industries, and borders) are needed to boost blockchain. Currently, applications rely on various unstandardized implementations of blockchain. Thus, "*the lack of common industry standards is seen as a great bottleneck for mainstream acceptance of blockchain technology*". Hence, the development of "*consequent, and ideally global, standards is required*". Standards are important to enable "*interoperability of different infrastructures*" and better assessment of how to apply certain technological features. The panelists state that they do not expect blockchain technology to be suitable for large applications on entire transaction systems without standards.

[15] We find consensus on the technical requirements for blockchain in terms of high availability with no downtime, a high level of robustness, and 24/7 service in order to be used for payment transactions. Panelists consistently stress that "*payments must be processed around the clock and on every day of the year*". Absolutely no amount of downtime is acceptable, and even "*maintenance should not be connected with downtime*". Additionally, the international efforts toward instant payments require that blockchain technology ensures solidity in a "*real-time environment and, connected with that, constant accessibility to the clearing systems*".

[16] Panelists in our Delphi study highlight that also low latency is needed to allow short response times and fast acceptance of transactions. The status of blockchain currently seems to entail a trade-off between the "*development of a ledger protocol that will enable high-volume/low-latency real-time transaction processing […] [and] processing capacity saturation challenges*". Moreover, the panelists expect the capacity requirement to significantly increase the closer the technology gets to market maturity. In the near future, the scaling issue of the technology has to be tackled. As with most new technologies, however, scalability is a particular problem at this early stage.

[17] Consensus is reached that a closer exchange between market players is needed to further develop regulatory standards for blockchain. Regulation is one of the main determinants when it comes to new

technology in financial services, especially in payments. Consequently, "*significant legal and regulatory work will be required and common standards need to be agreed upon (including regulators and non-financial competitive players), before blockchain technology can be broadly adopted*". On the regulatory side, parties such as "*banks, regulatory agencies, and central banks have to be integrated*" into the discussions to start "*regulatory discourse to allow the wide application of blockchain*". In essence, "*collaboration between all parties involved, including regulators and tech firms*", is necessary, especially since the rationale behind the challenge is that "*the regulatory framework is in principle agnostic to the underlying technology*" of blockchain, while the ultimate hope is "*that regulation should not stifle innovation*".

[11] Lastly, the panelists stress the increased efficiency in transaction processes with blockchain. This is due to "*leaner internal processes*" (e.g., "*process automation*") and a streamlined industry structure ("*openness of the system*" and "*peer-to-peer transactions*"). The efficiency aspect is mirrored in the new services and innovations that blockchain may bring to payments.

All of these 17 statements reached high consensus in our study.

The second consensus cluster (medium consensus) contains statements with evaluations which fulfill two out of three consensus criteria. Thus, compared to the first cluster, this cluster reflects a lower degree of consensus among the panelists. Especially in regard to the future role of banks, intermediaries, and new market entrants, the agreement seems to disperse. We get statements underlining that the role of established players will differ widely in the future as blockchain will lead to an elimination of intermediaries in the market [19]. Hence, certain businesses will fade and new ones emerge. Also, we see the potential that with the rise of blockchain, fintechs will gain a large market share [20]. Still, the large market share of fintechs reaches less consensus among the experts than the statement that fintechs will influence the development of blockchain. Regardless of the potentially disruptive impact of blockchain, experts tend to assume that the role of established players will still not be entirely obsolete. This is supported by the statement that banks will remain important with blockchain and positively influence its development [21]. It is worth noting that the majority of statements in the medium-consensus cluster are from the thematic group *Competitors*, showing that the impact of blockchain on market players and competitors is still less clear as compared to, for example, the impact on services or innovations. This can also be attributed to the early stage of the development and, hence, the lack of mature new market players. Although work around regulatory standards receives high consensus, the general update of regulations receives less consensus [24].

The low consensus cluster contains 19 statements with evaluations fulfilling only one of the three consensus criteria. Low consensus indicates that uncertainty around these statements still exists. The fact that the panelists find it difficult to agree on the statements in this group can be seen as an indicator of the importance of use cases. As many statements stem from the thematic groups *IT* [32–37] and *Constraints* [38–42], statements could be clarified in use cases or first applications where the application of blockchain would be tested under real-life conditions. While experts are clear on additional solutions blockchain can offer (such as smart contracts), they are less clear when it comes to statements such as the required level of transparency. Transactions based on blockchain need to be transparent enough to enable identification and verification of the parties involved while at the same time enabling anonymous transactions, in order not to jeopardize the core advantages of the technology.

The last cluster consists of two statements with no consensus. Marketing for blockchain [44] and micro payments based on blockchain [45] currently represent the highest uncertainty. Evaluations among experts on these statements diverge substantially.

From our analysis we can conclude that with lower levels of consensus, uncertainty increases and a rise of dissent is observable. Hence, we interpret statements with low consensus as areas where a lot of work is still needed in order to clear the fog.

Analysis of Ranking

The second dimension of our analysis covers the ranking. As panelists were asked to rank all statements within the thematic groups, we were able to derive two ranks for each statement, one for Round 2 (R2) and one for Round 3 (R3) of our Delphi study (Table 7.3). The ranks for each round are calculated based on the average ranks across all panelists and

Table 7.3 Statements grouped based on their ranking (within each thematic group)

Statements	Rank R2	Rank R3	Ranking group
Group Innovation			
Blockchain will allow P2P transactions and make direct transactions possible	1	1	Top
Blockchain will allow a connection of contracts and transactions	2	2	Top
International transactions in cross-currency and cross-border context will be improved by blockchain	4	3	Middle
Blockchain will introduce instant and real-time transactions in the payments industry	3	4	Middle
Micro and nano payments become possible with the blockchain	5	5	Bottom
Blockchain will have less influence on customer side	6	6	Bottom
Group Competitors			
Banks will remain important with blockchain and positively influence the development	3	1	Top
Blockchain will lead to an elimination of intermediaries in the market	1	2	Top
As the blockchain develops further, banks will lose importance	5	3	Middle
Fintechs will positively influence the development of blockchain	2	4	Bottom
With the rise of blockchain, fintechs will gain a large market share	4	5	Bottom
Group Business Models			
With the blockchain, new business models in payments will develop	1	1	Top
More practical use cases for blockchain are needed, and less theoretical concepts should be put forward	3	2	Top
Blockchain will make some business models in payments obsolete	2	3	Top
In order to boost blockchain, collaboration and project work are needed	4	4	Middle
Due to the blockchain, the income structure in payment transactions will change	5	5	Middle
Good marketing and lobby work for blockchain are important for the further development	6	6	Bottom
Generally, blockchain leads to low margins in payment transactions	7	7	Bottom
The development of blockchain reveals several challenges around human resources	8	8	Bottom

(*continued*)

Table 7.3 (continued)

Statements	Rank R2	Rank R3	Ranking group
Group Services			
With blockchain new services in payments will develop	1	1	Top
Blockchain will increase the efficiency in transaction processes	2	2	Top
Blockchain will make some services obsolete	3	3	Middle
Blockchain technology allows cost reduction in different types of cost	4	4	Middle
A higher speed will be reached in transactions with blockchain	5	5	Bottom
With blockchain the relevance of external and internal audit will decrease	6	6	Bottom
Group IT			
Blockchain tremendously changes the existing backend infrastructure leading to a reduction of traditional infrastructure and an elimination of legacy systems	1	1	Top
Firms are required to adapt new technology more strongly and integrate new blockchain in existing systems	2	2	Top
Standards, unification, and interoperability are needed to boost blockchain	4	3	Top
Change management is important and strongly needed to further blockchain	3	4	Middle
Central service providers will provide blockchain service platforms using decentral ledger technology	5	5	Middle
More data will be included in transaction records when using blockchain	6	6	Middle
There are increased requirements for privacy to allow for anonymous transactions with blockchain	8	7	Bottom
With blockchain transactions will be irreversible	7	8	Bottom
Blockchain raises concerns concerning identification and authentication of transaction partners in addition to higher transparency requirements	9	9	Bottom
Group Constraints			
High scalability has to be ensured by blockchain in payments	1	1	Top
Blockchain has to provide high availability in terms of no downtime, high robustness, and 24/7 service in order to be used in payments	2	2	Top

(*continued*)

Table 7.3 (continued)

Statements	Rank R2	Rank R3	Ranking group
Low latency is needed to allow short response times and fast acceptance of transactions by blockchain	3	3	Top
Legal, compliance, and regulation risks have to be resolved to advance blockchain	4	4	Middle
High risks to blockchain are cyber-risks	5	5	Middle
Main security issues for the blockchain emerge from the end-user side	6	6	Bottom
With the development of blockchain, no new risks will arise but existing risks of the payment industry will remain	7	7	Bottom
Blockchain faces mainly security issues around the system security of the technology	8	8	Bottom
Group Regulatory			
Overregulation of blockchain can hinder innovation and needed advancements	3	1	Top
Closer exchange between all market players is needed to develop further regulatory standards	1	2	Middle
A general update of regulation due to blockchain is needed	2	3	Bottom

are within the respective thematic groups, as we did not consider feasible a ranking of all 45 statements at once.

The idea behind the rankings was to investigate the individuals' sentiments on each statement in addition to the level of consensus. Hence, the panelists were asked to rank each statement with respect to importance and relevance. As the statements were then ranked within the thematic groups, the maximum rank depends on the number of statements within the groups (i.e., between three and nine). As a result, we obtained the importance of each statement expressed through its average rank. The first rank signifies the highest degree of importance, whereas the lowest rank shows the least importance. As the ranking was part of both R2 and R3 of our Delphi study, we were able to compare the ranks between both rounds—similar to the analysis of consensus. Changes in ranking positions were easily visible after finishing R3 (Table 7.3).

Our analysis focused on the ranks in R3, as the panelists had the opportunity to update their ranking based on the average ranking of all participants in R2. Due to the different numbers of statements in the thematic groups, a general measure to categorize the ranks could not be applied. Therefore a simpler approach was chosen which categorizes the statements within each thematic group as “top”, “middle”, and “bottom” depending on the ranks in R3.

The ranking groups shed light on which statements were considered to be most important. This allows understanding of which priority should be given to the respective statement in the discussion. Consequently, statements from the top-ranking group should be given more attention and thus higher priority when it comes to the discussion of blockchain in the payments industry.

Discussion and Development of an Agenda

From our analysis we derive the following implications. First, statements with high consensus represent high unison, and there is less need for discussion as the discrepancy among experts appears to be rather low. Second, statements with high ranks are considered to be more important than others and should be discussed with higher priority.

In the next step, consensus and ranking will be combined. As Fig. 7.3 shows, we obtain a two-dimensional figure with the four levels of consensus (horizontal axis) and the three ranking groups (vertical axis). This results in 12 possible combinations of consensus and ranking, of which

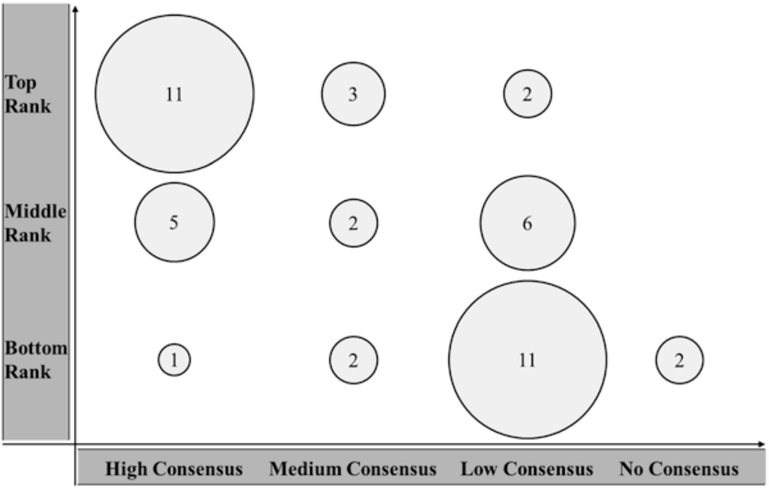

Fig. 7.3 Representation of consensus clusters and ranking groups

10 are filled. The combinations are illustrated by bubbles, which vary in size depending on the number of statements within each combination.

Figure 7.3 extends our understanding of the 45 statements, as we can now develop an agenda for the further discussion on blockchain in payments based on unison (derived from the level of consensus) and priority (derived from the ranking group). Rather than just presenting a list with the statements, we suggest structuring the discussion in practice and academia based on unison between experts and priority.

Statements with high consensus represent somewhat of a common understanding among experts. It is advisable to be informed about these statements, but the high consensus yields a low need for further discussion. Statements with low or no consensus are far from maturity and may indicate lower levels of knowledge or higher levels of disagreement among experts, as the evaluations regarding the impact of blockchain are diverse. Moreover, statements with low consensus are currently still discussed widely and naturally have to take a larger part in the discussion to reach higher consensus.

We interpret a high consensus within the discussion on blockchain as helpful, since it helps to understand what is common understanding and where experts are in unison. Furthermore, a high consensus may ensure that experts are talking about the same thing rather than missing each other's points. In contrast, statements with low consensus require more room in the discussion, as evaluations and opinions are diverse. Eventually, statements with currently low consensus could reach higher consensus through the discussion over time.

Next, we interpret statements with top ranking as having above-average importance. Thus, they should be given higher priority in the discussion on blockchain in payments. Consequently, statements with high ranks should be discussed first. While statements with low ranks are relevant and should not be neglected, they should be deprioritized, as other statements have been ranked as more important.

The two analyses (in terms of consensus and ranking) should not be mixed. Still, regardless of the level of consensus, not all statements can be discussed with the same priority. Hence it is advisable to deliberately combine both aspects to develop an agenda for discussion. By analyzing the ten combinations of consensus and ranking, we gain three streams for discussion (Fig. 7.4).

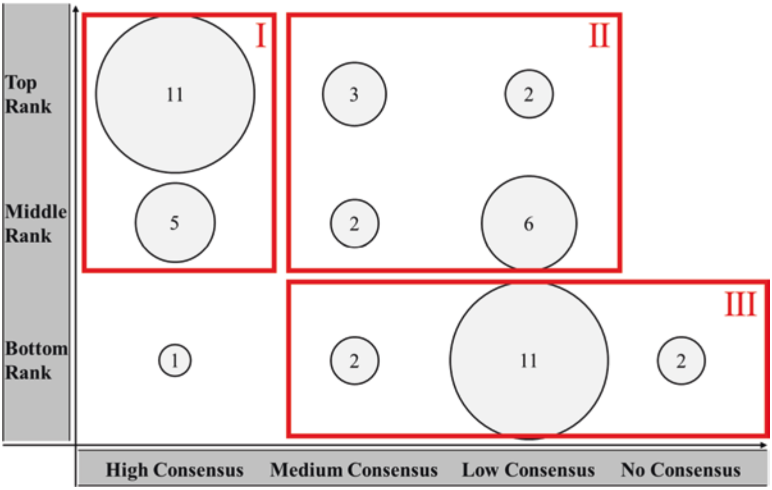

Fig. 7.4 Representation of consensus clusters and ranking groups with three streams for discussion

First, stream I includes statements which have already received a high level of consensus among experts and are ranked high (top and middle). These statements are of high importance for the discussion but do not have to be discussed further, as experts are in unison and have clear ideas about the impact of blockchain. They carry importance for the discussion because they best show the impact of blockchain in the payments industry and can yield starting points for further discussion to deepen the understanding of that impact. These statements present to some degree the pillars on which further discussion rests. This stream of discussion is particularly important for practitioners with low expertise on the topic. Statements in this stream have to be understood and acknowledged.

Second, statements in stream II are considered to have a middle-to-top rank and a medium-to-low consensus and should be included in the discussion, as there exist high priority but also diverse opinions on the statements. This stream of discussion is ideal for practitioners with high expertise, as it allows them to advance their knowledge on the dissemination of blockchain in the payments industry. The goal of this stream should be to reach higher consensus on the statements included as fast as possible due to the high priority of these statements.

Table 7.4 Statements with consensus cluster, ranking group, and discussion stream

Statements	Consensus Cluster	Ranking Group	Stream
Blockchain will allow P2P transactions and make direct transactions possible	High	Top	I
Blockchain will allow a connection of contracts and transactions	High	Top	I
With the blockchain new business models in payments will develop	High	Top	I
Blockchain will make some business models in payments obsolete	High	Top	I
More practical use cases for blockchain are needed, and less theoretical concepts should be put forward	High	Top	I
With blockchain new services in payments will develop	High	Top	I
Blockchain will increase the efficiency in transaction processes	High	Top	I
Firms are required to adapt new technology more strongly and integrate new blockchain in existing systems	High	Top	I
Standards, unification, and interoperability are needed to boost blockchain	High	Top	I
Blockchain has to provide high availability in terms of no downtime, high robustness, and 24/7 service in order to be used in payments	High	Top	I
Low latency is needed to allow short response times and fast acceptance of transactions by blockchain	High	Top	I
International transactions in cross-currency and cross-border context will be improved by blockchain	High	Middle	I
Due to the blockchain, the income structure in payment transactions will change	High	Middle	I
Blockchain will make some services obsolete	High	Middle	I
Blockchain technology allows cost reduction in different types of cost	High	Middle	I
Closer exchange between all market players is needed to develop further regulatory standards	High	Middle	I
Blockchain will lead to an elimination of intermediaries in the market	Medium	Top	II
Banks will remain important with blockchain and positively influence the development	Medium	Top	II

(*continued*)

Table 7.4 (continued)

Statements	Consensus Cluster	Ranking Group	Stream
High scalability has to be ensured by blockchain in payments	Medium	Top	II
Blockchain tremendously changes the existing backend infrastructure leading to a reduction of traditional infrastructure and an elimination of legacy systems	Low	Top	II
Overregulation of blockchain can hinder innovation and needed advancements	Low	Top	II
Blockchain will introduce instant and real-time transactions in the payments industry	Medium	Middle	II
Central service providers will provide blockchain service platforms using decentral ledger technology	Medium	Middle	II
As the blockchain develops further, banks will lose importance	Low	Middle	II
In order to boost blockchain, collaboration and project work are needed	Low	Middle	II
Change management is important and strongly needed to further blockchain	Low	Middle	II
More data will be included in transaction records when using blockchain	Low	Middle	II
Legal, compliance, and regulation risks have to be resolved to advance blockchain	Low	Middle	II
High risks to blockchain are cyber-risks	Low	Middle	II
Fintechs will positively influence the development of blockchain	High	Bottom	III
With the rise of blockchain, fintechs will gain a large market share	Medium	Bottom	III
A general update of regulation due to blockchain is needed	Medium	Bottom	III
Blockchain will have less influence on customer side	Low	Bottom	III
Generally, blockchain leads to low margins in payment transactions	Low	Bottom	III
The development of blockchain reveals several challenges around human resources	Low	Bottom	III
With blockchain the relevance of external and internal audit will decrease	Low	Bottom	III
A higher speed will be reached in transactions with blockchain	Low	Bottom	III
With blockchain transaction will be irreversible	Low	Bottom	III

(*continued*)

Table 7.4 (continued)

Statements	Consensus Cluster	Ranking Group	Stream
Blockchain raises concerns concerning identification and authentication of transaction partners in addition to higher transparency requirements	Low	Bottom	III
There are increased requirements for privacy to allow for anonymous transactions with blockchain	Low	Bottom	III
With the development of blockchain, no new risks will arise but existing risks of the payment industry will remain	Low	Bottom	III
Blockchain faces mainly security issues around the system security of the technology	Low	Bottom	III
Main security issues for the blockchain emerge from the end-user side	Low	Bottom	III
Micro and nano payments become possible with the blockchain	None	Bottom	III
Good marketing and lobby work for blockchain are important for the further development	None	Bottom	III

Third, stream III includes statements with a bottom rank and medium-to-no consensus, which are of less priority for the discussion on blockchain in payments. However, there is still a lot of discussion needed regarding these statements, as the experts' evaluations are diverse. Again, the goal is to reach higher consensus for these statements, but other statements are more important and, hence, should be given higher priority. The statements in the third stream present a niche for practitioners with medium expertise on the matter, since new insights for these statements are needed but are not as urgent or important as for other statements.

The three streams for the discussion are designed to host an effective and efficient discussion with relevant outcomes which allow the debate on the dissemination of blockchain in the payments field to be advanced. Table 7.4 provides an overview of the 45 statements and the corresponding streams.

The diverse issues among the 45 statements and the three streams also nicely depict the variety within the discussion. Nonetheless, it is difficult to assign priorities to the three streams. There is value in including statements with the highest consensus in the discussion: they can build the foundation since experts are likely to be in unison. Equally, top-ranked statements with medium consensus are of value for a particular discussion, as they represent areas of dissent and a need for further exchange. Moreover, the ranks and the resulting priorities have been identified within the thematic groups, which limits their explanatory power to structure the overall agenda for the discussion. Naturally not all statements can be discussed first, and priorities can be used as an indicator for the structure of the discussion.

Changes resulting from the application of blockchain will be noticeable not only in the form of new business models but also in the form of new services and revenues. However, pain points remain, and more discussion is needed, as the partly low levels of consensus demonstrate. Despite all the opportunities blockchain may offer to the financial services sector, and in particular the payments industry, the technology is still at an early stage of its development. Thus, more research and use cases are needed. Both will advance the dissemination of blockchain in the payments field.

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8

Blockchain and Initial Coin Offerings: Blockchain's Implications for Crowdfunding

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Crowdfunding and Blockchain

The concept of crowdfunding, a novel method for raising venture capital (Mollick 2014), has increasingly gained recognition from entrepreneurs and established companies, leading to an estimated $738 million in allocated funds in 2016. Crowdfunding can generally be described as a public invitation to invest in a project or startup, usually issued via the Internet, where campaigns may be supported by a large group of interested individuals (Danmayr 2014).

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There are multiple examples of successful crowdfunding campaigns. Likely the most popular was that by the US technology startup Oculus VR. In April 2012, the company announced a virtual reality headset and subsequently started a campaign on Kickstarter, the most prominent crowdfunding platform. The campaign not only proved successful but also raised $2.4 million in funding—ten times more than its initial goal of $250,000 (Kickstarter 2012). Approximately six weeks after the campaign, Oculus started shipping the advertised product (Luckey 2013). The project was not only known to developers but also generated strong media attention (Griffiths 2013). Naturally, even established technology firms became interested in Oculus's virtual reality technology. Two years after this Kickstarter campaign, Facebook acquired Oculus for $2.3 billion.

Although there are many successful examples of crowdfunding campaigns, the concept still has significant downsides, especially for a funder. Use of a crowdfunding platform is seldom free. To use its service, one usually must pay a commission based on the total funds raised, as well as a payment processing fee (Taylor 2013). Also, trust is a key challenge when seeking venture capital via crowdfunding. As a company without any prior business, it may be hard to gain sufficient investor credibility. To ensure that investors feel safe enough, most companies use platforms such as Kickstarter for their crowdfunding activities. These platforms seek to implement far-reaching policies to reduce the risk of fraud for investors. Although these mechanisms may help to build some trust, they also strictly limit the way crowdfunding can be done according to the platform's rules.

In the same year as Oculus VR's Kickstarter campaign, the software developer J. R. Willett also sought to raise venture capital for a project called MasterCoin. He was fascinated by the opportunities offered by the cryptocurrency Bitcoin and wanted to further enhance them. At the time, Bitcoin was mainly used to do very simple transactions, namely, sending money from one account to another. Willett saw a strong potential to enable even very complex financial functions—for instance, the implementation of smart property and savings wallets—by adding a new communication layer on top of the existing Bitcoin network. To support this project, one could send Bitcoins to the team overseeing the software development. In exchange, contributors received digital tokens that represented the provided support. These tokens would later be used as the primary currency to conduct financial services in the MasterCoin environment. Even if someone was unwilling to use these financial services, they would still have incentives to purchase tokens. The ongoing development of the project may attract more people who would like to use the service. The higher demand would then result in a higher value of the usage token, so that initial contributors could sell their tokens and make a profit (Willett 2012). Willett's idea succeeded. After his fundraising campaign in July 2013, he had a fund of 5000 Bitcoins, then worth approximately $500,000 (Jaffe 2018). This process of raising venture capital later became known as an *initial coin offering* (ICO), relating to the term *initial public offering* (IPO) (Schweizer et al. 2017).

Comparing the concepts of crowdfunding and ICO, we find several similarities. First, both approaches are primarily used to get venture capital to fund overall growth of a company or to finance new projects. Second, a public fundraising call makes it possible for almost anyone to invest. Third, since the Internet provides the fundamental basis for communication and payment, anyone can contribute from almost anywhere in the world. Fourth, in most cases, the contributors get something in exchange for their investment, for instance, hardware, a token that makes it possible to use a software package, or a share in the company's equity (Kravchenko 2017).

We also find differences between crowdfunding and ICO. Foremost, the underlying system employed in the fundraising process has far-reaching implications. While traditional crowdfunding uses central platforms hosted by a third-party provider, an ICO utilizes a decentralized peer-to-peer (P2P) network and blockchain technology to conduct operations (Schweizer et al. 2017). Blockchain enables the completion of financial transactions in a trustless environment—there is no need for trust in any entity. In a crowdfunding campaign, crowdfunding platforms and banks serve as these trusted entities. In an ICO, transactions are verified by a network-wide consensus mechanism. Applying these attributes, we can see how blockchain in the form of an ICO counteracts the aforementioned downsides of crowdfunding. Since one no longer needs platforms or financial institutions, funders can save money they would otherwise need to spend on related services. Further, there are almost no rules or platform policies to be considered when doing an ICO, which gives one great flexibility when raising funds (Enyi and Le 2017).

Since its first appearance, blockchain technology has steadily evolved, and is now seen as a multipurpose technology, providing Turing-complete programming languages that allow for the implementation and execution of business logic. These blockchain programs are called *smart contracts* and are based on computer protocols. Smart contracts enable complex transactions without being explicitly triggered by an external third party. The smart contract source code is stored on every node of the blockchain and, when triggered, is executed on every node of the network (Christidis and Devetsikiotis 2016; Glaser 2017). These smart contracts make it now very easy to issue digital on-chain tokens and thus implement trust-free trade in an asset (Buterin 2014; Beck et al. 2016; Kõlvart et al. 2016). Thus, in 2016 alone, the estimated volume of raised funds via blockchain tokens was $250 million. By November 2017, the cumulative funding exceeded $4500 million (CoinDesk 2018; Smith and Crown 2017). While technology startups are interested in raising funds via the sale of crypto-tokens, regulators are also addressing this topic. For instance, the Swiss Financial Market Supervisory Authority has released guidelines describing how to do ICOs and how to apply financial market legislation (Lux and Mathys 2018). The potential of this unregulated sale in shares is substantial. Reducing costs for fund-seekers and increasing trust for potential investors are an exciting improvement over the previous crowdfunding system.

To be able to fully leverage the potential of this novel form of fund-seeking, we must thoroughly understand the theoretical background of ICOs, as well as its implications. We will now focus on the underlying blockchain technology, the theoretical concept of crowdfunding, and ICOs' main characteristics. In section "Blockchain and ICOs Are Reshaping the Crowdfunding Sector", we take a close look at blockchain technology's implications for traditional crowdfunding and ICOs' roles regarding financial regulations. In section "Benefits, Challenges, and Consequences of ICOs", we will further describe potentials, challenges, and future development of ICOs.

Background

Blockchain and Smart Contracts

The global interest in blockchain has increased substantially in the past few years, since various practitioners and researchers are recognizing its potential to radically change a broad spectrum of business processes (Beck et al. 2016; Wright and Filippi 2015). While the technology is commonly known as the enabler of Bitcoin, numerous current applications already go beyond its initial cryptocurrency application (Crosby et al. 2016).

Blockchain can be described as a decentralized transaction and data management technology (Yli-Huumo et al. 2016) that enables data sharing across a network of multiple participants (Xu et al. 2017). Transactions between users are grouped into blocks that are cryptographically chained to one another in chronological order—hence the name blockchain. A consensus algorithm running on all participating nodes guarantees the correctness and order of transactions. There are multiple such algorithms (proof-of-work, proof-of-stake, proof-of-elapsed-time, etc.) that provide varying levels of security, latency, and energy consumption (Christidis and Devetsikiotis 2016; Zhang et al. 2016).

In short, blockchain systems have the following characteristics (Schlatt et al. 2016):

- Data redundancy, to ensure persistence among the transactions and data
- Use of cryptography, to ensure data security and integrity
- Use of a consensus algorithm, to coordinate transactions among the network peers
- Decentralization, which enables trusted direct interaction among the network peers
- Auditability, transparency, and verifiability of network activities

Blockchain can be used in various ways, from allowing new forms of distributed software architectures to a wide range of associated use cases and tokens (see section "Tokens and Cryptocurrencies"). The associated tokens range from distributed virtual currency (called cryptocurrencies) to asset representation or digital rights management on the blockchain (Conley 2017; Nærland et al. 2017).

Since its introduction by Satoshi Nakamoto in 2008, there has been a three-step evolution: blockchain 1.0, 2.0, and 3.0. These categories illustrate the way of blockchain technology from its original cryptocurrency use case of Bitcoin (1.0) to the ability to implement programs on the blockchain (2.0) (so-called smart contracts), to justice, efficiency, or coordination applications (3.0) (Swan 2015).

Public interest in the first generation of blockchain only sparked when its role as the basis for cryptocurrencies was discovered after the publication of *Bitcoin: A Peer-to-Peer Electronic Cash System* under the pseudonym Satoshi Nakamoto (Nakamoto 2008). The first generation of blockchains was a breakthrough in computer science, because distributed networks, cryptographic technologies such as hash functions, and asymmetric encryption were first linked. The technology was the first to efficiently solve the double-spending problem (Kopfstein 2013), which allowed one to infinitely copy digital assets (Swan 2015).

The second generation of blockchain evolved in 2013 with the introduction of Ethereum, which went beyond (cash) transactions. Ethereum has a built-in, Turing-complete programming language called Solidity, which provides a general-purpose programmable infrastructure. This infrastructure enables the use of smart contracts (Buterin 2014). The concept of smart contracts, which was first introduced in 1994 by Nick Szabo, describes a computerized transaction protocol that automatically executes terms of a programmed contract on a blockchain. Although not all smart contracts are contracts in the official form of contract law, they can enable massive automatization of processes, since their tamperproof characteristics allow for the option to design generic interactions between mutually distrustful parties (Lauslahti et al. 2017). A trusted network is controlled by a network administrator, whereas an untrusted network cannot be controlled or managed. Smart contracts enable programmable transactions and can be used to control digital assets, implement a trust-free trade in assets, and facilitate the issuance of tokens (Buterin 2014; Teutsch et al. 2017; Nærland et al. 2017).

Currently, second-generation blockchains are still in the prototype development phase. The next steps will be a rollout of the blockchain 2.0 use cases in working environments. Thus, as yet, blockchain 3.0 is mostly still a concept and an ideal.

The third generation of blockchain is expected to move beyond transactions and second-generation smart contracts and is mainly about three topics: scalability, interoperability, and sustainability. In the context of cryptocurrencies, one can think of scalability from three perspectives: transactions per second, network, and data. These perspectives are directly interlinked; that is, the more people join the network, the more data will be produced and the more transactions per second will be needed to handle the increasing number of transactions and data in the blockchain.

Interoperability means that not one blockchain rules them all. We already have many blockchain networks such as Bitcoin, Ethereum, Ripple, or Litecoin. All these systems have their own business logic and rules. As yet it is difficult for the different networks to understand one another. Blockchain 3.0 must offer a standard and must link these different networks without a trusted third party, such as an exchange.

Sustainability means that, once implemented, blockchains should not be seen as a static technology but as a technology that can be modified when technology and use cases change. Changing something in a blockchain means that a so-called forking (i.e. changing the underlying protocol) must be done. This is a problem faced by first-generation and second-generation blockchains. Thus, blockchains can break apart. Examples of forks are Bitcoin and Bitcoin Cash or Ethereum and Ethereum Classic.

In third-generation blockchains, smart contracts are being developed into decentralized autonomous organizational units with their own laws and high autonomy and in almost all spheres of life, including government, health, and science (Swan 2015). Cardano and ICON are examples of projects that are building third-generation blockchains.

Cardano as third-generation blockchain addresses the scalability aspect by using a proof-of-stake consensus mechanism instead of proof-of-work. In terms of interoperability, Cardano has a sidechain concept which allows cross-chain transfers. For sustainability Cardano plans to implement improvement proposals via hard or soft forks (Cardano 2018). ICON is a decentralized network hyperconnecting the world, with the goal of developing global standards for inter-blockchain networks. With ICON, isolated communities like capital markets and insurance and healthcare companies can connect and share various services through the ICON network (ICON 2018).

New distributed ledger technologies besides blockchain are also being developed; these can become part of and often referred to as blockchain 3.0 although they are not strictly blockchains. These new technologies no longer have blocks but are directed acyclic graphs. The tangle of IOTA and Swirlds hashgraph are well-known representatives of directed acyclic graphs. Especially blockchain's limitations in terms of scalability and micro-transactions for Internet of Things (IoT) applications can be overcome with these technologies (Bashir 2017). A block in the Bitcoin Blockchain currently has a limited size of 1 megabyte and is mined about every ten minutes. Subsequently, only seven transactions per second can be executed (Zheng et al. 2017). Many micro-transactions must be executed in order for machine-to-machine communication in the IoT to occur. This demands a technology that can handle many more transactions per second than first-generation and second-generation blockchains.

Tokens and Cryptocurrencies

Token can have a multitude of meanings and can be defined as "a piece resembling a coin issued as money by some person or body other than a de jure government" (Merriam Webster 2018). We use *token* to refer to the usage of digital tokens in the context of blockchain. From a technical perspective, tokens can be used for various purposes, such as the facilitation of transactions, as an internal unit of account, or to grant tokenholders privileged access (Conley 2017; Glaser and Bezzenberger 2015; Schweizer et al. 2017). As illustrated in Fig. 8.1, tokens can be separated into the tokens inherent to a blockchain (*protocol tokens*) and tokens issued on top of a blockchain using smart contracts (*application tokens* or *on-chain tokens*). On-chain tokens are created by smart contracts whose

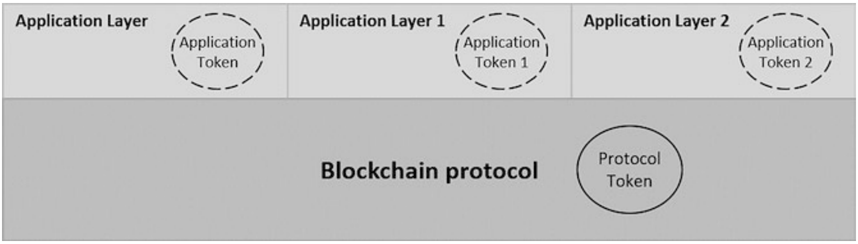

Fig. 8.1 Differentiation between application tokens and protocol tokens

most prominent enabler is the Ethereum Blockchain (Schweizer et al. 2017).

It is also important to distinguish tokens according to their types and purposes (see Table 8.1). Tokens can be categorized into *usage tokens*, which give the holder access to a digital service, *work tokens*, which enable holders to contribute work to a network (Tomaino 2017), *funding tokens*, which have the use to raise funds, and *staking tokens*, which refers to the potential use of tokens as the right to be a stakeholder, participate in a network's decisions, and—in some cases—earn a reward (Buterin 2014; Nærland et al. 2017).

Tokens can be facilitated in various ways, the most common being a token sale, while airdrops or rewards are also possible forms. When participating in an airdrop, one can be credited airdrop tokens for free when holding a specific other token. The airdrop tokens will be sent proportionally to the current balance of the referenced token (for instance, for holding one Ether, one will receive ten airdrop tokens). Airdrops are especially used as a marketing instrument for investors. One can reach millions of users within a short time, creating much awareness for the token. Further, governments are interested in any project in which capital is being generated or a product is sold. With an airdrop, these risks can almost be eliminated (Malwa 2018). Tokens facilitated as rewards are especially created for the mining process of the proof-of-work algorithm in the blockchain, where the community is motivated to contribute computational resources to solve cryptographic puzzles (Tomaino 2017). Tokens can also be emitted and used for payment in the form of legal tender or cryptocurrency.

Table 8.1 Classification of tokens by type and purpose

Token type	Example	Description/function
Usage token	Ethereum (ETH), Bitcoin (BTC), Litecoin (LTC)	A usage token is required to access the digital service, which no central party controls. The most common example is Bitcoin. To use the Bitcoin Blockchain, one needs BTC. The resources this digital service provides are its hashing power, which secures the blockchain, the users, and developers. Bitcoin gets its value from providing these resources and people benefitting from the secure, publicly distributed ledger
Work token	Reputation (REP), MakerDAO (MKR), Ethereum (ETH)	With a work token, one has the right to contribute work to a decentralized network to help that organization to function. When Ethereum is going to switch from proof-of-work to proof-of-stake, ETH will also be a work token, since it gives users the right to validate transactions and earn a fee in exchange
Funding token	Ethereum Funding Token (EFT)	This token is used to raise funds. A good example is the Ethereum Funding Token, which is provided in exchange for donating to someone in need. It can be held or traded for profit like any other token but mainly represents pride of ownership
Staking token	tZero	These tokens (also called tokenized securities) represent shares in a business and can allow users to have active roles in corporate governance. Since they have been deemed securities, the tokens now fall under the regulatory scope of governmental regulators. An example is the tZero token, which entitles token-holders to quarterly dividends derived from the tZero platform's profits

Cryptocurrencies as an Example of Digital Tokens

All digital currencies have in common that some digital token type is used as a medium of exchange, a unit of account, or a store of value (Monetary Authority of Singapore 2017). Frequent flyer miles or computer game and online casino currencies are examples of digital currencies (Lee 2015). One can generally buy a digital currency with physical goods or services, identical to physical currencies, or the currency is only valid online, for instance, for a specific game or airline. Digital currencies that are restricted to a certain ecosystem, such as the airline ecosystem, are also known as virtual currencies (Akkizidis and Stagars 2015).

With the advent of Bitcoin, a new digital currency type emerged: cryptocurrency. The notion of cryptocurrency dates back to the financial crisis in late 2007, in which people experienced dramatic declines in the value of physical currencies such as US dollar and the euro. Central banks around the world began to flood the markets with liquidity in order to maintain confidence in their economy. Thus, banks changed the key characteristics of the currencies' values. Satoshi Nakamoto is said to have developed the cryptocurrency Bitcoin, issuing it in 2009 to create a new monetary system that belongs to no one and can therefore not be steered (Istomin 2017): Bitcoin—a P2P version of electronic cash—which is the first use case that made use of blockchain technology as a distributed ledger.

Cryptocurrencies differ from other digital currencies mainly in that transactions do not rely on trustworthy intermediaries but are shared in a decentralized network. Here, cryptographic hash functions and a network protocol secure and verify the transfers' values. Generally speaking, cryptocurrencies share attributes with other digital currencies. Further, cryptocurrencies are based on cryptography, facilitating security via encryption. One cryptography type used in cryptocurrencies is a digital signature, which proves to the network that one is the owner of a specific account and that a transaction is authorized by this account's legitimate owner. The concept is comparable to a digitally signed e-mail, where the signature proves that the sender is who they claim to be and that the message was not modified during its transit (Grant 1998).

Since the phenomenon of cryptocurrencies is very young—compared to traditional fiat money—they lack transparency and experience high volatility as well as high credit, liquidity, legal, and operational risks (European Central Bank 2015).

Crowdfunding

Crowdfunding is a revolutionary concept initiated as early as 2006 during the Web 2.0 era that has since gained popularity. It may be described as a public call for financial investment that is distributed among a large group of users who can evaluate the project owner's concept and can support them (Danmayr 2014). While any single investor would be unable to sponsor the endeavor as a whole, the group or crowd may be able to provide the necessary capital. Thus, crowdfunding is based on the "ability to pool money from individuals who have a common interest and are willing to provide small contributions towards the [project]" (Lynn and Sabbagh 2012). While venture capitalists only provide money toward selected projects that seem to have the potential to exceed expectations, crowdfunding became popular to fund smaller projects.

Crowdfunding campaigns are executed through so-called crowdfunding platforms. These platforms are usually hosted on a website, and traditional financing schemes efficiently facilitate the interaction between project owners and individuals willing to fund their project. This inevitably leads to a significant reliance on the trust of at least one third-party actor. Beyond their website, crowdfunding platforms must cooperate with banks and payment service providers to facilitate the necessary financial transactions. There are three actors in any crowdfunding venture: the investors (who give money), the intermediary (who transfers the money), and the project owners (who seek money). They all take various risks and opportunities, which are necessary to a successful crowdfunding.

Figure 8.2 demonstrates a common crowdfunding service ecosystem, comprising a bank, capital-seekers, investors, payment providers, crowdfunding partners, and their various connections. While both the payment providers and the bank offer fairly traditional services, crowdfunding partners are increasingly making use of disruptive services. While capital-seekers are increasingly seeking to use these disruptive and innovative services and infrastructure, many conventional intermediaries are bound to traditional services.

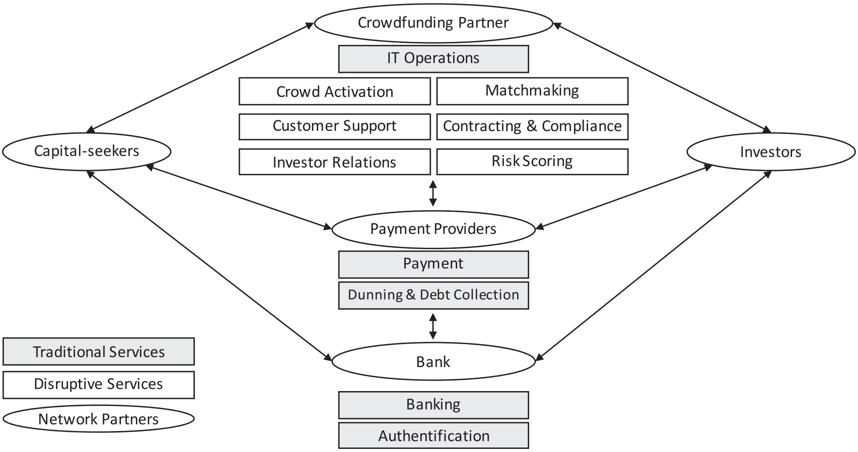

Fig. 8.2 Crowdfunding service ecosystem. (Haas et al. 2015)

Table 8.2 Characteristics of the four most prominent forms of crowdfunding

Donation-based crowdfunding	Capital-seekers receive their funding without any requirements to return their investment
Reward-based crowdfunding	Capital-seekers receive their funding in exchange for—usually non-monetary—rewards
Lending-based crowdfunding	Capital-seekers must fully refund the monetary resources they have raised through their campaign. They may have to cover interest or fees for receiving such funds
Equity-based crowdfunding	Capital-seekers must provide their investors with a share of equity and part of their profits

Academia and business usually differentiate between four different forms of crowdfunding: donation-based crowdfunding (crowd-donation), reward-based crowdfunding (crowdsupporting/crowdfunding and pre-selling), lending-based crowdfunding (crowdlending), and equity-based crowdfunding. Table 8.2 sums up their respective key characteristics.

Crowd-donation is one of the earliest forms of crowdfunding and involves a capital-seeker demonstrating their project online and several individuals or groups making small donations without the expectation of any return on investment. This form of crowdfunding has become increasingly popular among philanthropic organizations (Yen et al. 2018). The second form of crowdfunding is reward-based crowdfunding, where capital-seekers receive their funding in exchange for—usually non-monetary—rewards. While, as explained in Table 8.2, there is a close relationship between crowdlending and equity-based funding models (Mollick 2012), since they closely resemble standard investment schemes, other crowdfunding forms are based on alternative schemes. Crowd-donations, for instance, may be most appropriate for social entrepreneurship projects (Frydrych et al. 2014): individuals may donate to a cause without expecting any direct monetary or reward-based returns on their investment, since they are convinced that this project will create positive and worthwhile impacts for others.

Crowdfunding is primarily used to fund small, early-stage, emerging firms or projects (Schwienbacher and Larralde 2010). While traditionally a small number of venture capitalists and business angels provide most of the capital for startups and small businesses, crowdfunding capital is raised through large groups of individuals that each decide to invest a small amount of money in a potentially successful, relevant, or interesting idea. Further, crowdfunding platforms strongly rely on intermediaries such as banks and payment service providers (Haas et al. 2015). While crowdfunding platforms mostly focus on connecting a group of individuals (the crowd) to capital-seekers, the banks and payment services facilitate capital flow between these two actor types. These actors are motivated by both intrinsic and extrinsic factors (Koch 2012), including economization, cooperation, and community (Massolution 2012). Ultimately, there are entrepreneurs who seek to finance their innovative ideas through crowdfunding. For many years, they were the individuals who failed to raise capital through other means, since they were unable to generate any interest from venture capitalists. This has changed somewhat in modern crowdfunding.

Crowdfunding's strengths include the potential for entrepreneurs, depending on the previously agreed-upon terms, to retain their right to make business decisions, the accessibility of low-risk capital for individual contributors, and an opportunity to test the business model's marketability (Valančienė and Jegelevičiūte 2013). Despite the many potential benefits that crowdfunding may provide in a Web 2.0 environment, it also has several weaknesses that have not yet been resolved. These potential weaknesses include administrative and accounting challenges, a strong reliance on intermediaries, and weak investor protections (Valančienė and Jegelevičiūte 2013). A novel form of blockchain-based crowdfunding is emerging that seeks to overcome these issues in order to bring equal benefits to investment-seekers and investors (Yadav 2017).

From Crowdfunding to Initial Coin Offerings

While crowdfunding and crypto-tokens have worked in isolation from one another for some time, combining them turned out to be a very successful way for startups to raise early-stage financing. Instead of spending weeks convincing a venture capitalist or bearing the cost of an IPO of stock to get money for growth, blockchain startups began to sell their tokens—a process called initial coin offering (Conley 2017).

While ICOs bear some resemblance to IPOs, their structures and processes differ in many aspects, such as underwriting, distribution, and regulations (Kuo Chuen et al. 2017). A token sale refers to a method of selling participation or royalties in an economy or a project that starts at a later date, whereas an IPO sells a share of ownership in the company. An ICO presents a new form of crowdfunding, in which participants exchange existing forms of cryptocurrencies (mostly Bitcoin or Ether) for entity-specific crypto-tokens (Robinson 2017). The phenomenon was first called *the Bitcoin model for crowdfunding* in 2014 and was described as a new business model for open-source software, in which any participant in a blockchain protocol can participate anonymously in the funding, development, and revenue collection using tokens (Ravikant 2014; Kuo Chuen et al. 2017). However, the ways in which campaign creators and potential investors are brought together differ significantly between crowdfunding and token sales. As crowdfunding platforms need intermediaries such as payment services to collect money, ICOs are completely decentralized and rely solely on P2P mechanisms provided by blockchains (Danmayr 2014; Ehrsam 2016; Schweizer et al. 2017). Thus, ICOs enable investors from across the globe to participate, which can lead to more money being collected. In 2017, $3.7 billion was collected in 235 ICOs (Coinschedule 2018). While traditional financing is tilted toward an intermediary and is designed to lower their risks, ICOs exploit these fundamental flaws of middlemen and bring equality to a project. According to the venture capitalist Fred Ehrsam, the ICO model of funding projects in advance can also help to overcome networks' classic "chicken and egg" problem. By buying tokens early on, becoming a partial owner of the network, and profiting from potential token price appreciation in later stages, users are incentivized to join a network (Ehrsam 2016).

As the crypto-token market matures, potential risks and challenges can be observed. The most severe is that token-issuing startups often provide an intangible product or no product at all. Since ICOs are used to generate early financing during the lifetime of a crypto-platform, token purchasers typically invest in a basic crypto-idea and the promise of the idea associated with the platform. While this may work well with core infrastructure systems such as Ethereum, many other token platforms struggle to keep their promises (Kaal and Dell'Erba 2017).

With little information given about a crypto-platform's business plan and purchasers' expectations of a token price's potential appreciation comes high volatility. Tokens issued to have functional and consumptive value are increasingly becoming objects of speculation, since the prospect of buying the token early on at a low price, holding it, and reselling it later at a higher price is increasingly attracting investor attention (Rohr and Wright 2017). There is also a lack of constant cash flow to offset any upcoming costs, since the ICO tends to be a single event with a set market cap. After this initial funding phase, it may be hard for investors to collect further financial resources, especially when further funding is needed for another research, development, or production project. In the case of an ICO, more cash can only be generated by issuing additional tokens, which would devalue the tokens already held by other investors. However, similar effects may be observed in the case of IPOs. As soon as a company decides to issue new stock, existing investors are compensated, much like an airdrop usually leads to compensation.

The ICO Process: How to Do an ICO

While there is a wide range of flexibility regarding how to conduct an ICO, some fundamental steps are recommended to fully leverage the aforementioned benefits. The full process is shown in Fig. 8.3.

In step 1, one must choose an appropriate infrastructure. From a technical perspective, there are two ways to carry out an ICO. First, a firm can decide to create a custom blockchain platform, where the native coin represents the issued token. When, for instance, IOTA was doing its ICO, it developed its blockchain protocol and set up the network. The main advantage of this method is that it facilitates maximum flexibility concerning the ICO's fundamental infrastructure. For small and medium-sized companies, on the other hand, implementing the network and attracting miners represent massive barriers. Thus, most ICOs are based on existing infrastructures—most dominantly, the Ethereum network. Using, for instance, Ethereum's inherent capabilities to create smart contracts and tokens makes it much easier to conduct an ICO, yet the process is strictly limited by the underlying infrastructure. In the end, the decision whether to create an infrastructure or issue a token based on an existing blockchain is based on the specific business case and its requirements (EYGM Limited 2018).

After one has made decisions regarding the business model and the underlying technology, one must communicate the intention to do an ICO to the community and potential investors. A typical pattern to do so for a startup is to publish a white paper. In this document, a range of information is revealed to the public. It can comprise an extensive business plan including revenue streams and partners, but also a history of previous business experience in an industry. Thus, all information communicated via a crowdfunding platform during a standard crowdfunding campaign will be published in an ICO's white paper. Most importantly, the white paper also points out key token parameters, namely, the function

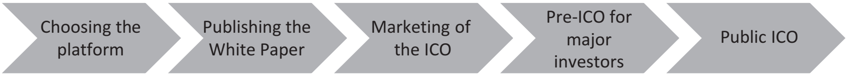

Fig. 8.3 The initial coin offering process

of the issued token, the token creation process, and how tokens can be purchased (Conley 2017). After publishing the white paper, the campaign creators do a virtual roadshow, to generate interest and present their project to potential investors. Since this is a critical period for a successful ICO, credible community management and rapid response rates in various channels are key. This marketing process may take up to several months.

Before offering the token to the public, a firm has the option to run an ICO pre-sale, also known as a *pre-ICO*. In this round, the acquisition is reserved to a small group of investors, and tokens are usually sold cheaper than in the later main ICO to compensate for the higher risk in this early funding stage. A primary reason for an ICO pre-sale is to raise funds used for future expenses that occur along the way to the main ICO; these likely include the costs for promotion, recruitment, and software development. Besides monetary functions, a pre-ICO can also help to create positive buzz around a project. The information that a startup has already raised a certain sum through investors can send optimistic signals to other potential investors, fostering credibility and trust in the project. Thus, a successful pre-ICO may boost fundraising in the main ICO. Some firms even use these positive aspects and conduct more than one pre-sale round (Jeffries 2018). Although dedicated pre-sales for selected investors are common practice, this approach also has downsides. The risk in this early stage of a company in which the pre-sale occurs is fairly high. Thus, the likelihood of the funded project failing, and the buyers of pre-sale tokens finding themselves holding worthless tokens, is also higher. Further, as tokens are usually cheaper in a pre-sale than in the main ICO, investors may use this property to leverage arbitrary profits. Divestment of discounted pre-sale tokens in the following main ICO phase can dilute the token and may drive down its price (Coinist 2018).

In the last step, the ICO takes place at a pre-announced date, and members of the public can purchase tokens to participate in the project; in some cases, they also have a stake in the project (Kuo Chuen 2017; Johnston et al. 2018). Many token sales are capped; that is, only a fixed number of tokens are distributed. For the most popular projects, these tokens sell within minutes, if not seconds (Rohr and Wright 2017).

Practical Views

Ethereum's Crowdsale

The invention of ICOs goes back to J. R. Willet and his *The Second Bitcoin Whitepaper*, which was published in early 2012. Here, he hypothesized that someone could raise much money for a computer science project if a coin were created that is used by that project. In 2013, Willet started the first ICO for his project, Omni (formerly known as MasterCoin), publishing a white paper and a Bitcoin address. The idea was "that the existing Bitcoin network can be used as a protocol layer, on top of which new currency layers with new rules can be built without changing the foundation" (Willett 2012). A year later, Ethereum, the most important platform for ICOs today, was founded. Ethereum was financed by a crowdsale, a crowdfunding type in which cryptocurrency tokens can be sent in exchange for ICO tokens. During Ethereum's crowdsale, it was possible to send 1 Bitcoin and receive 2000 Ether in exchange. As at March 2018, this investment would mean that someone who sent 1 Bitcoin in 2014 (worth $600 at the time) would have 2000 Ether to the value of $1.4 million.

The Ethereum Network

Today, Ethereum is the primary platform for conducting ICOs. Approximately 57% of 2017's ICOs were so-called Ethereum-based ERC-20 tokens, and only 30% built their custom blockchain (Darko 2017). ERC-20 is a standard offered by Ethereum and can be seen as a guideline that provides rules and defines how an Ethereum-based token must be implemented. This standard enables various applications to interact with the ICO token. Interacting applications include wallets or crypto-exchanges. One significant advantage of the ERC-20 standard is that ICOs are easy and quick to set up; also, investors who participate in the ICOs can use Ethereum's infrastructure. This means that received ICO coins can be saved in—safe—Ethereum wallets; further, most crypto-exchanges now support the Ethereum token and the ERC-20 standard. This progress lowers the risk for investors that the purchased ICO coin can only be traded on some but not all token exchange platforms.

Owing to its ability to include smart contracts and decentralized applications, Ethereum has a special significance for ICOs. For instance, a smart contract can automatically receive tokens from other wallets or can decide how many tokens will be transferred to whom. The rules on which smart contracts are based on are set arbitrarily by the programmer, who then stores the contract on the blockchain. Thus, the contract is stored immutably and will be executed in the same way for all network participants.

The smart contract is unlocked if certain conditions in the network are met, for instance, when it receives tokens (Buterin 2014). One example of the use of a smart contract is an auction. During an auction, the smart contract registers all the participants' addresses and bids. At the end of the auction, the smart contract chooses the highest bid and publishes the winner, refunding all other bids. One key advantage of smart contracts is that everyone can participate without credit cards, verifications, or e-mail addresses. Further, the blockchain guarantees transparency and security.

The Filecoin and ICOBOX Use Cases

The number of ICOs increased from 1 in 2014 (value: $450.000) to 883 in 2017, to the value of $6 billion (ICO Data 2017). On the supply side, the significant increase in ICOs in recent years can be attributed to the simplicity of setting up an ICO and swiftly raising large sums of money. Filecoin's ICO in 2017 raised $252 million in 30 minutes (including pre-sale figures). On the demand side especially, an ICO's potentially high return on investment (ROI) makes ICOs attractive to investors. For instance, the ROIs of Ethereum and NEO, since their ICOs in 2014 and 2016, were 280,000% and 379,000%, respectively (ICO Stats 2017). Such potential ROIs and cryptocurrencies' liquidity are two key reasons why people are investing in ICOs (Metke 2017).

Increasing attention in and values of such ICOs have led to new business models around the execution of an ICO. ICOBOX's business idea is to support startups to sell their products via an ICO. To execute an ICO, they set up your Ethereum-based smart contract, support marketing actions, and/or help to draft a white paper in various languages. Almost anyone can now do an ICO to realize their software project, owing to the professional and specialized competences of companies offering facilitating services. On the other hand, scams and unsuccessful ICOs are on the increase. Almost half of 2017's ICOs have failed, which illustrates the high risk of investing in them.

Blockchain and ICOs Are Reshaping the Crowdfunding Sector

Why ICOs Matter

In 2017, both blockchain technology and ICOs had a substantial effect on early-phase funding and have reshaped the entire crowdfunding sector in ways that experts could scarcely have imagined. The ICOs of Bancor, a decentralized liquidity platform (Bancor 2018), and Gnosis, a decentralized platform for prediction markets (Aitken 2017), started a wave of campaigns, interest in this "new form of crowdfunding" has grown steadily (Mougayar 2017), and the results of this development are fairly clear: ICOs first topped the monthly average of angel and seed-stage investments in June 2017 (Verhage 2017), and the amount invested in ICOs has more than doubled by December 2017 (ICO Data 2017). During this time, the industry has seen fundamental transformation, which will continue to affect the technology-centered startup scene and will continue to disrupt the IT industry; it should therefore be taken seriously by both market leaders and established companies that seek to build on their success, as well as startup founders who seek to increase their liquidity in the early stages of their company.

ICOs have been extremely popular, since they deliver advantages to both investors and technology startups that could not be realized in a traditional crowdfunding or IPO environment. On the one hand, technology startups may benefit from the anonymous, decentralized, and participatory nature of ICOs, allowing them to receive their funding anonymously from across the world while enabling shareholders to participate in any decision contained in their investment's contractual basis. Further, companies that self-fund through ICOs don't have to work with international investment banks, financial service providers, or crowdfunding platforms, which allows them to not only set the rules of their ICO but also the save the fees levied by the aforementioned intermediaries.

On the other hand, investors may profit from ICOs, since they can speculate not only on a company's success but also on the underlying cryptocurrency; that is, individuals may invest in companies while the BTC/USD exchange rate is tilted in their favor. Further, the fact that ICOs allow anyone to invest any amount in a company enables individuals who don't want to interact with a company through intermediaries to become involved and invest in projects they consider worthy.

The North American and European capital markets were robust throughout 2017, and one could get the impression that technology-related IPOs are no exception to this overall trend. However, experts have concluded that "despite strong capital markets, tech companies were largely absent from the US IPO market" (Chitkara 2017). Founders and investors argue that ICOs may have played a key role in this development. For European tech startups, a fairly similar pattern may be observed, as European tech startups represented 56% of tech IPOs' proceeds in the third quarter of 2017, a stable development based on traditional indicators (Chitkara 2017). However, beyond these indicators, the appearance of European tech IPOs declines, since their proceeds and profits are based solely on two companies' offerings: Landis+Gyr and Rovio Entertainment (known mostly for its mobile game Angry Birds). There were no European tech IPOs in the first quarter of 2017, with the second quarter showing little improvement.

Considering the constant decline of Western tech companies' interest in IPOs, despite welcoming capital market conditions, Northern American and European companies and investors are turning to ICOs as an alternative form of funding. Further, regulators are well advised to follow suit if they wish to sustain their—arguably—successful research and innovation scene.

Blockchain Technology's Implications for Crowdfunding

Looking closely at ICOs' implications on all four forms of traditional crowdfunding, one can see that ICOs have the ability to transform them to become more transparent, more effective, and cheaper. In Fig. 8.4, one can see that a blockchain-based crowdfunding ecosystem relies on P2P transactions. This makes the concept of crowdfunding more interesting for both capital-seekers and investors. Thus, ICOs may become increasingly popular, potentially replacing traditional crowdfunding efforts in the foreseeable future.

First, donation-based crowdfunding campaigns are crowdfunding campaigns in which the investor/donor usually acts based on an altruistic motivation or on peer recognition (Arvidsson 2009), which may be either intrinsic or extrinsic. Thus, the investor expects no monetary return on their investment and will receive no reward besides personal happiness or social recognition. On the one hand, while the ways in which charitable organizations are operated have changed significantly (Choy and Schlagwein 2016), they are usually the ones that profit directly from donation-based crowdfunding. On the other hand, researchers have argued that donation-based crowdfunding campaigns could even be economically useful, since they could contribute to the efficient allocation of

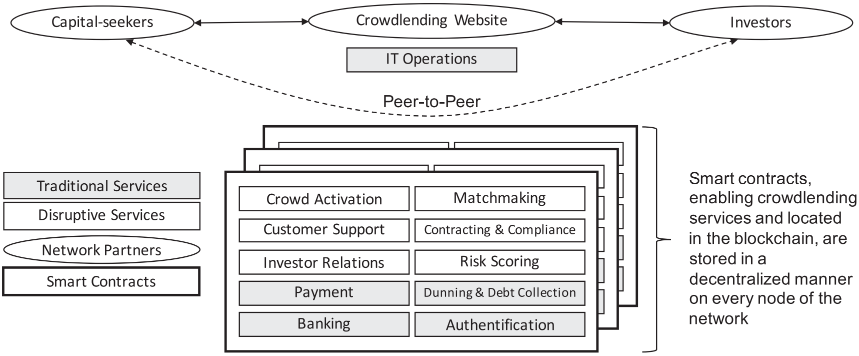

Fig. 8.4 Blockchain-based crowdfunding service ecosystem (Schweizer et al. 2017)

a society's social capital and production (Knudsen and Nielsen 2013). This may be one of the crowdfunding forms most easily represented in a blockchain environment, since blockchain technology allows any organization to receive funds from any individual across the world by providing them with their wallet's address. One could swiftly realize crowdfunding in a blockchain 1.0 environment, since it only requires two individuals with a wallet in order to be executed. This facilitates a fairly simple representation in a smart contract-enabled blockchain environment such as Ethereum (Ethereum Foundation 2018a) and has attracted several high-profile organizations that have successfully used the technology; these include the Bitcoin Foundation, WikiLeaks, and Internet Archive (TrueDonate 2018).

Second, in reward-based crowdfunding campaigns, the capital-seeker offers a—usually non-monetary—reward to attract potential investors. Reward-based crowdfunding may be one of the most visible forms of crowdfunding, since it is the model that most projects on popular platforms such as Kickstarter and Indiegogo have relied on. In the blockchain world, reward-based crowdfunding may be most accurately represented in the form of an ICO token reward: individuals buying a certain cryptocurrency early on will receive a certain number of tokens as a form of reward. These tokens can usually be used later to access a certain service or even as a lead currency of a newly developed blockchain environment. If the project is successful, and more people want to use it, the demand for these tokens rise, which makes them more valuable. Since tokens bought through an ICO are fairly cheap compared to later market prices, early investors can use this phenomenon to leverage high profits when they sell their tokens to potential platform users. If there is no demand for the service or the project fails prior to its completion, investors will be left with tokens with no use and therefore with no value.

Third, lending-based or debt-based crowdfunding campaigns are a crowdfunding form that most closely represents the process of traditional banks issuing loans to their customers. In this scenario, the customer would, for instance, present himself and his project to a bank's representative, who would then decide whether or not to approve the project for a loan. This form of financing used to have both upsides and downsides, since it provided stability for both a bank and an investor but also included several intermediary parties. There are now several blockchain-based ICO platforms; these include the Tokenlend Platform and Crowd Genie. The Tokenlend Platform seeks to provide potential investors and loan-issuing entities with a blockchain-based toolset via a web interface (Tokenlend 2017). To do so, the Tokenlend team is working on a smart contract-based business logic that automatically issues loan repayments according to a previously agreed-upon schedule and representatively distributes the overall payment amount between the loan-issuing entities (Tokenlend 2017). Crowd Genie is a P2P platform for small and medium-sized businesses (Jain 2017) in which loans are, similar to traditional loans, backed by personal securities. Owing to this, Crowd Genie has gained momentum as a blockchain-based P2P lending platform that is officially recognized by its national monetary agency (Monetary Authority of Singapore 2018). Despite an increase in the number of lending-based crowdfunding campaigns that involve the blockchain technology, many newly established platforms may effectively be classified as novel intermediaries, since they provide the marketplace for transactions to be executed.

Finally, equity-based crowdfunding most closely represents the traditional stock market, since it allows capital-seekers to offer some of their company shares in exchange for an investment. Such platforms usually require relatively high transaction costs, since they are often executed under significant financial regulations and high operational efforts. Owing to these aspects, one may argue that equity-based crowdfunding could be substantially improved by using blockchain technology. In a blockchain environment, equity tokens are used to facilitate such transactions. They represent an underlying asset, namely, a share in a company (Wilmoth 2017). Instead of a third-party intermediary, the trading of company shares is managed by a smart contract. This not only accounts for the balance of the tokens but also implements corresponding rights and duties. For instance, depending on the number of tokens held by a single entity, the smart contract provides individual investors with some say (a certain number of votes) in a decentralized autonomous organization (Ethereum Foundation 2018b).

Legal Analysis and Implications

Given the speculative success of ICOs, the lack of regulation and the risks attached to them for investors are becoming a focus of jurisdiction. Dealing with this is more complex than it seems, for two primary reasons: first, the characterization of ICOs has not yet been defined; second, ICOs' virtuality and pseudonymity make it difficult to enforce laws.

Most ICOs are structured as virtual currencies, but some are also loans, vouchers, securities, or other financial service instruments. Given this variety and the lack of clarity of many tokens sold, ICOs have not been subject to governmental regulatory scrutiny for some time, although they have dealt with digital assets. This stands in stark contrast to proceedings of *investment contracts*, since in the US, for instance, they are strongly regulated under the Securities Act of 1933 and Securities Exchange Act of 1934 (Robinson 2017). These acts seek to ensure that security sellers provide truthful and accurate information to buyers, so that they can make informed investment decisions. In such a transaction or arrangement, all securities offered must either be registered with the US Securities and Exchange Commission (SEC) or must be eligible for one of several exemptions to such registration.

To address this, on July 25, 2017, the SEC released an investigative report on "The DAO"—the most prominent case of a blockchain-based decentralized autonomous organization—and the offering and sale of digital assets (referred to as ICOs) by "virtual" organizations, pointing out that these transactions are subject to the federal securities laws' requirements. This was the first attempt to provide a broadly applicable analysis to classify ICOs. But since the DAO case differs significantly from most contemporary ICOs, to date, most have not complied with any of the registration or disclosure requirements; thus, the SEC cannot control the truthful and accurate distribution of information and tokens; it can only prohibit them in extreme cases (Robinson 2017). Similar processes can be observed in the case of the German Federal Financial Supervisory Authority, which wants to investigate case by case whether an ICO even categorizes as a security or investment and which laws apply (BaFin 2018). Taking a broader view, it is unsurprising that some ICOs even have been launched without ever having a functioning prototype or viable product, expressing their idea on little more than a few lines of code in a white paper.

Second, ICOs' virtuality and pseudonymity make it hard for governments and regulators, which seek to enforce tax and banking laws. Given their virtuality, the main risks of ICOs are the issuance of scam coins (Matsakis 2018) and cybersecurity. Although the blockchain has the reputation of being very safe and an unfalsifiable ledger, there have already been hacks and cyberattacks. While a ledger was never manipulated through a hack, systems surrounding it, like trading platforms, were. The most prominent case hereby is the DAO hack, which demonstrates the expansion of legality through blockchains. The DAO was hacked only one month into action, and the hackers managed to divert $53 million in DAO tokens to their account, which was immediately frozen. Since the DAO functions on the Ethereum Blockchain and was "too big to fail", the Ethereum Foundation decided to create a hard fork, which led to a split in the Ethereum Blockchain but which allowed investors to recover their money in the new chain. This system comes close to rewriting history as if the hack had never existed, allowing the crowd to erase unwanted events, provided that all participants accept it (Biederbeck 2016).

Many other examples (*pump-and-dump* schemes, where capital is swiftly raised and immediately dumped in exchange for other instruments at a profit) illustrate the risks of cryptocurrencies and ICOs for investors (Crypto Calls 2018). To address the problems and risks, one must decide which regulations apply to ICOs. To do so, tokens must first be characterized, but this is challenging, given the variety of possible uses (see section "Tokens and Cryptocurrencies") and different proposed solutions based on case-by-case decisions, owing to the complexity surrounding the topic. However, it appears that most tokens can either be specified to have currency-like features, dealing with the question whether cryptocurrencies are money in the legal or economic sense[1] or have security-like

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[1] For characterizations according to German law, see Boehm and Pesch (2014); Engelhardt and Klein (2014).

For characterizations according to US law, see Enyi and Le (2017).

features, granting the tokens share-like features, sometimes even bond-like ones.

Once ICOs can be categorized and partially regulated, the question arises which party receives jurisdiction and which laws will apply to the case. Since ICOs are carried out on public blockchains, which are virtual spaces without any territorial or geographical boundaries, it is unclear which laws apply in a given situation, to date leading to decisions being made case by case. Another conflict arises from the fact that subscribers from across the world can take part in an ICO, which leads to permanent conflicts of laws and jurisdictions (Robinson 2017).

Benefits, Challenges, and Consequences of ICOs

The benefits of ICOs are becoming increasingly apparent to investors and startups, as well as to the public and major players in the international markets. While many of them appreciate the decentralized, anonymous, and unregulated nature of ICOs, established companies have begun to recognize the ability to raise capital for projects they could not finance via their budgets or traditional forms of finance. Owing to the white paper process, entrepreneurs and capital-seekers are receiving early and direct feedback from their potential customers. This helps them to create viable products that are approved by the public rather than the opinions of "enlightened VC managers". In fact, ICOs are increasingly positioning themselves as a serious alternative to existing financing options, since they create independence from existing financing instruments and shorten the current time to market. The latter is especially true when comparing an ICO and a stock market IPO. Stock market regulations are fairly strict and only offer limited flexibility.

While the blockchain may offer the possibility to interact completely without any existing platforms or intermediaries, the latter will not vanish completely. At least as long as cryptocurrencies are not part of everyone's daily lives, people will still have to rely on banks, marketplaces, and ICO platforms to be able to spot new projects and buy their tokens. On the other hand, with the advancement and acceptance of cryptocurrencies, these dependencies are decreasing. Especially for technology startups, an ICO often matches the business plan very well. The issued tokens work as an asset and can also be used to gain access to a particular service offered by the company. Thus, an ICO can also enable new business cases, potentially bringing value to the public.

Regarding the potential challenges and disadvantages of ICOs, compared to traditional financing schemes, the legal implications for coin-offering startups and businesses, and the risks that investors take, must be at the forefront of any decision being made.

The legal analysis uncovered some major implications for ICOs which remain to be discussed, if they benefit or risk them. As at early 2018, there is still broad disagreement on how ICOs and the issued coins should be recognized under existing regulations in a proverbial patchwork of national jurisdictions. Thus, it remains to be seen whether supranational institutions will be able to establish common frameworks on how to interact with the revolutionary concept of cryptocurrencies. Regulators must still answer very basic questions. For instance, many countries have not yet decided how to characterize an ICO and its tokens; while most authorities categorize them as virtual currencies, some consider them to be loans, vouchers, or even securities.

Further risks of ICOs are mainly the issuance of scam coins (Ponzi scheme) and cybersecurity. Although blockchain has the reputation of being a very safe technology, the de facto security depends on reasonable source code and the software's execution. The best example of this was the Ethereum DAO hack. In fact, the blockchain was not hacked; one of the smart contracts the DAO was set up on was. This means that firms and individuals who are willing to do an ICO must acquire advanced knowledge and must audit the code. Although a set of standard token contracts is now available and can be adapted, one wrong line of code can render a whole ICO vulnerable. Thus, the potential risk that needs to be faced may lead to new platforms and intermediaries, which then seek to provide certain security levels. By doing so, some benefits (e.g. lower transaction costs) will no longer be able to play out to their full capacity.

We have sought to demonstrate that ICOs have fundamentally reshaped the crowdfunding sector and have become a leading investment source for startup companies with a focus on technology or banking. Thus, ICOs have become more popular than traditional IPOs for tech startups in the Western hemisphere (EYGM Limited 2018) and have managed to exceed venture capital investments for blockchain and blockchain-related startups in both Europe and North America. This fairly recent development signals the massive potential to disrupt the market that can be expected in the next few years.

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9

Insurance Under the Blockchain Paradigm

Paolo Tasca

Background

Although the origin of insurance is shrouded in obscurity, it is commonly assumed that the adoption of insurance can be dated back to around the second millennium BC in China and Babylon, where people developed a mechanism to pay their creditors an additional fund in exchange for lenders' guarantee to cancel loan in case a shipment was lost at sea or robbed (Vaughan 1997). This original model has then gradually evolved into our modern form of insurance. Nowadays, insurance products are pervasive in our socio-economic systems. Property insurance, life insurance and accident insurance are just a few examples of insurance products that are part of our daily life and which provide various forms of risk protection. Essentially, insurance is a risk management tool provided by

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insurance companies to compensate specific damage, loss, illness or death in return by paying a certain amount of premium in line with the level of risk.

Insurance has allowed economy to face potentially serious problems. Empirical evidence suggests that the insurance industry contributes materially to the economic growth by improving the investment climate and promoting a more efficient mix of activities that would not be undertaken in the absence of risk management (Brainard 2008). This contribution is magnified by the complementary development of banking and other financial services.

However, the insurance industry has been currently facing some important challenges. In a 2017 PwC annual report, insurers were asked to list the major challenges and hindrances they were currently facing (PricewaterhouseCoopers 2017). As shown in Fig. 9.1, apart from talents that are related to human capital, all the other challenges can be related to technology: data storage and privacy, IT security, digital identity and new business models.

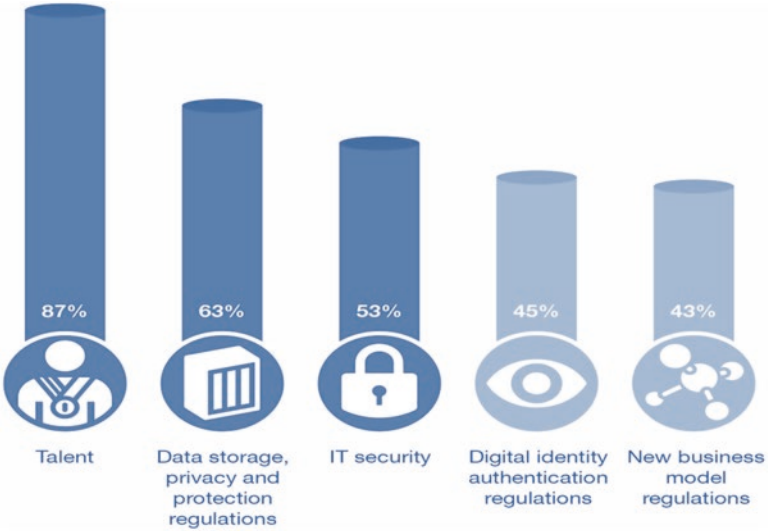

Fig. 9.1 Challenges faced by current insurance industry

At the same time, emerging technologies like blockchain can potentially empower the insurance industry with new tools to redesign products and business models. Thus, technology-related challenges can be somehow addressed by blockchain-enabled solutions. If these new properties provided by blockchain can be combined together, it will be very beneficial for the insurance industry.

In the next section, the properties of blockchain technologies are introduced and their impact on the insurance industry is analysed. For the sake of simplicity, we will refer to blockchains or blockchain technologies as distributed ledger technology (DLT) in order to encompass all the possible architectural configurations and also the larger family of distributed ledger technologies, that is community consensus-based distributed ledgers, where the storage of data is not based on chains of blocks (see e.g., Dag-based systems like IOTA or General Byzantine fault tolerance systems like Ripple).

Blockchain Applied to Insurance

Blockchain is a mutualised multi-master state machine replication system. It enables new forms of distributed software architecture where agreements on shared state for decentralised and transactional data can be established in a network of peers. The states are recorded in the ledger or "book", which record all related data happening on blockchain. Blockchain enables to achieve a consensus between peers connected in a network, even in the presence of anonymous peers which could be unreliable and potentially malicious. Nevertheless, even in the presence of malicious nodes, the system can still run and achieve consensus on share state of data (Nakamoto 2008).

Peers hold a replica of the data that is append-only and updated with one-way hash function encryption.

The analysis and interpretation of blockchain can be achieved by digging into its different properties and characteristics. Essentially, the blockchain relies on five key drivers, which represent five dimensions. For each of them, this chapter will explain how they can impact the insurance industry, respectively (see Fig. 9.2).

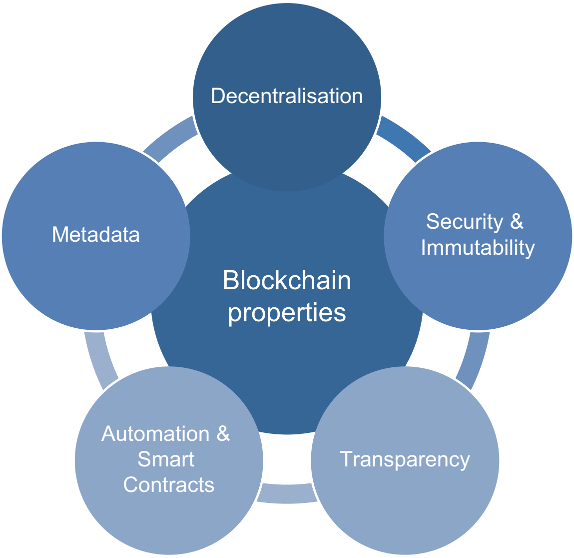

Fig. 9.2 Drivers of the blockchain technology

Decentralisation

The distributed nature of the network requires unreliable nodes to reach consensus. The decentralised consensus protocols govern the update of the ledger with the transfer of responsibilities of transaction validation and verification from central to local nodes. There is no integration point or central authority required to both approve transactions and set rules (Glaser 2017). Therefore, decentralisation can be interpreted as a non-single point of trust, control or even failure.

In order to elaborate the meaning of decentralisation in insurance industry, it is necessary to understand the nature of insurance itself at first. What can blockchain decentralisation bring to the insurance industry? The insurance industry by definition is the business of centralised risk pooling. Insurers collect risks from the market and they centralise it because they are able to hedge the risk across a large pool of events. In so doing, insurance companies can lower the risk.

Decentralisation can give control on the premiums back to the insurers, who can pool risks via the so-called P2P insurance. Indeed, the P2P insurance model existed before blockchain, and it is a practice in which a group of associated or like-minded individuals pool their premiums together to insure against a risk. In truth, there is no need for them to use blockchain technology, but thanks to it this type of insurance can gain several advantages. P2P insurance models can exploit the benefits of decentralisation by allowing every member to put in their premium an escrow-type account only to be used if a claim is made. At the end of the year, if the amount of the loss is not bigger than the amount of the total premium, then the remaining amount (eventually nominated in cryptocurrencies) in the escrow account will be automatically returned to the policyholders. An example of this model is called Teambrella (https://teambrella.com/), which offers this type of P2P blockchain solutions in insurance markets where a group of people does not have the costs of an insurance company and they keep 100% of the money if there are no claims (Paperno et al. 2016). In this case, we can say that blockchain technology rather than changing the nature of insurance (risk management to protect against financial losses) is more prone to improving the collaborative consumption process in the insurance industry with the scope of reducing overhead costs, increasing transparency, reducing inefficiencies and especially reducing the inherent conflict between insurers and their policyholders at the time of a claim.

Another benefit stemming from decentralisation is given by the fact that blockchain allows the end users or the policyholders to keep control of their own data, such as records, identity or even their healthcare data (Liu 2016; Zyskind and Nathan 2015). This customer-controlled data is not stored in a centralised server that can be easily hacked. Meanwhile, this data is not directly stored on blockchain either. The use of hash pointers can help customers to retrieve their personal information with no concerns about security. Thus the users can gain access to the insurer's data, which is encrypted and can be recovered from the ledger with the help of hash pointers. These pointers allow counterparts to extract location and information of data in the data structure of the blockchain, which is the Merkle tree. We can say that the concept of digital identity is similar to the concept of giving back control of the data to the end users, in this case to the policyholders. Having direct control of data and the need to set unique identifiers and attributes for a user enables the unique identification of the user in a specific context. In perspective, this can bring to a global ID system assisted by blockchain to be applied globally for different use cases, such as self-sovereign identity for individuals, legal entities, things (IoT & objects) and processes.

Another benefit stemming from blockchain decentralisation is the possibility to create valid meta-reputation scores across different on-chain platforms. Along the course of our evolution, humanity has developed sophisticated concepts of trust, relationships and communication. As our society becomes increasingly digital and data-driven, we need to develop similar digital skills to manage the risks in our digital interactions. In this context, we have to train new skills for trusting (which is a risk decision) and understanding each other. With regard to this, trust can be provided by community-based reputation systems rested on transaction-based feedback mechanisms. Over time, members of the platform will develop a feedback profile, or reputation, based on other people's comments and ratings. Blockchain can decentralise this process by offering an automatic way to generate trust between people, who do not know or trust each other, by preserving truth about records and transactions. This will give individuals incentives to be diligently trustworthy because their reputation in one platform will depend on their behaviour among many others. Moreover, people can benefit from different on-platform service providers by using the same credentials. Thus, they can create and build their credit scores and risk profile that can be used in the insurance market in the long term without the need to start from scratch every time they change to another platform. They can use the reputation scores gained in other platforms and they can import them into their new system. In this way, it is possible to exchange meta-reputation scores across different platforms to be used for different insurance products which sit on top of different platforms. This mechanism also favours limitation or prevention of moral hazard for policyholders. In fact, they are somehow forced to behave in a trustful way because any misconduct in one platform will be reflected in bad scores also in other platforms where the users interact.

To sum up, this system potentailly generates an overview of users' risk scoring at a global scale.

Security and Immutability

Blockchain is a shared, tamper-proof replicated ledger where records are irreversible and cannot be forged thanks to one-way cryptographic hash functions. Although security is a relative concept, we can say that blockchains are relatively secure because users can transfer data only if they possess a private key. Private keys are used to generate a signature for each blockchain transaction a user sends out. This signature is used to confirm that the transaction comes from the user and also prevents the transaction from being altered by anyone once it has been issued. Blockchains work under the principle of non-repudiation and irreversibility of records (Mainelli and von Gunten 2014). Furthermore, they are immutable because once data has been recorded in the ledger, it cannot be secretly altered ex-post without letting the network know about it (data is tamper-resistant). On the other hand, from a governance perspective, immutability is never fully realised. There are several examples where the Bitcoin community had reverted Bitcoin blocks based on community decisions, like Bitcoin and Bitcoin Cash and Ethereum and Ethereum Classic (Javarone and Wright 2018). The division between Ethereum and Ethereum Classic and later between Bitcoin and Bitcoin Cash and Bitcoin Gold is not purely anecdotal evidence: they are strong indicators of the importance that the governing body—even if informal—ends up having on the information eventually stored in the blockchain. What does it mean in terms of security and immutability of records for the insurance company? Since everybody in the system can share the same source of data, which is secured in a tamper-proof ledger, the risk of having duplicated or wrong information is eliminated. The benefit here is that blockchain provides proof of how and by whom every piece of data has been assessed. Instead, in our current off-chain world, the access to the data is difficult, fragmented and heavily manual and it is impossible to understand who access the data and when. However, in blockchain this process of tracking becomes simple. The security and immutability of data increases the trust on counterparts. Translated into practice, this means that users can give decentralised proof of any document that cannot be modified by a third party. The fact that any attempt to manipulate the records is detected and blocked, it represents a powerful embedded anti-counterfeiting mechanism that protects the integrity of the documents uploaded by policyholders and insurers along all the insurance claim process. Together with the security aspects, immutability brings operational simplification by eliminating the need for reconciliation and by providing a single historical version of the truth for everybody to follow. Indeed, conflicts because of disagreement on the value of the contracts or claiming processes can often happen in the off-chain world. However, in the on-chain insurance world, data on transactions can be recorded permanently with a timestamp, which could not be altered ex-post. This reduces operational risks and eliminates the need of "specialised" auditors.

Transparency

Records are auditable by a predefined set of participants, albeit the set can be more or less open. The governance structure determines the authorisation and the control policy management functions (Tasca and Tessone 2018). For example, in public blockchains everyone with an Internet connection to the network holds equal rights and ability to access the ledger. The records are thus transparent and traceable. Moreover, participants to the network can exercise their individual (weighted) rights (e.g., measured in CPU computing power) to update the ledger. Participants have also the option to pool together their individual weighted rights.

This type of transparency in the ledger can bring some benefits, including the fact that the claim process can be transparent and auditable all the time. Moreover, since the information is shared in the same ledger, it eliminates the imbalance of information between market participants. So if there is inconsistency between copies and contracts or between values of assets, there is always one single evident, transparent true source of information, which is recorded in the ledger.

Moreover, the transparency of the data is fundamental to protect the insurers' right to subrogate or go after the assets of others to recoup their losses, especially when they are asked to insure assets in developing countries. In fact, when there is a loss the insurers need to recover it by chasing the assets or by tracking the chain of the assets. If the asset is not in the blockchain, it is difficult to know who the legitimate final owner of the assets is. So, bringing assets onto the blockchain will bring also transparency along the value chain, which helps the insurers to be protected from frauds or diversion of assets and funds.

Finally, blockchain transparency can favour the cooperation between insurance companies, customers and regulators/supervisors in the insurance market (Nath 2016). Automatic compliance on blockchain will become possible where legacy platforms of insurers and regulatory agencies will be capable of feeding data directly into and extracting data from distributed ledgers for continuous auditing, AML/KYC verification and automated tax filing. In this manner, compliance officials can maintain a real-time view of asset transaction history (value, ownership, risk position) to assist in the enforcement of regulatory control limits.

Automation and Smart Contracts

Blockchains embed an automatic dispute resolution that can prevent conflicting and double transitions to be recorded in the ledger. Any conflict is automatically reconciled, and each valid transaction is added only once (no double entries). Moreover, automation regards also the development and deployment of smart legal contracts or smart contract codes. In conjunction with the other blockchain properties, automation brings several benefits: (1) it facilitates the automatic verification of policyholders, identity and contract validation; (2) it allows to automate operations in the P2P insurance market; (3) it disintermediates the use of external verification/arbitration entities established to solve disputes, and it eliminates the need for reconciliation (in fact, if there is an automatism that prevents the information asymmetry along the value chain, then there is no need for any type of reconciliation over the time because the information is the same); and (4) it shortens the settlement and reconciliation time that in the traditional off-chain world can be very long (in some complex cases, it can even last for some years).

Smart contracts are probably the most important aspects of blockchain applying to insurance. A smart contract is a type of legal contract that can self-execute, self-enforce, self-verify and also self-limit the contractual performance. They can be combined to create decentralised applications and decentralised autonomous organisations (DAOs). A smart contract is a mechanism involving digital assets and two or more parties (Underwood 2016). According to the terms, assets are automatically redistributed among the parties by following a specific formula based on certain data that is not known at the initial time of contract. If you transfer an insurance contract to a smart contract, then you can achieve many benefits with respect to the enforcement of specific contract rules. In this case the use of "oracles" is necessary in order to automatically verify the correctness of the events matching contractual conditions. Oracles are digital or phisical agents that live outside smart contracts but are linked to them as they provide information, they automatically verify the correctness of events and they trigger the clauses of smart contracts. Different use cases can be applied to insurance. For example, if a field is on fire or simply the temperature is higher than expected, the products of the farmer will be damaged. In order to protect the policyholder, the oracle can certify that exactly on that day, time and geographical area the temperature reached a given threshold according to which the contract will automatically reimburse the farmer for the losses. Meanwhile, smart contracts in the insurance domain can be used to enforce contract-specific rules (e.g., in car insurance, a smart contract can ensure that the claim is only paid out if the car is repaired in a pre-agreed garage) or to amplify the automation property by speeding up claim handling (e.g., travel insurance and life insurance). This last example is remarkably important if we think that in the US there is approximately $7.4 billion in unclaimed life insurance money from insured people passing away and their beneficiaries being unable to connect the dots. They just simply do not know what to do and how. With smart contracts, all these processes could be simplified.

An interesting extension of smart contracts could be the creation of a decentralised autonomous P2P insurance community. In this context, users could insure each other by creating an ecosystem, which is controlled neither by any insurance company nor by any platform but by a DAO: a sort of blockchain-based mutual insurance "company" owned entirely by its policyholders. The DAO would be set up as a set of smart contracts linked together. This would be a decentralisation of the current P2P centralised platforms that we have seen emerging in the insurance market. The DAO will decentralise the decision-making process. It will automatically select the best insurance policy by changing between suppliers according to users' behaviour, price and their appetite for risk. This would eliminate: (1) conflicts between a traditional insurer and a policyholder when an insurer keeps the premiums that it does not pay out in claims (this is already done in P2P insurance centralised platforms, but there is still a certain degree of subjectivity by the managers or the platforms), (2) moral hazard and the problem of insurance coverage (i.e., insurers could cover lower amounts to prevent moral hazards by policyholders).

We can conclude by saying that the use of smart contracts will be pervasive in the next years because the emerging ecosystem of interconnected industry 4.0 will bring us to the so-called hyper network of (industry and user) devices connected all together and all the time to exchange data and value. Also the insurance companies will be interconnected together and with other different industries to collect and process more and better data that will be used to improve their internal risk models.

Metadata

The last interesting aspect of blockchain is metadata, that is the capacity to store extra data on the chain. The storage space available on blockchain networks can be used for the storage and exchange of arbitrary data structures (Calvaresi et al. n.d.; Davidson et al. 2016). The storage of the data can have some size limitations, which are placed to avoid the blockchain bloat problem. For example, metadata can be used to issue meta-coins (second-layer systems that exploit the portability of the underlying coin used only as “fuel”). Any transaction in the second layer represents a transaction in the underlying network. Alternatively, the storage of additional data can occur “off chain” via a private cloud on the client's infrastructure or on a public (P2P or third-party) storage. Some blockchains like Ethereum allow to store data also as a variable of smart contracts or as a smart contract log event.

This blockchain capability is very powerful as it allows storing any kind of extra information: it can be a digitalised version of assets, and it can be a land certificate, commodities or security, to name a few. This means that on the top of P2P networks, we can build other networks where a digitalised version of real assets can be transferred. Whatever happens in the underlining network, it is also reflected upstairs on the top network. This is the role of metadata in the blockchain.

In insurance, the use of metadata can increase fraud detection and improve the principle of trust. Moreover, it can be used to validate authenticity, ownership and provenance of all goods and assets as well as authenticity of documents (e.g., medical reports).

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[1] Note: Page numbers followed by ‘n’ refer to notes.

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