Blockchain and Other Distributed Ledger Technologies in Finance

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1 Introduction

A blockchain is a form of distributed ledger technology (DLT). Although this technology has grown in prominence, its full potential in terms of practical financial applications and academic research is not completely understood. Blockchain technology was first implemented in 2008 as the underpinning of Bitcoin, which was the first cryptocurrency—a new concept at the time. What started as an esoteric idea to merge elements of finance, game theory, cryptography, and computer science has attracted mainstream attention in the last few years. For example, a study of Google queries from 2008 to 2018 for the word blockchain were rare before February 2013, but their frequency increased gradually until they peaked in December 2017. The pattern in the PRC has been similar, although the number of Baidu searches for the term blockchain peaked a bit later, in March 2018. Naturally, academic interest has followed a similar trend. A review of the number of studies

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of blockchains indexed by Google Scholar every year since 2008 (across all fields). Figure 1 shows that the number has exploded since 2015. Money has also followed a similar trend. According to Coindesk, the increase in investment in blockchain projects slightly predated the popular interest but, the pattern of investments in blockchain ventures also shows a similar pattern.

Although many sectors take a keen interest in blockchains (and other DLTs), at the time that we are writing this chapter, the fall of 2018, supply chain management and financial applications are the most common applications of blockchain technologies. Babich and Hilary (2019a, b) review the application of DLTs to operations (and more generally to enterprise applications) and the research opportunities for academics in that field. They note that fully deployed applications are still rare and many projects fail, but proofs of concepts (PoCs) are becoming increasingly prevalent in the fields of application.

At its core, a blockchain is a new database technology. We elaborate more on its technical details later, but we first consider its strengths and weaknesses. Babich and Hilary (2019b) identify five positive traits of DLTs (see Table 1): *visibility, aggregation, validation, automation, and resiliency.*

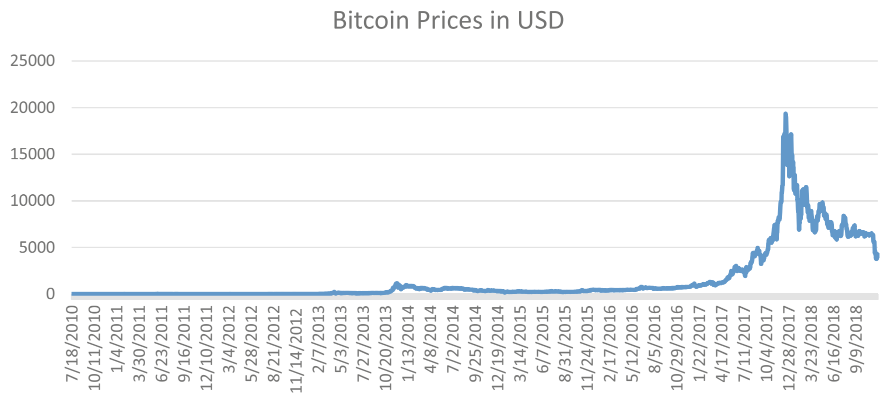

Fig. 1 Bitcoin prices

Table 1 Strengths and weaknesses of blockchain technology

Blockchain strengths	Blockchain weaknesses
Visibility	Lack of privacy
Aggregation	Lack of standardization
Validation	Garbage in, garbage out
Automation	Black box effect
Resiliency	Inefficiency

Visibility is the ability of network participants to follow information through a series of transactions. Aggregation ensures that the information in a blockchain can originate from a variety of sources: firms, customers, regulators, and smart sensors. Validation refers to the fact that information captured in a distributed ledger is difficult to tamper with. Automation is the ability to execute certain transactions automatically in response to pre-specified conditions. Resiliency is the feature whereby an entire blockchain database can withstand certain shocks (physical shocks, in particular) better than traditional databases can (see Hilary 2018, 2021 for a review of security issues).

However, Babich and Hilary (2019b) are quick to point out that those advantages are balanced by five corresponding weaknesses: *lack of privacy*, *lack of standardization*, the "*garbage in, garbage out*" (GIGO) problem, the *black box effect*, and *inefficiency*. Lack of standardization stems from the fact that a blockchain is not a unique technology but an umbrella describing a portfolio of protocols that are not yet stable and fully integrated. That lack of standardization can be an issue for financial institutions that for legal reasons must keep their records for decades. Lack of privacy stems from the difficulty in erasing data in blockchain networks; this may make compliance with privacy regulations difficult. The black box effect for blockchains refers to the fact that a blockchain can remove the need to trust a counterparty in some circumstances but at the same time requires "meta-trust" in the blockchain concept. For example, retail investors and regulators need to trust the integrity of the process without necessarily understanding the technical underpinnings. Blockchain inefficiency stems from current limitations in the technology. The GIGO problem stems from the fact that a blockchain is only as good as the information recorded in it. Paradoxically, the difficulty with modifying blockchain data may also make the correction of errors more arduous.

The financial world has applied blockchain technology in at least three main domains (and more applications may surface in the future): (1) the trading of crypto-assets that are standardized and treated like quasi-currencies, (2) the development of mechanisms to raise money by tying the crypto-assets to underlying assets, such as cash-flow rights, and (3) operational functions, such as mechanisms to transfer and store documentation. For example, HSBC Holdings realized the first trade finance transaction using a blockchain by issuing a letter of credit to Cargill in 2018.[1] The development of DLTs may impact operational activities such as custody, compliance

[1] https://www.cnbc.com/2018/05/14/hsbc-makes-worlds-first-trade-finance-transaction-using-blockchain.html.

(e.g., know your customer [KYC] procedures), or correspondent banking. However, whether and when these back-office tasks can be transferred to a DLT platform remain open questions. For example, in 2018, SWIFT released the results of a PoC in a sandbox environment that allowed the functional transfer of information. However, the report highlighted numerous issues that needed to be solved before the pilot could become fully operational in a real-world setting. Although operational aspects are economically important, we largely ignore them in this chapter because the topic is typically not the focus of academic finance research.

The rest of this chapter proceeds as follows. The second section focuses on the blockchain technology itself and the technical aspects of its first application, Bitcoin. The third section examines the issuance of crypto-assets. We start with cryptocurrencies (and their impact on monetary policy), move to initial coin offerings (ICOs), and finally discuss the issuance of other crypto-assets that are backed by a wide range of underlying assets. The fourth section analyzes the post-issuance behavior of crypto-assets. We explore market integrity, market efficiency, and market microstructure issues. The fifth section considers the token economy. We present our conclusions in the sixth section.

2 What Is a Blockchain?

2.1 The Technology

Blockchain was first introduced in 2008 as the technology supporting Bitcoin, the first successful virtual currency system that eschewed a central authority for issuing currency, transferring ownership, and confirming transactions (see Hilary 2021 for a discussion of the technology). Since then, blockchains have found many applications beyond their initial purpose and many different versions have been implemented. A blockchain is a new form of database technology known as a "distributed ledger." Traditional centralized databases hold only one master version at any given time. In contrast, a distributed database (as opposed to a distributed ledger) involves multiple nodes (computers) that cooperate under one umbrella to maintain the integrity of the database should one of the nodes fail (for example, experience a hardware problem). However, this approach assumes that no node will alter or manipulate content. That feature is known as "fault tolerance."

Distributed ledgers (such as blockchains) replicate the database, meaning that each node has an active copy. These versions can temporarily diverge from one another, but the technology constantly ensures that the different versions converge to a consensus version. A DLT such as a blockchain addresses the possibility that nodes may generate arbitrary data while posing as an honest actor. In other words, they remove the need for nodes to trust each other. However, this feature requires trust in the technology itself and its correct implementation. The goal is for the system to be "Byzantine fault-tolerant," which is the ability to handle component failure when there is uncertainty about the behavior of any component and its possible failure.

Distributed ledgers can either be decentralized (granting equal rights, within the protocol, to all participants) or centralized (giving certain users particular rights). A blockchain is a specific form of distributed ledger that has a specific data structure, but other forms of distributed ledgers exist. Blockchains can be either public or private. Everyone can join a public blockchain, but participants in a private blockchain must be vetted. Most cryptocurrencies (e.g., Bitcoin) are based on a public blockchain, whereas many enterprise applications rely on private blockchains.[2]

2.2 The Bitcoin Example

Bitcoin was the first public blockchain (see Harvey 2014, 2016 for an early introduction to the crypto-currency and crypto-finance, and Böhme et al. 2015 for an early economic analysis of Bitcoin). Bitcoin enables a distributed digital ledger to record transactions between two parties in a verifiable and permanent way. Bitcoin's blockchain is essentially a combination of peer-to-peer software with a public key cryptographic tool. The blockchain contains two kinds of records: transactions and blocks. Blocks hold batches of valid transactions and the additional information necessary for the system to work. To perform this validation, nodes use specific algorithms. These blocks are ordered in a single chain that is replicated over the entire network. Once verified, the transaction is combined with other transactions to create a new time-stamped block of data for the ledger. The new block is then added (by consensus) to the existing blockchain in a way that is meant to be (largely) unalterable. Many of the features present in Bitcoin are common to other distributed ledgers, but most of them (e.g., pseudo-anonymization, traceability, auditability, and immutability) are not intrinsic characteristics of distributed ledgers.

[2] Blockchain applications adopted and managed by a select group of enterprises are sometime called "consortium blockchains."

The current consensus mechanism in the Bitcoin blockchain uses the proof-of-work (PoW) approach to stamp blocks. In that approach, the Bitcoin blockchain determines the order of the blocks by using a mathematical "lottery" that is based on solving a mathematical problem (a "cryptographic hash"). The node (or "miner") that first completes the block can add it to the consensus. However, solving the hash function problem is costly, requiring, among other things, computer time, bandwidth, and electricity. To incentivize miners to incur these costs, the first node that solves the problem (and thus adds a block to the chain) receives a financial reward in the form of newly minted Bitcoins. However, Hinzen et al. (2019) point out some of the economic limitations of the PoW technology.

Various blockchain platforms have made different implementation choices, each with its advantages and drawbacks. For example, an alternative consensus mechanism design may have lower costs but suffer from other technical issues. Public blockchains (and, to a lesser extent, private blockchains) currently face performance and scalability issues. Bitcoin, for example, can handle approximately seven transactions per second (usually fewer), whereas VisaNet can allegedly handle up to 65,000 transactions per second.[3] Other DLTs offer the possibility of greater scalability but have not yet been extensively deployed and tested. Chiu and Koeppl (2017) and Huberman et al. (2017) find that the current Bitcoin system generates a large social welfare loss, and they explore ways of mitigating that cost.

2.3 Smart Contracts and Tokens

Records in blockchain databases can contain any number of elements, including executable software often called "smart contracts" that can facilitate, verify, or enforce the negotiation or performance of a contract. However, "smart contract" is often a misnomer because self-executable sets of instructions (i.e., lines of codes) will not typically create legally binding contracts.[4] By allowing the addition of redacted materials to its database, Corda, a blockchain platform commonly used in financial applications, increases the likelihood that a contract integrated on its platform will be legally binding.

Relatedly, the elements contained in the database may lead to "tokenization," which is the process of converting rights to an asset into a digital token (or record) on a blockchain. Bitcoins and other cryptocurrencies are types of

[3] https://usa.visa.com/dam/VCOM/download/corporate/media/visanet-technology/aboutvisafactsheet.pdf.

[4] Smart contracts are called « chain codes » in the Hyperledger environment.

tokens. However, other assets can be similarly tokenized. The tokenization process can, for example, facilitate the trading of illiquid assets and enable micropayments. Tokenization enables an ICO, a financial mechanism that takes advantage of blockchain technology to raise funds.

3 Crypto-Asset Issuance

A DLT facilitates the issuance of different types of assets. In this section, we discuss several cases.

3.1 Cryptocurrency Issuances

As already noted, Bitcoin was the first cryptocurrency. The concept paper was published in 2008, but the first coin was not created until 2009. The first transaction occurred in 2010.[5] The volume of bitcoin transactions gradually increased until it peaked in late 2017 at more than 400,000 per day; it has since declined to fewer than 250,000 transactions per day (as of the fall of 2018). The price of a bitcoin increased from an initial value close to zero to a historic high of nearly 20,000 USD in late 2017, but by autumn 2018, it had fallen back to less than 4000 USD. We show the historical price of a bitcoin in Fig. 1.[6]

By 2011, other cryptocurrencies had started to appear, using alternative technologies that provided different features. For example, some (e.g., Monero) offer enhanced privacy to execute transactions. By autumn 2018, more than 2000 cryptocurrencies existed. On October 8, 2018, the website coinmarketcap.com indicated an overall market capitalization of the 2042 listed currencies as amounting to 221 billion USD (115 billion for Bitcoin and 23 billion for Ethereum, the second most valuable cryptocurrency). In comparison, the market capitalization of Apple during the same period was approximately 1000 billion USD. Vietnam and Portugal each had GDPs of approximately 220 billion USD in 2017.

The development of cryptocurrencies is creating new policy challenges and opening new areas for research. Most tokens can only be redeemed within their own ecosystem (e.g., FileCoin).[7] In contrast, cryptocurrencies such as Bitcoin represent a special type of crypto-asset: owners can exchange them

[5] https://www.cnbc.com/2018/06/18/blockchain-what-is-it-and-how-does-it-work.html.

[6] We obtained the Bitcoin price data from Coindesk.

[7] FileCoin tokens are used to create a storage marketplace. Users pay storage providers for the service with FileCoins. https://medium.com/swlh/filecoin-and-ipfs-f5e84ae79afa.

for other products or services outside their own blockchain.[8] However, even if most crypto-assets do not aim to reach this level of acceptance, they can still be a substitute for fiat money within their own ecosystem. That substitution can be problematic for monetary authorities. For example, Hendry and Zhu (2017) model the coexistence of fiat money and cryptocurrencies and allow the use of both types for different kinds of transactions. Their model shows that the existence of cryptocurrencies can restrict the monetary authorities' ability to control inflation and raises concerns about monetary policy coordination.[9]

Perhaps in response to those concerns, several countries, including the PRC, are considering the possibility of using a digital currency backed by central banks (a central-bank digital currency, or CBDC). Such bank-backed digital currencies are fundamentally different from decentralized cryptocurrencies such as Bitcoin because they benefit from the full support of central banks and are directly controlled by those institutions.[10] A CBDC may play a role in mitigating the zero lower bound issue in interest rate adjustment (Haldane 2015). However, they can create a multiplicity of other problems. For example, Keister and Sanches (2018) analyze a situation in which a CBDC and a private bank's deposits coexist in the marketplace. They find that the introduction of a CBDC often raises general economic welfare but crowds out the banks' deposits and investment. At this time, we do not fully understand the consequences of cryptocurrency development for macroeconomic policy (e.g., optimal monetary policy), if any. These issues offer interesting avenues for research.

3.2 Initial Coin Offerings

As we discussed above, a token is an "object" (or a record) associated with certain rights. Economic agents can exchange tokens to transfer those rights between parties. That process allows for the possibility of ICOs, which are a new method to raise capital. ICOs first appeared in 2014, but there were very few before 2017 (e.g., Giudici et al. 2018). Momtaz (2018a) indicates that the volume of funds raised in ICOs represented 6 billion USD in 2017,

[8] Several companies, including Overstock, take Bitcoins as payment. In August 2018, a company listed on Austrian Securities Exchange, CCP Technology, issued shares to Singapore-based Penta Global Blockchain Foundation, taking a cryptocurrency, PNT, as payment.

[9] In a working paper, Lee and Xiao (2018) model how fiscal policy and monetary policy can affect investors' portfolio choices when investors can hold cryptocurrency to circumvent capital control regulations.

[10] The PRC's central bank had filed more than 60 patent applications related to digital currencies as of late 2018.

approximately a fifth of the amount raised in initial public offerings (IPOs) that year. Bourveau et al. (2018) identify 750 ICOs from April 2014 to May 2018 collectively raising 13 billion USD for organizations from 50 countries. Some ICOs are large and skew the distribution. For example, Telegram was able to raise $1.7 billion, but that amount is exceptional. The vast majority of ICOs are much more modest. For example, Momtaz (2018a) finds that the median amount of money raised in an ICO is less than 6 million USD.

After announcing their decisions to offer an ICO, ventures typically issue a "white paper" describing the technology, the product, the team, and the strategy. The white paper typically states a minimum amount necessary for the ICO to be fully executed, and it may include a maximum amount. Bourveau et al. (2018) mention that in their sample, approximately 85% of ICOs were successful. Investors tender fiat money or crypto-money in exchange for the tokens. Lu (2019) shows that issuing cryptocurrency-denominated ICOs may lead to mispricing as investors improperly associate the fundamental value of the token with that of Bitcoin.

Importantly, the ICOs can be preceded by several rounds of private token issuances. The rights associated with the tokens vary. They can be very similar to stocks, give rights to products (in this case, the tokens are often called "utility tokens"), or, in principle, be any combination of rights that are legally enforceable (e.g., a discount on the price of future shares or products). Giudici et al. (2018) report that only a quarter of ICOs in their sample offered cash flow and governance rights. Interestingly, Giudici et al. (2018) note that 16% of the ICOs offered the opportunity to determine the characteristics of the product/service to be offered (contribution rights). Unlike IPOs, ICO firms do not use an underwriter to help determine the value of the tokens and attract buyers. They may use "advisers"—individuals who publicly endorse the organization but often provide little actual technical advice. Once the process is completed, the tokens are listed on various online platforms (e.g., Bitfinex) and often appear on multiple ones. However, Montaz (2018a) indicates that approximately 13% of ICOs are subsequently delisted from all platforms. He also indicates that the average time from project initiation to the ICO start is 598 days, with a median time of 312 days.

The regulation of these ICOs is currently relatively fluid and varies across jurisdictions. However, the view that ICOs are unregulated is incorrect, at least in major jurisdictions. For example, the United States Securities and Exchange Commission (US SEC) issued a series of pronouncements in 2017 and now holds the view that most ICOs are securities offerings and should be regulated as such.[11] In November 2018, the US SEC announced settled charges against two companies that had sold digital tokens in ICOs. These are the commission's first instances of imposing civil penalties solely for registration violations of ICO securities offerings.[12] Switzerland classifies tokens into three categories: payment (currency) tokens (which are not regulated), asset tokens (which are considered securities), and utility tokens (which are unregulated only if the platform/product behind them is already functional).[13] As of October 2018, both France and the European Union (EU) were considering a specific form of regulation for ICOs.[14] In 2017, the PRC banned individuals and companies from raising funds through ICOs. Hong Kong allows ICOs but imposes de facto regulation.[15]

ICOs offer a new mechanism for raising capital that is distinct from other options, such as going through an IPO on a leading exchange, listing on an over-the-counter (OTC) market, using a crowdfunding platform, receiving funds from a venture capital (VC) funding, and other forms of private financing. However, ICOs are substantially different from VC funding in that there is no bilateral discussion with a supplier of capital; rather, ICOs attempt to raise funds from multiple capital suppliers. For example, Giudici et al. (2018) report an average of 4121 contributors (with a median of 2394) in their sample of ICOs. Chod and Lyandres (2018) compare the use of an ICO with traditional VC financing. They show that ICOs can facilitate risk-sharing between entrepreneurs and investors without transferring control rights, but that such activity may cause underinvestment.

In contrast, IPOs, at least in major jurisdictions, represent a highly regulated activity that often involves large sums of money. Although the situation might change in the future, firms currently engaging in ICOs are very different from those typically engaging in IPOs on a large exchange. As noted above, ICOs (with a few exceptions) involve small ventures. Indeed, many of them do not have revenues or even a finished product to sell.[16] Amsden and Schweizer (2018) cite an Ernst & Young (2017) study reporting that only 5% of ICO ventures had running projects, 11% had prototypes, and 84%

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[11] https://hackernoon.com/united-states-ico-regulation-9e2381dee202.

[12] https://www.sec.gov/news/press-release/2018-264.

[13] https://cryptovest.com/features/ico-regulations-by-country-a-global-coin-offering-regulatory-overview-may-2018/.

[14] https://cointelegraph.com/news/france-finalizes-new-ico-framework-to-attract-innovators-globally.

[15] https://cryptovest.com/features/ico-regulations-by-country-a-global-coin-offering-regulatory-overview-may-2018/.

[16] Signori (2018) notes that 15% of firms launching an IPO in Europe had no revenue prior to the IPO, but that population includes firms listed on secondary markets, such as the Alternative Investment Market (AIM), or on national markets with limited depth, such as Belgium or Denmark.

were merely ideas. However, the behavior of IPOs is well-researched and can constitute a benchmark against which the performance of ICOs can be evaluated. Indeed, Lyandres et al. (2019) point out empirical similarities between IPOs and ICOs. In a recent review of the IPO literature, Lowry et al. (2017) find that the short-term returns in the days following an IPO are consistently positive (close to 20%, on average). The long-term returns are more controversial, with the authors concluding that IPOs underperform the market as a whole but obtain returns comparable to those of similar firms. Studies of over-the-counter markets both in the USA (e.g., Brüggemann et al. 2017; Ang et al. 2013; Eraker and Ready 2015) and in the UK (e.g., Gerakos et al. 2013; Hornock 2015) are consistent with that finding and further suggest that firms do worse when they are listed on illiquid markets than when they are listed on the main markets. The firms have a low probability of graduating to the main market but a high probability of delisting. Returns for most firms are low, although some do spectacularly well.

Overall, ICOs are probably most similar to crowdfunded capital issuances. For example, the US SEC regulation A + , issued in 2015, allows small businesses and startups to raise to $50 million, which makes this population comparable to the ICO populations. In crowdfunding, entrepreneurs reach out to a potentially large number of investors on selected Internet platforms, such as Kickstarter or Indiegogo. As is the case with ICO investors, crowd-funders can be rewarded with financial compensation, with future products, or with the intrinsic rewards associated with charitable contributions. However, a key difference between crowdfunding and ICOs is that investors in an ICO are free to resell their tokens (upon completion of the lockup period), whereas there may not be a secondary market for financing done through a crowdfunding platform. Furthermore, large ICOs are not fundable through crowdfunding.

The literature on ICOs remains limited. To a large extent, it reproduces the findings of studies on IPOs. For example, preliminary findings suggest that the ICO market behaves like other illiquid and weakly regulated markets. Giudici et al. (2018) report a first-day average return of 930% (with a median return of 25%) for a sample ending in mid-2017. Bourveau et al. (2018) indicate that the median return on the first day is 6% (with a mean of 14%) for a sample ending in mid-2018. Momtaz (2018a) finds similar estimates for the mean (7 to 8%) and a lower number for the median (3%), although he finds an average underpricing of 15% using a larger sample (Momtaz 2018b). Benedetti and Kostovetsky (2018) reach a similar conclusion with larger point estimates (14 to 16%, on average). Long-term returns are always more difficult to estimate than returns over brief periods. This is particularly true for illiquid markets with a short history. Nevertheless, Bourveau et al. (2018) report a mean return of +39% for ICOs over the first month of trading, but a median of −30%. Momtaz (2018b) reports that although the mean return remains significantly positive over a longer period, investors withholding periods of one month to two years lose approximately 30% from investing in the median firm. Smaller firms outperform larger firms. First-day returns are negatively correlated with long-term returns.

Academic studies have shown that in nearly every market, issuances of capital are more successful when there are more transparency, better governance, higher-quality "guarantors" (e.g., VCs, auditors), and stronger regulations.[17] Giudici et al. (2018), Amsden and Schweizer (2018), Bourveau et al. (2018), and Howell et al. (2019) use multiple proxies to provide evidence for similar patterns in the ICO market. For example, Bourveau et al. (2018) show that weaker information environments are associated with a higher risk of a stock price crash, illiquidity and volatility. Most projects financed by an ICO rely on the existence of a computer code to succeed. The transparency and quality of the code have been consistently shown to be an important aspect of ICO performance. In an interesting paper, Momtaz (2018c) shows that ICOs managed by executives who have a track record of being loyal to their employers fare better than ICOs without such executives. Somewhat relatedly, previous studies show a link between the decision to finance a crowdfunding project and geographic participants (e.g., Agrawal et al. 2015) or social ties (Kuppuswamy and Bayus 2018), but to our knowledge, researchers have not empirically investigated these relations for ICOs.

Indeed, documenting these stylized facts for a new and potentially significant financial market is useful. However, diminishing returns to scale are associated with such documentation. It would be more useful at this point to consider questions that can only be answered in the context of ICOs. For example, most ICOs occur before a product is actually designed, and 16% of tokens give the right to influence the proposed product. Even absent formal rights, the wisdom of the crowd can help to provide important information about future development. Strausz (2016), for example, explains in an analytical study how crowdfunding allows entrepreneurs to contract with consumers before investment. That study describes the tension between increased project screening and moral hazards, but the basic tension could also be analyzed in the context of ICOs. For example, it would be interesting

[17] See Yermack (2017) for a preliminary discussion of the governance issues associated with blockchains.

to analyze the effects of a secondary market and a smart contract on incentive structures. Providing empirical insights on the link between financial and product markets in the context of ICOs would also be relevant. Relatedly, although the vast capital-structure literature has considered the trade-off between equity and debt (with some interest in mezzanine financing), many ICOs provide a new type of instrument on which the cash flows are still contingent by offering rewards directly tied to products but are based on sales rather than on dividends (or earnings).

As discussed above, crowdfunding and ICO platforms offer many similar features but also display certain differences. For example, the seemingly more complex nature of DLTs relative to the more familiar Internet channels could draw or repel certain types of investors. Are there economic benefits and costs associated with one approach versus the other? For example, the open nature of the DLT technology may ensure a greater pool of investors in the secondary market. However, the centralized nature of the crowdfunding platform may give its owners incentives to behave as gatekeepers for removing fraud. In principle, ICOs could offer more liquidity in aftermarket trading, and identifying precisely how this liquidity would behave would be useful.

In addition to providing new research questions about the financing of new ventures, ICO markets offer possibilities for research on other topics. Naturally, that is contingent on their development, which remains somewhat speculative at the time we are writing this chapter. One such area is trade credit.[18] DLTs have the capacity to reduce the friction in supply chains (see Babich and Hilary 2019b). For example, smart contracts coupled with sensors can ensure prompt and guaranteed payments as soon as goods reach their destination. More traceable products and cash flows might allow firms to collateralize their accounts receivable more effectively and to receive payments from banks even faster—for example, through factoring. This faster collateralization can help firms reduce the need for working capital and can lessen the need to conserve cash on the balance sheet to buffer against unexpected delays in collection, which may also affect other dimensions of corporate behavior. For example, if firms do not have to worry as much about the risk of bankruptcy induced by working capital fragility, they may increase other aspects of corporate risk-taking (e.g., innovation).

A second potentially important area is the development of illiquid asset markets. The analytical literature (e.g., Ang et al. 2014; Vayanos and Wang 2012) has noted the importance of liquidity for asset-pricing in a portfolio context, but the ability to "liquefy" extends beyond thinly traded stocks. For

[18] Gelsomino et al. (2016) provide a review of the literature on supply chain finance.

example, new classes of assets (such as art, fine wines, and pollution quotas) could become mainstream investments if more effective trading mechanisms become available. As we note above, illiquidity and crash risks plague OTC markets. It would be interesting to analyze how the acceptance of blockchains by exchanges (e.g., the NASDAQ) could affect liquidity, trade efficiency, and ultimately price behavior. Another area of interest for analysis would be the development of internal markets. Distributed ledger technologies can provide a structure for efficiently trading thinly traded assets. One can imagine the trading of claims on internal projects (essentially internal ICOs) or the development of a trading platform for internal resources such as machine hours. Those sorts of trading markets would lead to more efficient use of internal resources.

3.3 Other Crypto-Assets

In addition to cryptocurrencies (which are typically not backed by any other assets) and ICO tokens (which are backed by a specific venture), other assets can now be traded through tokens. Indeed, anything of value can be associated with a token and traded on an exchange that is more or less organized. Examples include gold (e.g., HelloGold), oil (e.g., OilCoin), or even DNA (e.g., Nebula Genomics). In the midst of a devastating financial and economic crisis, Venezuela launched a cryptocurrency (El Petro) backed by national reserves of natural resources. The typical justification for creating these derivative assets is to lower the transaction costs associated with the trading of the underlying assets.

Recently, cryptocurrencies have been created that are backed by fiat money. The goal of these "stable coins" is to offer a relatively stable exchange rate to make the cryptocurrencies an electronic "unit of account" while preserving features of crypto-assets such as the possibility of executing smart contracts. As we noted above, the value of cryptocurrencies such as Bitcoin is very volatile. Tether, the most popular stable coin to date, claims to maintain 100% USD reserves as collateral to guarantee a one-to-one exchange rate pegged to the US dollar. Other stable currencies use alternative mechanisms to maintain the exchange rate. For example, they can over-collateralize other crypto-assets (e.g., DAI) or use another floating-rate cryptocurrency to adjust the supply of the stable coin (e.g., BaseCoin). Recently, the New York Department of Financial Services approved the issuance of two stable coins pegged to the US dollar (GUSD and PAX). The two companies backing those coins

(Gemini Trust and Paxos) obtained the endorsement after convincing the regulator that they would comply with stringent compliance requirements.[19]

Recent blockchain projects, such as Valid and GXChain, allow individuals to own and use the data they have generated. Individuals can then obtain compensation from companies that use their data. New technology, such as zero-knowledge proof combined with a blockchain, enables data sharing in a decentralized environment without revealing proprietary information.[20] That type of data sharing may lead to the distribution of a large amount of data and the creation of a new asset class. Recent papers have started to investigate the economic consequences of data ownership and sharing. For example, Jones and Tonetti (2018) build a macroeconomic model showing that the allocation of data property rights to consumers may provide a more efficient resource allocation. Easley et al. (2018) analyze the economic consequences of selling consumer data to oligopoly producers. They consider e-commerce settings with three players: a platform (e.g., e-Bay or Taobao), firms (companies that sell their products through the platform), and retail consumers. Their model shows that data ownership by either consumers or platforms can maximize social surplus, whereas firm ownership cannot because competition among firms will lead to suboptimal levels of data sharing.

Research on such alternative crypto-assets is limited (the modeling of the stable coin mechanism by Routledge and Zetlin-Jones, 2018, is an exception) but may be fruitful. For example, understanding how data assets are measured, valued, and shared would be interesting. More work will also be required if we are to understand the optimal design of a stable coin and the potential risks associated with different models.

4 Post-issuance Behavior

4.1 Market Integrity

Historically, unlike ICOs, cryptocurrency exchanges, and especially the coin-to-coin exchanges that do not take fiat money, have been largely unregulated. Criminals have used this new medium of transaction for illicit trading (e.g., Foley et al. 2018) and other criminal enterprises such as money laundering.[21]

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[19] For example, Griffin and Shams (2018) provide results suggesting that Techer's USD collateral may be less than 100% and find evidence consistent with this hypothesis. *Official endorsement may mitigate the risk of a similar problem for GUSD and PAX*.

[20] See Hilary (2018, 2021) for a discussion of the zero-knowledge proof approach.

[21] https://bitcoin.fr/ce-que-dit-tracfin-a-propos-de-bitcoin/.

However, that lack of regulation may be changing. China banned all crypto-exchanges in 2017. Japan had 16 licensed exchanges by autumn 2018, but fewer than 10 cryptocurrencies are allowed to be traded on those licensed exchanges. In the USA, the CEO of NASDAQ said in April 2018 that it would consider becoming a crypto-exchange in the future.[22]

Theft, fraud, and price manipulation affect the markets that remain unregulated, reducing their liquidity. For example, Coinmarketcap lists 225 token exchanges, but only 125 of them had a meaningful trading volume in 2018.[23] Li and Wang (2018) explore pump-and-dump schemes in several cryptocurrency exchanges. They demonstrate the benefits, in terms of liquidity and prices, of fighting those schemes, using the example of Bittrex, a trading platform.[24] One of the most famous theft cases was that of Mt. Gox, a platform that was the largest cryptocurrency exchange at the time (2014). After 450 million USD worth of bitcoins disappeared, Mt. Gox shut down. Other platforms (Cointrader, Bitcurex, and Youbit, to list a few) also shut down after falling prey to alleged cyber-hacks.[25] Furthermore, theft is not the only market integrity issue. For example, another large exchange, Binance, canceled suspicious trades following a cyber-hack of the platform.[26] One of the largest token exchanges, OkEx, canceled a series of Bitcoin future trades that followed a coordinated market manipulation.[27] An analysis of transactions from Mt. Gox, Gandal et al. (2018) finds that the suspicious trading activity of a single actor caused massive spikes in Bitcoin's price and trading volume. Griffin and Shams (2018) investigate the trading activity of the stable coin Tether. They show that large Bitcoin purchases with Tether follow market downturns and precede subsequent increases in Bitcoin prices. They report that 50% of the return from Bitcoin and 64% from other top cryptocurrencies are concentrated in 1% of the periods with heavy Tether transactions.

The academic literature has thoroughly studied the market structure of established markets (e.g., Easley and O'Hara 1995) and price manipulation in

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22 https://www.cnbc.com/2018/04/25/nasdaq-is-open-to-becoming-cryptocurrency-exchange-ceo-says.html.

23 https://coinmarketcap.com/exchanges/volume/24-hour/. We define a meaningful volume above one million USD over the previous 24 hours (website was checked on December 2, 2018).

24 Anecdotal evidence suggests that some exchanges may be inflating their trading volume (e.g., Ribes 2018).

25 One exception is Bitfinex, which claimed to have lost approximately $69 million of Bitcoin, but later managed to repay its customers.

26 https://cointelegraph.com/news/binance-reverses-irregular-trades-resumes-trading-amidst-community-confusion-about-hack.

27 https://support.okex.com/hc/en-us/articles/360002320751-Details-of-the-Futures-Trading-Incident-on-Mar-30.

equity and derivative markets (e.g., Aggarwal and Wu 2006; Ni et al. 2005). In contrast, the literature on crypto-markets is more limited. Additional rigorous academic analyses of these crypto-exchanges are warranted, not only for their academic merits but also for their implications for regulators.

4.2 Market Efficiency

Several studies have investigated the pricing of cryptocurrencies. Most of the early empirical studies focused on Bitcoin. Perhaps unsurprisingly, many researchers (e.g., Urquhart 2017; Bariviera 2017; Nadarajah and Chu 2017; Brauneis and Mestel 2018; Detzel et al. 2018) have found multiple examples of inefficiencies in market pricing. Makarov and Schoar (2019) show there exists potential cross-crypto-exchange arbitrage opportunities. Athey et al. (2016) find mixed evidence on whether market fundamentals can explain Bitcoin prices. In particular, they show that as of mid-2015, active use of Bitcoin as a means of payment was not growing quickly, and investors and infrequent users held the majority of Bitcoins. Ciaian et al. (2016) and Liu and Tsyvinski (2018) show that macroeconomic factors do not explain Bitcoin prices well. Gandal and Halaburda (2014) and Hu et al. (2018) show that Bitcoin returns move negatively with other cryptocurrencies. Yu and Zhang (2017) show that the Bitcoin price often violates the law of one price, and they link this finding to capital controls in different countries. Mai et al. (2018) document that posts on social media platforms significantly impact on Bitcoin returns. Several papers, including one by Bukovina and Martiček (2016), find that sentiment affects Bitcoin volatility, and they conclude that Bitcoin is speculative. Yang (2018) tests several price-related anomalies and finds that momentum exists in cryptocurrency markets.

However, one challenge for this line of research is that the baseline model of market equilibrium has not yet been fully characterized, and progress in that direction would be particularly useful. Liu et al. (2019) represent a step in this direction. They show that three factors (i.e., cryptocurrency market, size, and momentum) capture the cross-sectional expected cryptocurrency returns. Given the intensity of speculation in crypto-markets, they also represent an ideal setting for testing predictions stemming from bubble theory. For example, Scheinkman and Xiong (2003) and Hong et al. (2006), among others, propose a "resale option" theory that may be applicable in this setting. Cong et al. (2018) provide a stochastic, rational bubble model of Bitcoin in a macroeconomic framework, and they show that regulation risk and sentiment both affect the value of Bitcoin—a finding that is consistent with their predictions.

4.3 Market Microstructure

Several papers investigate mining protocol designs, largely in the context of Bitcoin. Using different game theory approaches, Eyal and Sirer (2014), Biais et al. (2019), and Cong et al. (2018) consider the mechanisms that lead to token production concentration and collusion in cryptomarkets. The general intuition is that risk-sharing benefits attract independent producers to mining pools and decrease mining diversification. However, cross-pool diversification and endogenous pool fees can mitigate that gradual pool concentration. Easley et al. (2019) also investigate the role of transaction fees in the Bitcoin blockchain's evolution from a mining-based structure to a market-based ecosystem. They also find that microstructure features, such as exogenous structural constraints, influence the dynamics of a crypto-asset environment.

5 Token Economy

5.1 Tokens and Industrial Organization

Distributed ledger technologies have enabled two key innovations: decentralized consensus and tokens. These innovations have important implications for research on industrial organizations. For example, Abadi and Brunnermeier (2018) point out that no ledger can simultaneously satisfy correctness, decentralization, and cost efficiency, although they are the ideal qualities of any record-keeping system. Still, they conclude that a blockchain is more efficient than a traditional ledger managed by a centralized intermediary. Cong and He (2019) show that decentralization through a blockchain facilitates the entry of new competitors but may foster collusion among incumbents. Babich and Hilary (2019b) describe how the concept of *diagonality*, a complex hybrid market structure in which *horizontalities* (e.g., spot markets) and *verticalities* (e.g., supply chain networks) come together, can affect monopoly power.

Several other studies have investigated the importance of native tokens. Cong et al. (2018) focus on the network effect and show the existence of dynamic feedback between user adoption and the responsiveness of token prices to expectations about the future growth of the platform.[28] Li and Mann (2018) explore the use of native tokens to overcome coordination

[28] Sockin and Xiong (2018) also model a network effect in a blockchain system. They show that two equilibria exist, with either a small or large number of people joining the platform.

failure when a platform needs a critical mass. Catalini and Gans (2018) point out that distributing native tokens can assist entrepreneurs in discovering the consumer valuation of their service.

With the evolution of the industry and the adoption of more applications, additional theoretical work focusing on understanding the economic fundamentals of industrial decentralization would be useful. Examples of interesting questions that link cryptomarkets and industrial organizations include the following. What are the implications of decentralization? Why would a blockchain ecosystem need a native token? What is the optimal token design for the success of a blockchain ecosystem?

5.2 Token Economy and Theory of the Firm

Finally, an understanding of decentralized blockchain communities or ecosystems as forms of organization is potentially very important. For example, the academic literature approaches many corporate finance questions, such as the characterization of agency issues, assuming that firms should maximize the value of their equity and debt. However, in a decentralized blockchain ecosystem, there is no "firm," even though blockchain participants are similar to corporate stakeholders.[29]

Magill et al. (2015) explore the stakeholder view of the firm. They show that once property rights have been granted to employees and consumers, boards can instruct managers to maximize the total value for all stakeholders. They argue that "if the firm can issue consumer and worker rights and if these rights can be traded on reasonably liquid markets, then their market prices will reveal the benefits that consumers and workers derive from being stakeholders of the firm" (Magill et al. 2015: 1689). Although Magill et al. do not make explicit references to DLTs, such technologies would enable the implementation of their models. For example, DLTs facilitate the allocation of property rights through token issuances and subsequent trading on platforms that can provide liquid markets for those rights.

Various organizations have already adopted this approach. For example, FCoin, a cryptocurrency exchange, implemented a "trading as mining" mechanism in 2018 that granted consumers (in this case, traders) rights similar to those of equity holders. Traders received a cryptocurrency, FCoin Token (FT for short), based on their trading volume and the most recent FT market price. FCoin distributed most of the transaction fees it charged to FT coin

[29] Liu (2018) argues that a blockchain community is a new organizational form in which stakeholders are also the owners of the organization.

holders. The trading platform was initially very successful, but it stopped using this distribution mechanism when the FT price dropped significantly.[30] Qutoutiao, a reading application, adopts a "reading as mining" mechanism and allocates tokens to people who use the application to read. The firm distributes a certain percentage of the profits to the token holders.

Practitioners are still pondering whether a traditional corporation can evolve into a decentralized ecosystem, and this is a fruitful line of research for academics. Potential research questions might include the following. How would these decentralized organizations differ from traditional value-maximizing corporations or mutual companies? What would be the impact of decentralized organizations on social welfare and resource allocation? If these decentralized ecosystems become common, they will profoundly impact the theory of the firm.

6 Conclusions

Bitcoin, and the blockchain technology underlying it, have drawn significant attention in recent years. Other crypto-assets and additional distributed ledger technologies have emerged. Practitioners are exploring their applications, but most projects are still at the POC stage, and many have failed. Regulators are looking for the optimal way to regulate these new activities, especially activities related to cryptocurrency issuances and exchanges. The challenges for the regulators are multidimensional and include issues in accounting, taxation, and security. For example, firms typically record cryptocurrencies as intangible assets on their balance sheet. As the cost method is used, companies can cherry-pick realized gains or losses on their income statements. However, dubious quality prices mean that these assets are unlikely to be marked-to-market anytime soon.

In this survey, we first introduce the distributed ledger technologies that enable crypto-assets. We then review questions and findings related to the issuance of crypto-assets (e.g., through ICOs). We highlight research questions in corporate finance regarding how to take advantage of these new settings. In the asset-pricing field, we review previous studies that have focused on market integrity and market efficiency and highlight salient unanswered questions.

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30 https://www.coindesk.com/new-crypto-exchange-draws-fire-over-controversial-business-model.

However, crypto-assets introduce a new economy in which information can be directly distributed and traded. These assets raise novel and fundamental research questions. For example, the development of various forms of decentralized organization may materially impact the theory of the firm. These DLT-based communities are different from value-maximizing firms in many respects. How they might optimally finance, invest, and govern themselves are open questions. For example, new agency conflicts between the community funders, participants, and other stakeholders may create new challenges.

As new industries emerge and old ones reinvent themselves, academics can play a role in shaping our understanding of the emerging challenges. We hope this work will have a positive impact both on the firms involved in these new developments and on society at large. We expect that academics and practitioners alike will be interested in reading more on these various issues.

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