Corporate Governance Meets Data and Technology

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Abstract

Corporate governance encompasses a set of processes, customs, policies, laws, and institutions that affect how a corporation is directed, administered, or controlled. Technology both enhances and disrupts the traditional board-centric corporate governance system, enhancing efficiency and transparency while introducing new challenges and risks. In this paper we examine three key themes comprehensively: the redefinition of information and information asymmetry through the generation of and access to big data; blockchain technology's transformative potential for aggregating preferences and exercising shareholder voting rights while blurring the line between securities and tokens; and the impact of smart contracts and their underlying infrastructure on the expansion of contracts and the implementation of decentralized governance through decentralized autonomous organizations. These innovative technological solutions empower stakeholders to exercise governance rights effectively, but their complexity also gives rise to new barriers and inequalities. As technology evolves, collaboration among researchers, policymakers, and practitioners is imperative to ensure that corporate governance remains effective and responsive to the current dynamic business environment.

Keywords: Corporate Governance; Technology; Blockchain; Big Data; AI; decentralized autonomous organization (DAO)

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Abstract

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Foundations and Trends in Finance, Forthcoming

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Contents

1 Introduction

While there is no official definition of corporate governance, it is generally accepted that it pertains to the system through which companies are directed and controlled. When discussing corporate governance, several issues immediately come to mind, including board elections, executive compensation, corporate disclosure, shareholder activism, leadership diversity, and more recently emerging topics such as environmental, social, and governance (ESG) policy and sustainability.[1] Beneath the surface of these specific concerns lies the essence of corporate governance, which fundamentally consists of the processes, policies, and institutions that influence how a corporation is guided and managed.

Why is corporate governance necessary in the first place? Two fundamental forces likely underpin its vital importance. The first force is the separation of ownership and control, a concept initially articulated by Fama and Jensen (1983). This separation becomes more pronounced as a firm's ownership extends beyond family and friends, particularly when it becomes publicly listed. From an economic perspective, we assume that individuals are primarily self-interested and that the disparity in power or authority between those in control and the large and diverse group that owns a firm naturally gives rise to conflicts of interest. The second force is information asymmetry between insiders and outsiders, as described in the longstanding literature pioneered by Leland and Pyle (1977). There exists a gap between what insiders, especially senior management, know about a firm's current condition and prospects and what outsiders know. Uninformed outsiders are, nevertheless, eager to infer some of the unknown information based on the actions taken by insiders (e.g., capital structure adjustments

[1] We refer readers to a comprehensive survey of corporate governance by Hermalin and Weisbach (2017).

or securities issuances) and often do so intelligently, motivating the firm to signal its quality (Myers and Majluf, 1984). Such a game of information inference often generates additional moral hazard and information frictions.

In the United States these two factors have led to widespread adoption and establishment of a board-centric governance structure. While CEOs and senior managers serve as commanders-in-chief on the front line, making day-to-day decisions about how corporations are run and operated, the ultimate authority lies with the board of directors, which is elected by shareholders. This hierarchical system is further complemented by a layer of external monitors and gatekeepers, including auditors, the media, analysts, and, notably, regulators such as the U.S. Securities and Exchange Commission (SEC).

Where does technology fit into this structure and how is it transforming it?

Technology introduces multiple factors to corporate governance and research in this domain. First, data and technology have the potential to reshape how corporations are governed. Real-time access to new information, improved infrastructure, and innovative toolkits can either enhance traditional systems or spawn entirely new ones. Second, data and technology governance presents pressing issues. Questions arise about data ownership, privacy rights, data monopolies, biases associated with algorithms, and the ethics of artificial intelligence (AI). Third, the incorporation of big data and machine-learning techniques into corporate governance research has swiftly transitioned from a new trend to mainstream methodology. Machine learning-based measures, analyses, and newer tools that use generative AI have revolutionized how researchers conduct corporate governance research.

Each of the three abovementioned factors related to corporate governance deserves its own in-depth examination. In this context, we have chosen to focus on the first factor to examine how data and technology are reshaping our familiar corporate governance system. Under this overarching theme, we provide a comprehensive review of three key topics: first, the evolving nature of information and its impact on the redefinition of information asymmetry; second, the transformative impact of new technologies, particularly distributed ledger technology such as blockchains, on ownership and governance; third, the role of smart contracts and their underlying infrastructure in expanding the contractual landscape by altering verification and enforcement mechanisms.

Technology has led to an explosion of data in the corporate world. Real-time information, big data analytics, and AI have revolutionized the way corporations access, process, and use information. Shareholders and other stakeholders now have access to a wealth of data, enabling them to monitor company performance more closely and make informed decisions. While some stakeholders may have access to sophisticated data analysis tools, others may be at a disadvantage, potentially leading to new forms of information inequality. Because the flow of information does not necessarily originate from inside a firm, such information asymmetry is fundamentally different from that under the classic definition based on the insider/outsider dichotomy. Exploring how technology shapes this changing information structure and assessing its impact on corporate governance is crucial to understanding corporate governance in data-intensive businesses. For additional details on the profusion of data in contemporary corporate operations, see Section 2.

Distributed ledger technology (DLT), of which blockchain technology is currently the most prominent, offers a decentralized and tamper-resistant way to record ownership and transactions. This technology has the potential to transform traditional ownership structures and governance models, a premise for shareholder governance. The transparency and immutability of a blockchain can enhance trust among stakeholders by providing a single source of truth for ownership, transaction records, and corporate actions (Yermack, 2017). This can streamline processes such as shareholder voting and proxy management. Additionally, blockchain makes it possible to create digital assets and tokens, such as tokenized securities and governance rights, that can represent ownership in new ways. These innovations have expanded the scope of ownership and corporate governance, which have been based primarily on securities and their trading in marketplaces, including exchanges and over-the-counter markets. The new system raises fresh questions about the allocation and distribution of both cash-flow and decision-making rights (e.g., Sockin and Xiong, 2023; Chod and Lyandres, 2021). Currently, DLT mitigates some, but creates new, governance issues associated with the separation of ownership and control as well as information or preference aggregation. We discuss these questions more extensively in Section 3.

Blockchain-based technology opens an opportunity to devise a fresh system for governance. Smart contracts are self-executing contracts with the terms of an agreement written directly in code. These contracts execute automatically and enforce themselves when predefined conditions are met, eliminating the need for intermediaries (Cong and He, 2019). Smart contracts have the potential to streamline various corporate processes, such as supply chain management, payment settlements, and shareholder agreements. By eliminating intermediaries and enhancing transparency and accuracy, smart contracts can reduce transaction costs and prevent fraudulent and unethical behavior. By enforcing pre-agreed-to rules and conditions, smart contracts also discourage strategic ex-post renegotiation, a classic contracting issue. However, many financial contracts, such as loan agreements, are inherently incomplete. In these situations, where ex-post risk sharing is desirable, standard smart contracts would be suboptimal. The technical features of smart contracts also generate additional limitations, such as the need for and challenge involved in online–offline interactions. Smart contracts may also facilitate collusive behavior. Therefore, we must explore how smart contracts change verification and enforcement mechanisms and understand their implications for corporate governance in a digital business landscape. See Section 4 for a fuller discussion of these issues.

The issues we have mentioned here represent critical facets of the evolving relationship between technology and corporate governance, each presenting its own unique challenges and opportunities. Investigating them in detail can provide valuable insights into the future of corporate governance in a technology-driven world.

2 Big Data and a New Era for Information and Information Asymmetry

2.1 Flows of information from firms and in the marketplace

Effective governance relies on transparency, accountability, and responsible decision-making. Corporate disclosure is the practice of sharing timely information about a company's financial performance, operations, and key risks with its stakeholders, including shareholders, regulators, and the public. Strong corporate governance relies on comprehensive and accurate corporate disclosure to ensure that shareholders' interests are protected, management is held accountable, and ethical business practices are maintained. Corporate disclosure provides a critical tool for enhancing corporate governance by providing the information and visibility that enables stakeholders to make informed decisions and exercise proper oversight of a company's activities. We believe that "sunlight is the best disinfectant," which implies that, if there were greater transparency and more publicly available information, many governance issues would have been resolved or significantly mitigated.

One of the most important paradigms of asymmetric information was proposed in Myers and Majluf (1984) and the work that has followed (e.g., Viswanath, 1993; Healy and Palepu, 2001; Hennessy et al., 2010), namely the idea that firms possess information that investors do not, and yet investors are eager to gain or infer information from corporate disclosures or actions (e.g., securities issuances). More recent studies (Chen et al., 2007; Edmans et al., 2015) and a survey by Bond et al. (2012) acknowledge that information flow between insiders and outsiders could run in both directions: Stock prices give managers incremental information on the basis of which to make strategic decisions. For example, reactions in the stock market and changes in company valuation enable managers to make better-informed merger-and-acquisition (M&A) or investment decisions (Luo, 2005; Dessaint et al., 2019). Such models and empirical evidence suggest that information aggregated in the marketplace may contain elements that are incremental to private managerial information.

2.2 Data generation and new information asymmetry

Data generated and distributed by technology can enhance the strength of managerial information or level the playing field between insiders and outsiders. Increasingly, firms are becoming data-intensive, where data and human labor combine to create knowledge (Abis and Veldkamp, 2024). Firms harness the power of data to transform raw information into valuable insights, giving them a competitive edge and often making them even better informed than outsiders. By collecting and analyzing data from multiple and diverse sources, including internal operations, customer behavior, market trends, and industry benchmarks, firms can uncover patterns, trends, and correlations to which outsiders may not have access.

New software that can be used to predict supply chain and sales trends enables firms to stay informed about issues of immediate concern much faster than traditional information-aggregation processes (Brynjolfsson and McElheran, 2019). These advanced software solutions utilize real-time data integration, predictive analytics, and machine learning algorithms to continuously monitor and analyze various factors that affect supply chain operations and sales, such as demand fluctuations, inventory levels, production capacity, and market trends. Unlike traditional methods that rely on periodic reports and historical data, these software tools provide immediate alerts and insights when anomalies or problems arise. These innovative technology solutions empower firms to stay ahead of challenges and capitalize on opportunities, while also providing firms with more time and space between the acquisition of knowledge and the need to disclose it.

On the other hand, a significant portion of data generated as "footprints" of business activities and sentiments have become widely accessible to outsiders, including investors. These "footprints" encompass both the literal (such as satellite images of cars in stores' parking lots) and the metaphorical (such as credit card transactions, internet traffic, and social media posts). Individuals with timely access to such data may gain insights into the business performance of a Starbucks store or the reception of a new Toyota model long before the CFOs of these companies receive official reports. It is important to note that such information is not only universal——available to anyone with the requisite technology——but also unevenly accessible because of the expertise and resources needed for data collection and analysis. This dynamic introduces a new form of asymmetry between outsiders rather than between insiders and outsiders.

2.3 Alternative data and governance

Technology has created a new class of data which have been bundled under a general term, "alternative data," which refers to nontraditional or unconventional data sources and types that businesses, investors, and researchers use to acquire information and make informed decisions. These data are considered "alternative" because they go beyond the more traditional sources of information, such as financial reports, surveys, and government statistics. Instead, the term "alternative data" encompasses a wide range of often unstructured or semistructured data that can provide unique perspectives on various aspects of business, finance, and other domains. Examples of alternative data include:

Web Data: Information gathered from web-scraping, including data from websites, social media platforms, forums, and news articles. These data can be used to gauge sentiment, track consumer behavior, and monitor online trends.

Satellite and Geospatial Data: Data obtained from satellites, GPS devices, and location-based services that can be used for such purposes as tracking supply chain activity, monitoring external conditions (e.g., weather), and assessing traffic flows.

Sensor Data: Information from sensors and devices on the Internet of Things (IoT), which can measure environmental factors, product performance, or consumer preferences. These data are often used in industries such as manufacturing and logistics.

Credit Card Transaction Data: Data derived from credit card transactions, offering insight into consumer spending patterns, preferences, and economic trends.

Social Media Data: Information from social media platforms, including text, images, and videos, that are used to analyze public sentiment, monitor brand mentions, and predict market trends.

Satellite Imagery: High-resolution satellite images used for applications ranging from monitoring of crop yields to assessing infrastructure and real estate development.

Sentiment Tracking Data: Analyzed text data, such as news articles, press releases, and social media posts that are used to gauge public sentiment and assess market sentiment.

Alternative data hold significant value by providing a select group of market participants with a distinct competitive edge in their decision-making processes. What sets alternative data apart from their conventional counterparts is the origin and distribution, as a substantial portion of such data is generated and disseminated beyond the confines of any given firm. In cases such as satellite images and social media chats, the data are generated or gathered from external sources without a firm's active involvement but can provide valuable insights into the firm's operations, customer sentiment, and overall performance, enabling market participants to make informed decisions without relying solely on the company's official disclosures. This characteristic effectively redraws the conventional boundaries of the information asymmetry that has traditionally separated insiders from outsiders.

The initial wave of research on alternative data demonstrates its potential for predicting stock returns and corporate performance, conditional on corporate disclosures and other market-related information such as analyst forecasts (Froot et al., 2017; Chen et al., 2014). This predictability naturally bears governance implications, a focal point explored by Zhu (2019). Zhu's central thesis posits that alternative data, by enhancing stock-price informativeness, exert a disciplinary effect on corporate managers. Introducing such data reduces the cost of acquiring information, especially for firms where sophisticated investors have strong incentives to uncover hidden insights. This increased integration of information into stock prices discourages opportunistic managerial trading. Simultaneously, managers are incentivized to make more efficient investment and divestment decisions, aligning their actions with enhanced information signals that are embedded in stock prices.

A crucial insight from Zhu (2019) suggests that the large volume of externally generated data improves governance through two distinct channels, both of which revolve around the theme of information. First, alternative data, often unstructured and requiring advanced technologies such as natural language processing (NLP) and machine learning for analysis, levels the information playing field between firms as security issuers and investors in those securities. This effect not only reduces insider rents but also alleviates dead-weight losses in signaling games arising from information asymmetry. Second, big data manage to find their way into securities prices, enhancing the latter's informativeness, thereby rendering them more efficient signals guiding investment decisions and acquisitions while incentivizing management to enhance effectiveness. In contrast, Goldstein (2023) cautions that the availability of alternative data can also lead to nuanced feedback effects, for example, the availability of imprecise information (e.g., social media data) may crowd out the demand for more precise information (e.g., fundamental analysis), resulting in a reduction in asset price informativeness (Dugast and Foucault, 2018).

In a recent study, Cao et al. (2023) further quantify the effect of external alternative data on narrowing the information gap. Their research demonstrates that, when a firm is covered by alternative data sources, the accuracy of forecasts made by analysts who cover the firm significantly improves in comparison with the benchmark achieved by an "AI analyst" who relies solely on processing the firm's disclosed information. This improvement depends, however, on the affiliation of the analyst with a brokerage that has developed adequate AI capacity, defined as a firm that hires employees with AI education or relevant work experience credentials. Because analysts serve as information intermediaries for external investors, this finding substantiates the notion that alternative data bridge the information gap between firms and their investors, but only with the help of the technology needed to extract and synthesize big data.

Consistent with the findings reported in Cao et al. (2023), Chi et al. (2023) find that analysts' adoption of alternative data and the dissemination of the corresponding insights to institutions have helped "traditional" institutional investors become better informed. Chi et al. (2023) also find evidence that this trend has narrowed the information gap between traditional institutional investors and hedge funds, the latter of whom are the earliest adopters and heaviest users of alternative data.

2.4 Data, technology, and "public information asymmetry"

There is demand for specialized talent to acquire and process data that should, in theory, be accessible to all, but financial and technical resources, including cloud computing, are also needed for this purpose. These factors are quietly giving rise to an expanding information divide between those who possess these resources and those who do not. Interestingly, such a gap can arise even with respect to the most publicly available information, including data collected and disseminated by regulatory authorities such as the SEC. One prime example is EDGAR, the Electronic Data Gathering, Analysis, and Retrieval system, which was established in 1992. EDGAR's functions encompass the automated collection, validation, indexing, acceptance, and forwarding of submissions made by companies and other entities that are legally obligated to file forms with the SEC. Designed as a central hub where investors and other stakeholders can access corporate information, EDGAR was originally envisioned as leveling the playing field in the quest for information and promoting broad market participation. The hurdles associated with accessing and effectively utilizing this wealth of data have, however, contributed inadvertently to creating a disparity in information access.

EDGAR estimates that approximately 3,000 terabytes of data are downloaded from its website annually. On the other hand, computational neuroscientists generally posit that the human brain stores between 10 and 100 terabytes of data.[2] This marked disparity suggests that

[2]Source: https://aiimpacts.org/information-storage-in-the-brain/.

the bulk of document processing is carried out by machines. According to a study by Cohen et al. (2020), the length of 10-K reports increased fivefold between 2005 and 2017, with annual incremental text changes surging nearly twelvefold. Coping with this volume of information is a formidable or even insurmountable challenge for a human being. Scott Bauguess, then Deputy Chief Economist and Deputy Director of the Division of Economic and Risk Analysis at the SEC, estimated, in a 2018 speech, that approximately 85% of the documents were accessed and processed by bots.[3] Cao et al. (2023) estimate that the percentage of EDGAR files that are likely retrieved by machine algorithms increased from roughly one-third in 2003 to more than 90% in 2017. This trend underscores the point that, while the information is technically "public," disparities in the capacity to process these data could give rise to information asymmetry—a situation marked by equal rights but differential power.

The more robust the deployment of algorithms and AI in the retrieval and processing of information, the faster the response from well-equipped investors, which in turn incorporates information into stock prices more rapidly. This relationship is examined and validated in Cao et al. (2023). Their findings reveal that, as machine-driven downloads double, the time it takes for the first trade after depositing a 10-K filing on the EDGAR portal is reduced by seven seconds, and the first "directional trade" (i.e., a trade that is expected to be profitable based on the stock price 15 minutes later) occurs nearly 12 seconds sooner. These results strongly suggest that technology facilitates the expeditious incorporation of information into

[3]Source: https://www.sec.gov/news/speech/speech-bauguess-050318.

stock prices, thereby enhancing their informativeness in relation to disclosures by firms.[4] This effect is generally considered positive for both market efficiency and corporate governance.

There is another side to this story. The growing integration of machines and AI into research and trading processes is also amplifying information asymmetry, even with respect to publicly available data. In fact, Cao et al. (2023) find that, immediately following the posting of a filing, the bid-ask spread widens, particularly when a stock is traded extensively by machine-driven systems. This suggests that market participants, including market makers, are well aware of the informational edge wielded by certain tech-savvy and tech-resourceful investors immediately after the release of value-relevant information. The irony lies in the fact that the prompt dissemination of information to all through platforms like EDGAR, which was designed to level the playing field, also fuels a widening information gap between its intended recipients.

More critically, such information asymmetry cannot be rectified solely through the implementation or spirit of regulations like Regulation FD because differences in participants' capacity to retrieve and process public information has exacerbated the asymmetry.[5] This effect has manifested itself on multiple occasions where technology favors some market participants (e.g., high-frequency traders (HFTs)) over traditional traders. For example, stock exchanges have made vast amounts of market data publicly available over the last decade, including

[4]The aggregate impact of AI-controlled or assisted trading on stock-price informativeness is not clear; see the model proposed by Dou et al. (2023). In particular, AI-powered trading can reduce the informativeness of stock prices, as informed AI speculators can learn autonomously to employ collusive trading strategies.

[5]Regulation FD, or Regulation Fair Disclosure, addresses the selective release of material nonpublic information by publicly traded companies. It mandates that, when an issuer shares such information with specific recipients, such as securities professionals or security holders who may trade based on it, it must also make the information publicly available. The objective of Regulation FD is to ensure comprehensive and equitable disclosure.

detailed order-book information, trade data, and other market metrics, effectively giving HFT firms more actionable information. This has led to wider bid-ask spreads for slower traders who are facing a less stable and predictable market environment (Lewis, 2014; Coughlan and Orlov, 2023).

2.5 Feedback effects: From technology to corporate decisions

Awareness that machines are increasingly processing corporate disclosures, press releases, and earnings calls underscores the motive that can induce firms to adapt their communication strategies accordingly. In the past, these communications were tailored primarily for human consumption, but the changing audience calls for a shift in strategy. Firms should be incentivized to craft their filings and verbal communications in a manner that facilitates more seamless processing by algorithms and interpretation by machines while avoiding unintended negative perceptions on the part of AI readers and listeners. Cao et al. (2023) documents these changes in disclosure practices, particularly in response to key developments such as the introduction of a lexicon specific to financial contexts (featuring lists of words associated with positive and negative sentiments) by Loughran and McDonald (2011) and the advent of BERT by Google in 2018.[6] The findings reveal that companies whose filings have become deliberately machine-oriented were more proactive in adjusting their language following these events, employing fewer "negative" words, as determined by the new Loughran and McDonald lexicon, although not necessarily by the earlier psychological Harvard-IV dictionary. Furthermore, companies where AI-powered institutional investors represent larger proportions of shareholders also demonstrated

[6]Bidirectional Encoder Representations from Transformers, or BERT, is an NLP model developed by Google AI in 2018. Unlike earlier NLP models that processed words in a sentence sequentially, BERT considers the entire context of a word by looking at both the words that come before and after it in a sentence.

a greater propensity to transform their disclosure materials to reduce the likelihood of being perceived negatively by the BERT algorithm after its launch.

Disclosure offers just one illustrative example of how evolving technology is increasingly driving companies toward adaptation, a phenomenon resulting in "feedback effects" from technology. That is, while financial markets reflect firm fundamentals, market perception (which is now powered by AI) also influences managers' information sets and decision-making (see surveys conducted by Bond et al. (2012) and Goldstein (2023)). The case of disclosure underscores that, as long as the encoded rules governing machine learning are not entirely opaque (i.e., they are transparent, observable, or can be reverse-engineered to varying degrees), agents affected by these decisions may be tempted by incentives to manipulate the inputs to machine learning algorithms to achieve more favorable outcomes.

While the connection between evaluation metrics and agent behavior is not a new concept, it is essential to emphasize the growing challenge that machine learning algorithms face in becoming "manipulation-proof." In this context, algorithms must anticipate the strategic behavior of informed agents without directly observing it in training samples. This challenge has been the subject of theoretical analysis, as seen in Björkegren et al. (2020) and Hennessy and Goodhart (2023). The consequence of such a feedback effect can be unexpected outcomes, including manipulation and collusion, as demonstrated in Calvano et al. (2020). As technology continues to advance, it becomes increasingly imperative for new studies to explore the impact of AI and the behavior it induces in financial economics and society at large.

3 Governance via Blockchain Technology

3.1 Blockchain, ownership, and shareholder governance

3.1.1 Challenges in the current system of ownership and voting rights

The modern corporation operates on a centralized, top-down governance model where managers are granted the authority to manage a company on behalf of shareholders, who expect to receive residual cash flows based on their ownership stakes. Because corporate directors are elected by shareholders, voting by the latter is a crucial mechanism for influencing company management and operations. Under the current proxy voting system, however, shareholders cast their votes through intermediaries,[7] which can result in inefficiencies characterized by Kahan and Rock (2008) as "pathologies," including votes not counted or left unverified, confusion involving ownership of lent shares, over-voting, and non-alignment between voting rights and economic interests. Such a sorry state of the current shareholder voting landscape led prominent Delaware attorney Gil Sparks to say famously in 2018 that, "in a contest closer than 55% to 45%, there is no verifiable answer to the question 'who won?"'[8]

These issues are especially problematic during proxy contests, i.e., contested elections by shareholders for changes in corporate control including M&A and contested board elections. In proxy contests, which involve pivotal ex-ante votes, incumbent management and dissidents who challenge those managers both expect that they can prevail (Brav et al., 2020, 2024). The proxy contest between Procter & Gamble (P&G) and Trian Fund Management, a leading activist

[7] In the United States, according to the SEC, approximately 85% of exchange-traded shares are held by securities intermediaries. For details, see https://www.sec.gov/spotlight/proxyprocess/proxyvotingbrief.htm.

[8] Source: https://corpgov.law.harvard.edu/2020/03/03/cii-comment-letter-on-proposed-amendments\-to-rule-14a-8/

investor, best exemplifies such inefficiencies. Shortly after its October 2017 shareholder meeting, P&G claimed a narrow victory. The winning side, however, kept flipping with each subsequent count, reflecting the razor thin margin. An independent tally on November 15, 2017 showed that the activist had won approximately 42,000 more votes than a P&G director, a margin of 0.0016% of the total outstanding shares. A month later, however, the final vote tabulation indicated that P&G nominees won by a margin of 0.025% of the votes cast.

Not all, but most, such challenges are related to frictions in the "tracing" of shares, i.e., the process of tracking the ownership history of shares in a company. Tracing shares accurately is essential for maintaining the integrity of securities markets and ensuring that ownership rights are properly respected and enforced. Share-tracing may also be necessary in situations such as corporate actions, M&As, or disputes involving ownership interests in a company. This process is however error- and omission-prone given the complexity of ownership chains (from brokers and custodians to clearinghouses and depositories), the potential for lost or incomplete records, variations in documentation standards across jurisdictions, and the frequent occurrence of corporate actions such as stock splits, mergers, and name changes (see Kahan and Rock (2008) for a detailed explanation).

Over-voting occurs when certain shares are voted multiple times, in extreme cases possibly resulting in more votes cast by shareholders than there are eligible shares to be voted. This situation typically arises following errors or discrepancies in ownership-tracking and vote-counting (Apfel et al., 2001). Smith (2013) estimates that over-voting accounts for roughly 4% of votes cast, which tends to introduce pro-management bias. When exercising their appraisal rights (Jiang et al., 2016, 2020), the same inefficiencies may induce dissenting shareholders to "over-surrender" shares to a court for a "judicially determined fair value." In 2015, shareholders of Dole Food Company, Inc. and chairman and CEO David Murdock reached a settlement that would give shareholders an additional \$2.74 per share for underpayment in the 2013 management buyout. During the settlement-claims process, stockholders submitted facially valid claims for 49,164,415 shares, representing 12,370,657 or 33.6% more shares than Dole's outstanding shares, based on information from the Depository Trust Company's centralized ledger.[9]

3.1.2 How can blockchains improve shareholder governance?

(i) Share tracing

To the extent that accurate share-tracing is a prerequisite for shareholder governance, blockchain technologies occupy a unique position in resolving or mitigating most of the challenges in shareholder governance analyzed in Kahan and Rock (2008). Blockchain is a DLT that is used to record and secure transactions across a network of computers. Such a technology can locate shares with voting rights by associating each share with a unique digital token on the blockchain. When a shareholder exercises their voting rights, that action is recorded as a transaction on the blockchain, linking their tokenized shares to their voting decisions. This process ensures that each share's voting rights are accurately accounted for and tracked in real time. Because the entire transaction history cannot be altered retroactively, shareholders can trust that there are no missing votes or discrepancies in the voting process. Smart contracts deployed on the blockchain can automate voting procedures according to predefined rules, ensuring that votes are executed as intended by shareholders (see additional details in Section

[9]See Brown (2018) for details.

4). Such smart contracts can also enforce governance protocols, such as quorum requirements and voting deadlines, further enhancing the accuracy and integrity of the voting process.

The defining features of a blockchain present a unique opportunity to decentralize and improve the voting system. As records are stored sequentially through all nodes on the network, they are immutable and accessible to all interested parties in real time. Altering or trying to spend the same digital currency or asset twice would require not only changing the specific transaction but also repeating the work required to add subsequent blocks to the chain. For networks using the proof-of-work consensus mechanism to validate blockchain transactions, this would mean having to control the majority of the network's computational power, which is highly unlikely in a decentralized and widely distributed network.[10] As a result, the level of security and computational effort involved makes double-spending practically impossible, ensuring the integrity of the blockchain ledger. Thanks to this inherent characteristic of blockchain technology, it holds the potential to address the issue of "double-voting" or over-voting, when shares are registered on the blockchain, with their values tied to voting rights. Leveraging blockchain for voting can thereby deliver unmatched transparency and accuracy in ownership records, ultimately leading to faster and more precise vote tabulation (Yermack, 2017).

Blockchain-based shareholder voting remains at an experimentation stage. A notable project was the 2016 NASDAQ pilot program that used blockchain voting in shareholder

[10]The proof-of-work consensus algorithm involves solving a computationally challenging problem to create a new block. The process is known as "mining," with the nodes in the network that engage in mining called "miners." Leading blockchain systems are increasingly adopting the proof-of-stake (PoS) consensus mechanism to verify transactions, with Ethereum becoming a PoS blockchain in September 2022. To validate a new block and add it to a blockchain, validators are selected randomly by an algorithm. In most cases the size of the stake determines whether a validator is likely to be chosen to forge the next block. In PoS systems, double-spending attacks require controlling a dominant amount of the staked cryptocurrency (Neuder et al., 2021). For details on how PoS systems work, see Saleh (2021) and John et al. (2024).

meetings for companies listed on the Tallinn Stock Exchange (DeMarinis, 2017). Shareholders of record were able to view relevant information, transfer voting rights to a proxy, monitor the proxy and recall votes if necessary, and review previous meetings and votes. In April 2018, the Dutch company KAS Bank tested an Ethereum-based blockchain service for shareholder voting at its annual meeting. The experiment was designed to expedite the collation of ballots and significantly improve reporting transparency.

Decentralized voting systems utilizing blockchain technology have the potential to introduce several innovative features that would enhance shareholder rights. For example, the concept of tenure-based voting, where investor voting rights increase (up to a predefined limit) with the duration of their share ownership, incentivizes long-term ownership. This approach is seen as fairer than the traditional dual-class share system, as it ensures that all shareholders have equal access to varying degrees of voting power (Edelman et al., 2018). This idea is in the process of being implemented by the Long Term Stock Exchange (LTSE) (`https://ltse.com/`) founded in 2015.

(ii) Implementation of multiple share classes

Blockchain technology allows for the creation of a range of share classes based on the level of privacy offered by the blockchain. Interested and authorized parties can view the real-time distribution of ownership and ownership changes, offering varying degrees of investor anonymity to cater to specific shareholder preferences (Yermack, 2017). Even in the most decentralized systems, where complete anonymity and multiple digital wallets per investor are possible, a reasonable level of transparency is maintained, akin to traditional "tape-watchers" on trading floors. Furthermore, as suggested by Yermack (2017), blockchain technology enables the encoding of regulations directly into the blockchain, such as mandating "type code" disclosure for insiders, 5%-plus block holders, and more. Regulators may also require public keys for insiders, backed by legal enforcement.

Thus, blockchain technology can help to improve the traditional dual-class share system. While the literature has offered mostly negative views of dual-class shares as they violate the general principles of shareholder governance, recent research suggests that such a system could help early-stage firms but it often overstays its welcome (Kim and Michaely, 2019; Cremers et al., 2022). As such, technology could help implement a contract that will "sunset" superior-voting shares contingent on a combination of firm age and performance. Lastly, blockchain technology could also empower retail investors by enabling them to set up DAOs that execute votes based on their preferences without intermediation by proxy advisories or other agencies. DAOs lack central leadership and operate based on a set of decision-making rules encoded into "smart contracts" on a blockchain. Both DAOs and smart contracts will be reviewed in greater detail in Section 4.

(iii) Pass-through voting

With "pass-through" voting, asset managers allow asset owners, such as endowment funds and mutual fund shareholders, to exercise their voting rights directly in corporate elections and resolutions. This approach to voting is often seen as a means of enhancing transparency and accountability in corporate governance, as it ensures that decision-making authority rests ultimately with beneficial share owners rather than asset managers. BlackRock and Vanguard launched their "Voting Choice" programs in 2022 and 2023, respectively, bring the approach into the mainstream.[11]

Blockchain technology presents significant opportunities to revolutionize pass-through voting processes in the investment industry. By leveraging a blockchain's transparent and immutable ledger, asset managers can tokenize voting rights, representing them as digital assets on a blockchain and facilitating direct voting by their clients in corporate elections and resolutions. Smart contracts can be employed to automate execution, ensuring that voting instructions are carried out according to predetermined criteria agreed upon by both parties. Blockchain's secure identity verification systems enhance the security of pass-through voting by allowing only authorized individuals to cast votes, thereby mitigating the risks of unauthorized access. Real-time updates and notifications provided by blockchain technology enable asset managers and their clients to track the status of their votes instantaneously.

Despite the promise of new technologies, though, they are not panaceas for governance issues in shareholder voting. For example, a distribution ledger that accurately records and traces ownership still cannot prevent investors with legitimate voting rights from engaging in "empty voting," where a shareholder holds more votes than her economic ownership entitles her to vote, a status often achieved through derivatives, hedging, or securities lending. This problem can occur because it is not feasible, in the foreseeable future, to record all economic interests of investors on the blockchain because of gaps in reporting requirements for derivatives and securities lending as well as the lack of any accurate way to track economic interests. Moreover,

[11] For additional information on these programs, see https://www.blackrock.com/corporate/about-us/investment-stewardship/blackrock-voting-choice and https://corporate.vanguard.com/content/corporatesite/us/en/corp/articles/empowering-everyday-investors-proxy-voting-choice.html.

technology may help managers identify and reach out to targeted investors to influence voting by the latter.[12] Bach and Metzger (2019) observe that, "when management strongly opposes a shareholder proposal, it takes meticulous actions to ensure that it does not pass," including reaching out to shareholders who favor management and acquiring additional voting rights itself, such as expediting option exercises even under conditions that are unfavorable to managers under normal circumstances (Fos and Jiang, 2015). Therefore, technology may also exacerbate managerial manipulation of votes when they are better equipped to observe voting outcomes in real time and identify pro-management shareholders.

3.2 Governance on the blockchain: Coins and tokens

3.2.1 Overview

In addition to streamlining the traditional corporate governance process—shareholder voting in particular—blockchain supports the creation, storage of,and execution of transactions involving digital assets, such as tokenized securities. Such innovations have expanded the scope of ownership and corporate governance that has centered traditionally on securities. The new system raises fresh questions about the allocation and distribution of cash-flow rights and decision-making rights (e.g., Sockin and Xiong, 2023; Chod and Lyandres, 2021). Thus blockchain technology mitigates some, but creates other, governance issues associated with the separation of ownership and control as well as information or preference aggregation.

[12] Listokin (2008) and Bach and Metzger (2019) present evidence that in close votes on management proposals, including director elections, Say-on-Pay votes, and shareholder proposals, management is far more likely than shareholder activists to win, suggesting that voting outcomes are subject to manipulation.

In recent years, token offerings, exemplified by initial coin offerings (ICOs), have emerged as a novel crowdfunding avenue for blockchain-based startups. On the one hand, tokens lack the conventional governance elements found in securities, such as equity and debt. On the other hand, the presence of governance provisions can prove particularly effective under specific conditions, thanks to the commitment technology facilitated by the underlying blockchain (Yermack, 2017; Cong and He, 2019). While there are certain parallels and analogies between governance in securities issuance and trading and governance related to token-based financing activities and transactions, the latter remain in the early stages where the appropriate legal/regulatory frameworks and best practices are still being defined. Within this context, a burgeoning body of literature has developed rapidly, encompassing both theoretical and empirical research.

In the following sections we focus on the nature of governance issues, including moral hazard and information asymmetry, that are commonly considered governance failures. When necessary, we discuss the defining features of smart contracts and DAOs that are related to governance facilitation, but the details involved in their implementation will be deferred to Section 4.

3.2.2 Startup governance on a blockchain

(i) Token offerings and taxonomy

An ICO represents a new fundraising method made possible by the development of blockchain technology and cryptographic tokens. In an ICO, an entrepreneur raises capital by creating and selling a virtual currency or token that provides a set of rights to its holders. These rights can include access to a platform or network, the right to create or develop features of an ecosystem, and the right to cast votes on governance issues (for startups organized as DAOs). We refer readers to Ofir and Sadeh (2020) for a comparison between ICOs and IPOs from a legal perspective, and Li and Mann (2021) for a general review of ICOs. We focus instead on governance issues.

Most offerings are initiated by white papers that present business ideas and models, identify those who will operate the businesses, and provide the technical specifications that apply to the projects on which the offerings are based. The entrepreneurs involved typically lay out a timeline for the projects and describe how the funds raised will be spent, such as on marketing or research and development. Such plans often include "soft caps" indicating the minimum amounts received that constitute the success of initial offerings. Startups usually also specify "hard caps," the maximum fundraising goals for crowdsales. When token sales do not reach their soft caps, funds are usually returned to investors, i.e., these are "all-or-nothing" arrangements. If hard caps are reached, additional subscriptions will be rejected and the funds will be returned.

Investors who purchase tokens early may benefit from "early-bird" bonuses or discounts. A bonus or discount might be offered to compensate for the higher risks that early buyers bear. Some ICOs include presale periods, also known as pre-ICOs. Presales generally target larger investors, including institutional investors. Presales typically involve lower fundraising targets than main sales, with tokens offered at steep discounts.

Following the successful completion of an ICO, most participating entrepreneurs prepare for an exchange listing. This typically involves an application and listing fee. In some cases the pre-listing period lasts from several days to several months, after which secondary-market trading begins immediately. A project that is implemented successfully but needs more capital may induce a startup to return to the ICO market with a seasoned offering. Lee et al. (2022) provides a typical timeline for an ICO.

Regulatory scrutiny, high-profile fraud cases, and falling digital currency prices likely contributed to the dramatic cooling of the ICO market in recent years.[13] Since late 2018, security token offerings (STOs) and initial exchange offerings (IEOs) have taken center stage in blockchain-based fundraising (Lee et al., 2022), responding to regulatory concerns that some issued tokens, e.g., that involved in SEC v. Ripple, may be deemed securities and hence should be subject to equivalent laws and regulations governing securities issuance.[14] The two new forms navigate securities regulations more effectively than ICOs, primarily because they are designed specifically to comply with existing securities laws and regulations. STOs are structured to meet regulatory requirements, which can include registering with relevant authorities and providing disclosure documents akin to those required for traditional securities offerings. They typically incorporate investor protections, such as adherence to Know Your Customer (KYC) and Anti-Money Laundering (AML) regulations, similar to protections required of banks. IEOs are conducted on cryptocurrency exchanges, which may already have some regulatory oversight and compliance measures in place. This involvement of established exchanges can provide a level of legitimacy and transparency that some ICOs have lacked.

[13] By the end of 2018, more than 5,500 blockchain startups had raised over $30 billion through ICOs (Lyandres et al., 2022). According to ICObench (2019), however, ICOs raised just $902 million in Q1 2019, about 14% of all funds raised in Q1 2018. Our analysis of ICO data from CoinMarketCap.com, a top source for data on cryptocurrencies, reveals that, during 2023, 29 ICOs actively sought to raise only $50.2 million. See `https://coinmarketcap.com/ico-calendar/` for details.

[14] On July 13, 2023, the court found that XRP (the cryptocurrency sponsored by Ripple) was not a security when sold to the public on an exchange, but it is when sold directly to institutional investors.

With the rise of DeFi, short for "decentralized finance" and referring to a set of financial services and applications built on blockchain technology, blockchain projects are increasingly launching tokens on decentralized exchanges (DEXs). For a modest fee, a creator can generate, within minutes, a standard token for which the total supply is capped while making it possible to burn tokens. After deploying the token on a blockchain, the creator adds the new token and the numeraire (Ethereum or any other token) to a "liquidity pool" and supplies the amount of the pair, the ratio between which determines the price of the token (see Li et al. (2022) for additional details on these steps).[15] Unlike listing on a centralized exchange (CEX), where a token needs to pass through the exchange's screening process, all the steps for DEX listing are automated.

Because ICOs are not subjected to due diligence, road shows, and regulatory filings that are typical with IPOs, concerns about adverse selection issues that have plagued the market for token offerings naturally arise. In the absence of meaningful "external" governance mechanisms and regulatory oversight, ICOs tend to rely on internal governance measures to safeguard investor interests and voluntary disclosure to reduce information asymmetry. For example, ICOs that set vesting schedules for insiders' token holdings are more likely to encourage firms to raise employment and avoid failure (Howell et al., 2020), and those that disclose information on a team or insider ownership are more likely to execute a successful fundraiser (e.g., Bourveau et al., 2022). In the following sections we explore these mechanisms in greater detail.

(ii) Tokenization vs. traditional financing

[15] See Capponi et al. (2023) for an overview of the workings of DeFi. Capponi and Jia (2023) study the incentives for liquidity providers to deposit tokens into liquidity pools.

A growing body of theoretical studies has studied the benefits and costs associated with token offerings, comparing those with the costs and benefits of traditional financing schemes. Among them, Sockin and Xiong (2023) examine tokenization as an innovation that might resolve the conflict between platforms and users, while most of the other studies, such as Chod and Lyandres (2021) and Chod et al. (2022), focus on the classic conflict induced by moral hazard between an entrepreneur and outside investors. These issues are reminiscent of the classical corporate governance issue: separation of ownership and control, which leads to agency conflicts.

Tokens, which are usually referred to as "utility tokens," are issued to fund a platform and later could be used to purchase products or services offered by the platform. Examples include NEO's GAS tokens, which are used to pay transaction fees on the NEO network. They may find old cousins in coupons or discount vouchers used by retailers or airlines as they are designed to be redeemable for some form of value. If tokens can be used to redeem a pre-determined value in products or services, then they are claims on the platform's future outputs. In other words, tokens represent claims on the platform's revenue as opposed to claims on its profits (or residual cash flows), as in the case of equity. It turns out that this feature of token financing helps to mitigate certain agency conflicts in the traditional financing model—while creating new ones.

It is well understood that equity financing leads to withheld effort by an entrepreneur, in the spirit of Jensen and Meckling (1976), because the entrepreneur internalizes the full cost of his effort but only part of the platform's profit. Token financing also leads to the withholding of effort because the founder's claims are partial. This aspect of moral hazard is less severe, however, because the fraction of tokens that the entrepreneur needs to sell to finance the platform is smaller than the fraction of equity she would have to sell to finance the same venture.

Consider a simple illustration of the concept, assuming a one-period model and a zero discount rate. If the entrepreneur opts for equity financing and sells an α fraction of shares to outside equity investors, the amount she is able to raise is $\alpha\mathbb{E}(R(\eta, q, e) - C(q))$, in which revenue R is a function of random demand shock η, output q, and entrepreneurial effort e. $C(q)$ represents the production cost. If the entrepreneur chooses to issue a β fraction of utility tokens, then she raises $\beta\mathbb{E}(R(\eta, q, e))$. To raise the same amount of funds, α will generally be greater than β, leading to greater dilution for the entrepreneur under equity financing. As a result, effort-withholding is generally less severe with token financing than with equity financing. We refer the reader to Chod and Lyandres (2021) and Garratt and Van Oordt (2022) for models featuring greater complexity.

Nevertheless, the "claim on revenue" model of token financing often results in underproduction, as highlighted by recent studies (Chod and Lyandres, 2021; Gan et al., 2021; Malinova and Park, 2023). This phenomenon reflects the fact that an entrepreneur who has sold a fraction of tokens to investors internalizes only a portion of the platform's revenue, while bearing the full burden of the production costs. The underproduction issue becomes more pronounced when the marginal production cost remains high even as production volume rises. In light of this trade-off, equity financing tends to outperform token financing for goods or services that involve substantial marginal costs but require relatively little entrepreneurial effort. Conversely, in cases where marginal production costs are negligible but entrepreneurial effort is paramount, token financing not only avoids underproduction but also mitigates the withholding of effort. Consequently, it dominates equity financing as a more efficient funding method as a result of the inherent governance alignment.

Another advantage of token financing over equity financing is that tokenization can act as a commitment device to prevent a platform from exploiting its users, as it would by selling user data to third parties (Sockin and Xiong, 2023). For example, in 2018 Amazon was investigated by the European Union for using its merchants' transaction data to launch private-label products that directly competed with those merchants' products. Equity owners would choose this action when the transaction fees from the platform fell below the gains obtained from exploiting its vending users. Such exploitation would benefit equity owners at the expense of all users. By issuing utility tokens with voting rights (i.e., governance tokens), the platform developer leaves control of the platform to users who vote on whether to take a subversive action to sell user data to third parties, which ensures that users would not act collectively to exploit themselves. Allocating control of the platform to users through decentralization is a key appeal of tokenization, to which we return when discussing DAOs in greater depth.

The downside of tokenization according to the analysis in Sockin and Xiong (2023) is that no equity owner subsidizes user participation in a way that maximizes a platform's network effect. In the digital era, centralized platforms typically devote substantial resources to subsidize user participation to broaden their user bases, especially in the early stages of their businesses. For example, when entering new markets, Uber shareholders have subsidized drivers heavily to attract a fleet of cars large enough to offer an instant service to customers and to undercut traditional taxi services. In other words, platform shareholders must pay the costs involved in subsidizing user participation so as to maximize future profits, which rise as the user base grows. As a result of this trade-off, platforms whose fundamentals are somewhat weak find that utility tokens are more attractive than equity as a means of securing funding. This is because the concern that equity owners might exploit users is serious when transaction fees are low; as a result, the commitment that tokenization creates is especially valuable.

Unlike Sockin and Xiong (2023), Chod et al. (2022) focus on the role of tokenization in reducing an entrepreneur's financing burden. To attract users, a platform may need to provide them with an initial subsidy. The need to provide additional funding for such a subsidy causes additional dilution of the entrepreneur's stake in the platform, exacerbating effort-withholding with equity financing. By selling tokens with voting rights, the entrepreneur can credibly cede her power to raise the transaction fee once the platform begins operations, as in Sockin and Xiong (2023). Tokenization thus eliminates the threat of a hold-up, which makes users reluctant to pay a fee (i.e., an investment) to join the platform ex ante inasmuch as they become vulnerable once they join the platform because joining involves a sunk cost. Such a hold-up problem is well recognized in the economics literature (e.g., Williamson, 1979; Hart and Moore, 1999; Hart, 2009). For this reason, tokenization alleviates the need to provide users with an initial subsidy.[16]

[16] Lee and Parlour (2022) and Goldstein et al. (2019) show that token financing can improve efficiency (i.e., eliminate or reduce the hold-up between financiers and consumers) even in the absence of moral hazard and asymmetric information.

Would security tokens, which are claims to a platform's future profits and are similar to conventional securities such as equity, improve welfare over what utility tokens do?[17] Gan et al. (2021) find that, in unregulated markets, although inefficiencies associated with utility tokens cannot be fully eliminated under security-token financing, they are less severe when it is possible to implement profit-sharing credibly (using smart contracts). Gryglewicz et al. (2021), however, show that when security-token holders are given dividend rights, platform adoption rises but developers' equity stakes are diluted, undermining incentives. As a result, an increase in financing needs or in agency conflicts makes tokens less like standard securities. It is worth noting that all the results we have reviewed thus far stem from the underlying distinction between tokens and equity and not from distinct contracting possibilities with the two financing methods (which we discuss in Section 4).

Token are distinguished by the capacity to commit to revenue- (or profit-) sharing: algorithmic commitment (see Cong et al. (2022) for a discussion of blockchain commitment). Smart contracts make commitment and automated implementation of certain contracts possible. However, blockchain-enabled commitment is not a panacea. As we detail in Section 4, there is limited commitment space and smart contracts can accommodate only limited contingencies. Moreover, not to mention, "oracles"—services that feed external data to a blockchain—are needed (Cong et al., 2023b). Consider the case of Quantstamp, a smart contract auditing platform that found itself caught up in controversy in 2018 when it failed to adhere to a medium-of-exchange commitment to accept its QSP token, instead accepting U.S. dollars and Ether for its services.

[17] A security token is the blockchain equivalent of a stock market-traded securitized asset. That is, the basic functions of a security token are similar to those of a stock. Similarly, depending on the type of token, investors may have voting rights and be awarded dividends.

(iii) Measured governance and ICO outcomes

In the previous subsection we focus on agency conflicts when comparing tokenization with traditional financing. As mentioned earlier, tokens lack the standard governance features of securities and could be vulnerable to scams, fraud, and abuse, resulting primarily from inadequate regulation. In the absence of any "external" governance mechanisms (such as rating agencies or auditors), ICOs at the current stage mainly rely on internal governance measures to safeguard investor interests.

Using a sample of about 1,500 ICOs, Howell et al. (2020) show that 22% of issuers establish a vesting schedule for insiders' token holdings and 43% set aside an incentive pool of tokens to compensate future external developers or contributors. Vesting requirements can help align insiders' incentives with those of token buyers. In the setting of equity IPOs, Brav and Gompers (2003) show that this commitment device that is designed to alleviate moral hazard problems is the best explanation for the standard 180-day lockups of insider shares in IPOs. Howell et al. (2020) find that these governance measures that are designed to reduce agency costs are indeed effective. Startups that set aside an incentive pool of tokens or establish vesting schedules for insiders' token holdings are more likely to raise employment, avoid failure, and be eventually listed on CEXs.

Most ICOs offer early-bird bonuses to attract investor subscriptions. Excessively high bonuses may however lead wary investors to conclude that such ICOs are overpriced or even perhaps lemons (Lee et al., 2022). Lee et al. (2022) find that 32% of a sample of 3,300 ICOs offer high bonuses, defined as 20% or more (equivalent to a discount of 16.7% or more), and they are more prevalent in ex-post failed ICOs. Offerings with high bonuses also exhibit lower primary market subscription volumes and post-ICO returns.

As discussed earlier, security tokens, which are explicitly designed to comply with existing securities regulations, are likely to provide a more transparent and secure investment option for both issuers and investors. Early examples of security token offerings (STOs) include INX and Exodus, which raised $85 million and $75 million, respectively, through sales registered with the SEC. Lee et al. (2022) show that token sales structured as STOs are 15 percentage points more likely to conclude fundraising successfully. This result suggests that stronger investor protection enhances confidence and encourages investor participation.

The relationship between measured governance and ICO outcomes mirrors that in the securities market. Deng et al. (2018) compute a governance index based on six governance indicators: whether an ICO has a vesting plan or lockup requirement, an escrow requirement, a milestone, voting rights, bonus plans, or hard caps. They find that the governance index positively predicts deal completion, the amount of capital raised, and post-ICO listings. Johnson and Yi (2019) find that, in countries where regulations are weak, ICO issuers tend voluntarily to adopt additional governance mechanisms, including voting rights and lock-up agreements. These governance mechanisms are associated with less managerial shirking, a higher likelihood of fundraising success, less underpricing, and enhanced efficiency in price discovery in the secondary market.

(iv) Information asymmetry

In this subsection we survey research on information asymmetry associated with token financing. Like traditional startups, blockchain-based startups are subject to the age-old asymmetric information problem: An issuer has more information about the cash flows its platform could generate. Leland and Pyle (1977) analyze this problem in a classic study and show that the amount of an entrepreneur's own funds invested in a project will be interpreted as a signal of its quality. Following this logic, when an entrepreneur keeps a relative large portion of tokens in an offering, the market receives a signal indicating that she has plenty of skin in the game and should therefore be expected to exert considerable effort to platform development.

The information asymmetry that is associated with ICOs is likely to be more severe than that associated with IPOs (Lee et al., 2022). First, blockchain startups are much younger and less established than typical IPO firms. The latter tend to hold tangible assets and to offer developed products to their customers. In contrast, ICOs typically provide only blueprints outlining future development, most of which can be found in white papers posted on ICO websites. Such information may not be sufficient for individual investors to understand the underlying venture's plan or potential. Second, most ICO investors are retail investors and therefore likely lack sufficient knowledge about the underlying project (especially when the project develops innovative technologies) or financial markets in general. In contrast, most IPO investors are relatively sophisticated institutional investors. Third, ICOs lack a traditional underwriting process that IPOs employ. Therefore, a significant stake retained by an entrepreneur can serve as a credible signal of an ICO's superior quality. Several theoretical papers, including Gan et al. (2023), Catalini and Gans (2018), and Canidio (2018), study token-retention decisions under moral hazard.

Consistent with the abovementioned prediction, Lee et al. (2022) find that, when a smaller fraction of tokens is offered to investors (i.e., greater token retention), fundraising campaigns are significantly more likely to complete successfully. Specifically, successful ICOs seek to sell 55.3% of generated tokens to outsiders, compared with over 59.4% in failed ICOs, with the difference being statistically significant. The fraction of tokens for sale is also positively associated with an ICO's removing its white paper (which usually happens for compliance reasons or lack of progress) or being charged with fraud. Davydiuk et al. (2023) also find that token issuers who retain large fractions of their tokens are more successful in their fundraising efforts, as measured by funds raised and exchange listings, and more likely to develop working products. Moreover, Davydiuk et al. (2023) show that retention sends a stronger signal when markets are crowded or investors do not have sufficient time to conduct due diligence.

Chod and Lyandres (2021) is the only study that connects token and equity retention under information asymmetry. They argue that, when platform heterogeneity is low (i.e., when the expected revenue generated by a low-quality entrepreneur is close to that generated by a high-quality entrepreneur), it is possible to use either tokens or equity to signal to the market. When this happens, the low-quality entrepreneur's incentive to imitate weakens and the high-quality entrepreneur can sell a larger stake in the platform without worrying about imitation. On the other hand, when platform heterogeneity is high, the low-quality entrepreneur sees powerful incentives to imitate, preventing the high-quality entrepreneur from signaling with either equity or token retention while raising the funds needed. Finally, when platform heterogeneity is moderate, signaling is possible with tokens but not with equity. As shown in Section 3.2.2 (ii), the entrepreneur is able to retain a larger share of the platform's future cash flows by issuing tokens than when issuing equity. A higher retention rate sends a more credible signal about platform quality. Token financing thereby expands the parameter space that allows for signaling to investors.

In addition to using token retention as a signaling device, blockchain startups have also relied on voluntary disclosure, in the form of white papers and websites, to rectify information asymmetries between issuers and investors during token offerings. These startups might favor voluntary disclosure because few investor protection rules or disclosure regulations apply to cryptocurrency, and hence voluntary disclosure serves a complementary governance role, consistent with the large body of literature on voluntary disclosure by public firms (e.g., Verrecchia, 1983; Eng and Mak, 2003). Such disclosures are generally unaudited and largely unverifiable, though, raising investor protection issues and questions about their effectiveness. Lee et al. (2022) and Bourveau et al. (2022) find that nearly all ICOs are accompanied by white papers, which is the primary means through which blockchain startups communicate with prospective investors before an offering takes places. Some platforms pull their white papers immediately after the sales are concluded or even during a sale, however, and such behavior is highly correlated with fraud. Lee et al. (2022) find that 7.7% of all ICOs are not accompanied by a downloadable white paper.

Bourveau et al. (2022) find that all of their sample white papers describe the primary business purpose, 81% disclose a roadmap for product development, 71% disclose team-related information, and 66% provide information regarding the allocation of tokens to insiders. About

65% of white papers feature a budget for use of the proceeds. Howell et al. (2020) show a somewhat lower figure: 42% include a budget for use of the proceeds. Zetzsche et al. (2019), however, document that more than two-thirds of the white papers are either silent on the issuing entity, initiators or backers, or they do not provide contact details, demonstrating that most ICOs are offered on the basis of inadequate information disclosure. The authors also show that still more ICOs fail to elaborate on applicable laws, segregation or pooling of customer funds, or the retention of an external auditor. In addition, Bourveau et al. (2022) find that few white papers disclose risk profiles or financial conditions, and only 14% include information regarding future dividends or distributions.

Although traditional firms are subject to stricter requirements and have available multiple channels for disclosure, Github represents an alternative disclosure channel, providing blockchain developers with a powerful tool with which to collaborate and share code with each other. An important aspect of GitHub is that it can be used by (sophisticated) investors to track the number of contributors and the volume of code being added to a project. This can provide insight into the health and growth of a platform and can be used to track the platform's development progress in real time, information that is not available to investors in traditional firms. Howell et al. (2020) and Bourveau et al. (2022) find that 53% of their sample ICOs post their source codes to GitHub repositories.

A question arises naturally as to whether these disclosure channels are effective at reducing information asymmetry between ICO issuers and investors. Howell et al. (2020) find evidence that voluntary disclosure is associated with superior post-ICO startup performance. Specifically, the availability of a white paper or the disclosure of a budget for the use of proceeds is correlated with higher future employment and a lower likelihood of startup failure, suggesting that white paper disclosures contain relevant investment-related information. In addition, posting a startup's source code on GitHub is associated with 100% employment growth and a 12 percentage point reduction in failure probability. Similarly, Bourveau et al. (2022) report that ICOs that disclose information on team or insider ownership are more likely to conduct a successful fundraiser. The probability that capital is raised is also higher for platforms that publish their source codes or video presentations, consistent with findings reported in Howell et al. (2020) and Adhami et al. (2018).

3.2.3 Governance void: The dark side of blockchain technology

Many stakeholders, entrepreneurs and investors alike, perceive cutting-edge technology ventures as entities that thrive solely on innovation and disruption, believing that rigid governance structures may stifle their progress or that technologies themselves could fix governance. But this perception overlooks the crucial role that governance plays in ensuring accountability, sustainability, and adherence to ethical practices within these ventures. The risk posed by unchecked power and information asymmetry does not spare high-tech entities or systems. The collapse of the FTX cryptocurrency exchange is a case in point. The exchange operator, once valued at $32 billion with $1.8 billion in venture capital raised, resisted creating a board until January 2022, less than 10 months before its demise. The three-person board, however, was reportedly controlled by then-CEO Sam Bankman-Fried, with no venture capitalists obtaining board seats (Mitchelhill, 2023). An FTX bankruptcy report highlights that board oversight was effectively non-existent and "the FTX Group lacked independent or experienced finance, accounting, human resources, information security, or cybersecurity personnel or leadership, and lacked any internal audit function whatsoever."[18]

Nicolle (2023) surveys 60 blockchain/cryptocurrency companies and finds that only half of the businesses engaged independent auditors to assess their finances and 63% of the companies had installed independent boards of directors, although nearly all of the 60 firms had raised outside investments. Among those that lacked independent boards were major exchange operators, such as Binance and Huobi as well as Tether, the issuer of the largest stablecoin. This circumstance stands in stark contrast to what occurs with (startup) firms in traditional sectors. Ewens and Malenko (2020) show that although a typical board is entrepreneur-controlled at formation, independent directors join more than half the boards after the second round of financing, when control becomes shared. At later stages, control switches to venture capitalists. Given the prevalent lack of effective corporate governance and due diligence conducted on corporate books in the blockchain/cryptocurrency sector, it is unsurprising that misreporting, manipulation, scams, fraud, and other illegal activities frequently make headlines, with the true extent of their pervasiveness still unknown. We review studies on these topics in the following subsection.

(i) Misreporting and manipulation

Misreporting by and manipulation on cryptocurrency exchanges have concerned regulators and investors greatly. Fusaro and Hougan (2019), in their Bitwise report presented to the SEC, indicate that 95% of trading volume on unregulated CEXs appears to be fake

[18]The bankruptcy report is downloadable through https://restructuring.ra.kroll.com/FTX/Home-DownloadPDF?id1=MTQ5MDc2OQ==&id2=-1.

or wash-trading, a deceptive practice where traders buy and sell the same cryptocurrencies to create the illusion of substantial trading activity, which is illegal in most regulated stock markets around the world. Cong et al. (2023a) use statistical and behavioral patterns in trading to detect wash trading on 29 centralized exchanges. They find that wash trading is prevalent on unregulated exchanges, which generally lack effective corporate governance, but is absent from regulated exchanges. Specifically, the average wash trading volume on unregulated exchanges is about 78% of their total trading volume. Wash trading is found to significantly improve exchange rankings and to inflate short-term cryptocurrency prices. Aloosh and Li (2022) use the internal trading records of a major Bitcoin exchange (Mt. Gox) leaked by hackers to detect and characterize wash trading. Their findings provide direct evidence of the widely suspected "fake volume" allegation against CEXs, which is consistent with indirect estimation results reported in Fusaro and Hougan (2019) and Cong et al. (2023a). Amiram et al. (2020) show that competition among exchanges results in volume inflation.

Wash trading is not restricted to centralized exchanges. Victor and Weintraud (2021) find that $159 million worth of wash trading has taken place on small decentralized exchanges, such as EtherDelta and IDEX, which lack governance oversight by any party. It is perhaps not surprising then that wash trading also plagues the non-fungible token (NFT) market,[19] which is generally much less liquid than the cryptocurrency market. Wash trading makes the market appear more liquid, thus attracting prospective buyers. Work by von Wachter et al. (2022) and Oh (2023) documents significant NFT wash trading volume on the Ethereum blockchain,

[19]An NFT is a type of digital asset that represents ownership or proof of authenticity of a unique item or piece of content, typically stored on a blockchain. Unlike cryptocurrencies such as Bitcoin or Ethereum, which are fungible and can be exchanged on a one-to-one basis, NFTs are non-fungible, meaning that each one is unique and cannot be exchanged on a like-for-like basis.

consistent with findings in industry reports.[20] Wash trading does not appear, however, to affect returns on NFTs (Oh, 2023). In addition, CryptoFisher (2018) estimates that one-quarter of ICOs have inflated investor demand by engaging in wash trading.

Manipulators also target Bitcoin, the largest cryptocurrency. Gandal et al. (2018) find that suspicious trading activity conducted by bots on the Mt. Gox exchange is highly correlated with a rise in the Bitcoin price during the sample period. Specifically, two actors' suspicious trading activity is associated with a 4% rise in the price on a daily basis. Griffin and Shams (2020) examine whether Tether, the largest stablecoin, was used to inflate Bitcoin prices during the 2017 market boom. By mapping the blockchains of Bitcoin and Tether, the authors find that one large player on the Bitfinex exchange creates Tether to buy Bitcoin when its price falls. Such interventions cause Bitcoin prices to rise. Interestingly, salient round-number price thresholds, which facilitate highly effective price support, seem to encourage rather aggressive price-support behavior. Both studies support the view that price manipulation can have substantial distortive effects on cryptocurrency prices.

Pump-and-dump schemes (P&Ds) in which an asset's price is inflated artificially before it is sold represent another example of price manipulation. Securities regulators deem these schemes illegal. P&Ds are pervasive on CEXs, however, as these exchanges lack incentives to police and report such incidences. These events also take place frequently on DEXs such as Pancake Swap, which feature high speed and low costs. A typical P&D scheme concludes within several minutes (Li et al., 2018). Li et al. (2018) find that P&Ds typically precede

[20] According to the analysis compiled by the pseudonymous researcher *hildobby*, wash trading accounted for over half (58%) of the total NFT trading volume on Ethereum in 2022, with wash trading volume of more than $30 billion. See `https://dune.com/hildobby/nfts-wash-trading` for *hildobby*'s real-time analysis of NFT wash trading. An analysis by Chainalysis (2022) shows that 110 profitable wash traders collectively made nearly $8.9 million in profits from trading NFTs.

short-term episodes of dramatically higher prices, volume, and volatility after which these conditions reverse quickly. The documented evidence, including price run-ups before P&Ds begin, suggests the occurrence of significant wealth transfers between insiders and outsiders. Furthermore, the authors exploit two natural experiments to study the economic consequences of P&Ds. The first natural experiment involves Bittrex, once a frequently targeted exchange, which banned P&Ds in November 2017, while the second features Yobit, an exchange that began randomly pumping cryptocurrencies listed on the exchange in October 2018. The authors conclude that P&Ds harm cryptocurrency liquidity and prices. Hamrick et al. (2021) and Xu and Livshits (2019) use similar data from CEXs to study cryptocurrency P&D schemes and find largely consistent results.

Analogies to "hostile takeovers" occur on blockchains except that such endeavors have so far been malicious in nature. Governance attacks include situations where players manipulate blockchain platforms that use decentralized governance structures by gaining sufficient voting rights to reshape the rules or influence sufficiently many token holders to cast biased votes on a targeted proposal. Prominent governance attacks include malicious proposals targeting Build Finance DAO and Beanstalk. To amass a large number of voting tokens, the attackers used vote-buying or flash loans, the latter of which are uncollateralized loans that are approved, executed, and paid back all in one transaction (see Lehar and Parlour (2022) for details on flash loans). In the case of Build Finance, such formidable voting power was used to pass a proposal that enabled the attacker to control the platform's token contract, which was used to unilaterally mint 1.1 million BUILD tokens, the platform's native tokens, for the attacker (see Dobos (2022) for additional details). In the Beanstalk attack, the exploiter submitted a proposal, disguised as a Ukraine donation proposal, to"improve" the platform's smart contract code. The attacker used his supermajority voting power to pass the proposal that transferred the protocol's funds to the attacker's own wallet (see Section 4.2.3 and Immunefi (2023) for additional details). Daian et al. (2018) and Buterin (2021) are among the authors who criticize on-chain vote-buying behavior because smart contracts, the same tool that executes blockchain-based voting, can facilitate efficient vote-buying. In other words, it is easy to unbundle governance rights from economic interests (Buterin, 2021).

Another type of governance attack launches through proof-of-work systems, the original consensus mechanism for validating on-chain transactions. Such an attack can occur when a single entity or a coalition of entities gains significant control over the mining power or computational resources of a network, enabling attackers to influence decision-making processes. The system may lead to a situation where blockchain conglomerates—companies that operate multiple businesses in the blockchain industrial ecosystem—"control" blockchain governance (Ferreira et al., 2023). Such "governance capture" occurs even in the presence of traditional governance mechanisms, such as market-monitoring, stakeholder-monitoring, and reputation-building. Governance capture via mining centralization undermines the decentralization and security of a blockchain network.

(ii) Misappropriation

Misappropriation constitutes a major corporate governance risk. Such misappropriation can be carried out through illegal or unauthorized use of funds, assets, or resources for personal gain or unsuitable purposes. Misappropriation typically involves someone who has been entrusted with managing or handling financial resources who then diverts them for their own benefit or for purposes unrelated to their designated use. In the blockchain world, misappropriation plays out in an elementary format inasmuch as entrepreneurs run away with backers' funds, which is prevalent in token offerings, as investors lack enforcement mechanisms to punish such misconduct. Shifflett and Vigna (2018) review 1,450 ICOs and find that 271 are susceptible to fraud or plagiarism. Investors in these ICOs have claimed losses of up to $273 million. Using an ICO's removal of its white paper as a proxy for the potential for fraud, Lee et al. (2022) find that ICOs with missing white papers exhibit lower governance quality, including offering excessively high bonuses. In addition, ICOs charged by regulators with fraud are less likely to require a KYC procedure.

On DEXs, issuers can create and list tokens, often profiting through exit scams also known as "rug pulls" in the cryptocurrency community. To list a new token, a liquidity provider (i.e., a token issuer) deposits the token and a numeraire asset, such as Ethereum, into a so-called "liquidity pool." The liquidity provider (LP) sets the initial exchange rate for the two assets and supplies a value equal to the value of both tokens to the pool. In return, the LP receives a pool-specific token called an LP token and can withdraw her share of the pool by redeeming her LP tokens. When traders swap their numeraire tokens for the new token, the liquidity pool grows in value. In a rug pull, the token issuer would typically drain funds from the liquidity pool by redeeming all her LP tokens. Using novel blockchain data, Li et al. (2022) find that in 2021 alone more than 300,000 meme tokens, which are inspired by internet memes or viral images and do not have any real business purpose or utility, were issued at a total trading volume of more than \$30 billion.[21] On average, about 94% of creators' profits during the first 30 days following issuance of such tokens are generated through rug pulls.

4 Using Smart Contracts and DAOs to Implement Governance

In Section 3, we summarize the key frictions in the traditional corporate governance system, especially those associated with share-tracing and ownership-tracking. We also consider how new technologies have the potential to resolve or mitigate such frictions. We have touched on the concept of smart contracts briefly in previous sections, where we describe them as facilitators of decentralized governance, token offerings, and DeFi protocols. In this section, we explore the mechanics involved in the implementation of governance innovations, primarily through smart contracts and DAOs, as well as the new problems they may create.

4.1 Smart contracts: Implementation and commitment

4.1.1 Smart contracts: Basics

Smart contracts consist of computer code that automatically executes all or parts of an agreement and is stored in a blockchain system. As noted by Cong and He (2019), smart contracts provide "terms contingent on decentralized consensus that are tamper-proof and

[21] The authors also explore why investors trade meme tokens despite their average negative profits. First, because the vast majority of meme tokens become worthless after several days post-issuance, overconfident investors who believe that they can time the market better than others are willing to participate in meme-token trading. Second, although the average short-term return is negative, the return distribution is right-skewed, suggesting that investors with a penchant for gambling who overweight high short-term returns may participate in meme-token trading.

typically self-enforcing through automated execution." Decentralized consensus has the potential to expand the contracting space by reducing the scope of non-contractible contingencies, a theme that occupies the core of the incomplete contract literature (e.g., Hart, 1995). Additionally, the transparency provided by blockchains makes many previously "hidden actions" verifiable, thereby mitigating traditional moral hazard problems. For instance, in the model proposed by Cong et al. (2021), the "effort" that miners exert is effectively observable by tracking the frequency at which a miner has solved mathematical puzzles that are lower-tier to those used in proof-of-work. Several recent papers, notably Levi and Lipton (2018), Makarov and Schoar (2022), and John et al. (2023), have provided comprehensive reviews of the mechanics of smart contracts.

Smart contracts offer many advantages, such as speed, efficiency, transparency, accuracy, trust, security, and cost savings, all of which are relevant to governance. First, by eliminating the need for intermediaries, such as brokers and lawyers, to validate signed legal contracts, smart contracts reduce the risk of third-party manipulation and minimize transaction costs. Second, smart contracts are designed to ensure that both parties fulfill their obligations, promoting trust and accountability among the involved parties, even in the absence of prior or expected future business and/or social interactions. By reducing the need for costly verification or enforcement, smart contracts can eliminate certain contracting frictions in an automated and conflict-free way (see Harvey, 2016; Cong and He, 2019). Third, smart contracts can also enhance transparency and accuracy by providing a tamper-proof record of all transactions on the blockchain, which can help prevent fraudulent or unethical behavior. Finally, smart contracts can address a major issue in classic contracting, i.e., strategic ex-post renegotiation. By enforcing rules and conditions based on prior agreements, smart contracts mitigate issues with adverse selection and moral hazard.

4.1.2 Power and limitations of smart contracts

For reasons discussed in the previous section, smart contracts are better suited to situations where a strong ex-ante commitment takes precedence over an ex-post renegotiation and where discretion in implementation is not valued or may even be detrimental given its potential to encourage strategic behavior in crucial scenarios. Such a cross-sectional comparison has not been examined either theoretically or empirically in the burgeoning body of smart contract literature. Therefore, our arguments draw primarily from earlier studies within the traditional governance framework. Nonetheless, our focus on the inherent properties of smart contracts enables us to project both their capabilities and limitations in the contracting space.

In practice, it is often challenging to predict whether ex-post renegotiation will be beneficial or detrimental. It may prove advantageous when ex-post renegotiation provides updated information to fill gaps in incomplete contracting, as suggested by Hart and Moore (1988), or when redistribution of risk becomes Pareto optimal after an agent has expended effort but before the outcome is fully realized (Fudenberg and Tirole, 1991). On the other hand, the possibility of ex-post renegotiation incentivizes moral hazard, particularly in the form of strategic default. Distinguishing between cash flow-triggered default and strategic default can be difficult, especially in a downturn or economic recession (Ganong and Noel, 2023). Economic theory suggests that even the most sophisticated code or platform cannot account for all possible contingencies (Aramonte et al., 2021). In other words, many financial contracts, such as loan agreements, are inherently incomplete (Coase, 1993; Grossman and Hart, 1986; Hart and Moore, 1988; Aghion and Bolton, 1992). Standard smart contracts, which are "hard-coded" and preclude renegotiation, may not be ideal for contractual situations where it is difficult to specify contingencies or where ex-post risk-sharing is desired.

The trade-off between mandatory and discretionary triggering of contractual terms could be intriguing. As we discuss in Section 4.1.1, algorithm-based decision-making is transparent or could potentially be reverse-engineered, thus encouraging behavior that could trigger an algorithm, with unintended consequences. Smart contracts, given their mechanical nature, are unable to manage contingencies that involve "feedback effects." Consider the design of contingent convertible bonds (CoCos) issued by banks. CoCos are debt instruments that can be written down or converted into equity when a nonviability condition is triggered. The triggering condition can be made objective, either based on market prices or at the discretion of regulators (Avdjiev et al., 2020). While the discretion to trigger typically carries the risk of encouraging moral hazard through the possibility of renegotiation (even if implied), mandatory triggering could lead to a "death spiral" (Sundaresan and Wang, 2015). This is because anticipation of a breach of the condition may lead to selling, which, in turn, accelerates the breach. In other words, the use of smart contracts for CoCos may make it difficult to manage risk. In general, smart contracts offer advantages when contract contingencies do not trigger actions that affect the occurrence of the contingency itself, thus avoiding feedback loops.

Smart contracts involve several additional limitations, some of which are related directly to their technical features. For example, smart contracts inherently depend on programmers and are vulnerable to bugs and logical errors in code. Any errors could result in significant risks for all parties involved, leading some blockchain ventures to hire auditors to evaluate the integrity of their smart contracts (Bourveau et al., 2023).[22] There are several elements that involve explicit or implicit features of governance. First, it is challenging for decentralized governance mechanisms to reconcile competing objectives among multiple parties, resulting in systemic instability when facing governance disputes within blockchain communities, especially when critical decisions about protocol upgrades or changes to contract rules are involved. Such a limitation was responsible for the eventual collapse of the Terra-Luna system in May 2022 (Liu et al., 2023).

Second, smart contracts operate primarily in digital, online environments but often interact with real-world, offline events and data. Smart contracts cannot retrieve data from external sources beyond the blockchain network, which is necessary with various real-world applications. For example, external weather data may be required by a smart contract that bases insurance payouts on weather conditions. They rely on trusted data sources or services ("oracles") to provide information about real-world events or conditions.[23] The connection with the latter exposes smart contracts to mundane governance issues in the offline world. Oracles, for example, can be manipulated through arbitrage (which utilizes flash loans), especially via DeFi protocols.[24] Moreover, in transactions that involve physical assets, smart contracts must be integrated with conventional legal structures.

[22] For example, in an incident involving the DeFi platform YAM Finance, the project's developers inserted a bug in the smart contract, thereby causing the collapse of the entire project, resulting in significant investor losses. Lehar and Parlour (2023) also describe a flash-loan attack that exploited a decentralized platform's coding mistake.

[23] Oracles could be application programming interfaces (APIs) or web pages. See Beaver Finance (2022) for various types of oracles.

[24] According to Chainalysis (2023), DeFi investors lost about $865 million in dozens of oracle attacks from 2020 to 2022. See Harvey et al. (2021) for additional examples of oracle attacks.

Third, while smart contracts themselves do not inherently encourage strategic behavior such as collusion, certain conditions or factors within a smart contract system or ecosystem can create opportunities for collusion among participants. Some collusive behavior is no different in nature from the strategic behavior that extends from offline to the online world in somewhat different guises. For example, token concentration may encourage a small group of participants to collude to control governance processes by coordinating their votes to sway outcomes. Colluding oracle operators could provide false or manipulated data to trigger contract outcomes that benefit them financially. More importantly, some types of collusive behavior have been encouraged precisely by the transparency that decentralized consensus provides, which would have been deterred by information asymmetry or lack of commitment. Cong and He (2019) have shown that smart contracts can encourage collusion among interested parties, as blockchain transparency and commitment help to sustain the collusive equilibrium. In DeFi applications, smart contracts could be exploited by colluding participants to create cartels that manipulate token prices or execute arbitrage opportunities, potentially harming other users.

So far, the only empirical evidence of trade-offs under incomplete contracting has been reported by Chen et al. (2023). Using staggered adoption of U.S. state laws that open new opportunities for within-state use of blockchain technology, the authors find that firms that have used blockchain technology experience significant improved performance. Of greatest relevance to blockchain technology, the authors show that such firms become less reliant on vertical integration, enter into strategic alliances more frequently, and develop new customers without regard for geographical proximity.

4.2 DAO Governance

4.2.1 DAOs: Overview

DAOs represent a new kind of organizational structure that is built with blockchain technology and is governed directly by members who have invested in it. Unlike corporations or centralized platforms as covered in Section 3.2.2, DAOs generally do not occupy physical headquarters or offices or employ directors, managers, or other personnel. A DAO's governance rules for decision-making are encoded into smart contracts, making management self-executing. Investors hold "governance tokens" that provide both decision-making and economic rights. Decisions are made through proposals on which a group votes during a specified period, with voting rights similar to those accorded to shareholders in traditional companies. Furthermore, the token holders are also users of a DAO's services. All of the DAO's transactions are recorded immutably on the blockchain, providing transparency to its members.

The first references to DAOs emerged in the 1990s when Dilger (1997) describe a DAO that would be integrated as part of the IoT. The modern version of DAOs can be traced to the concept of a decentralized autonomous corporation (DAC), a term that was coined shortly after the Bitcoin network was born. The term "DAO" became more widely adopted by blockchain enthusiasts and developers in 2013, most notably by Ethereum's Vitalik Buterin, who began theorizing in 2014 about DAOs as entities featuring "automation at the centre, humans at the edges" (Buterin, 2014).

Dash, a fork of Bitcoin, is considered the first self-funded DAO with a self-governing protocol. Dash pioneered decentralized governance using blockchain technology, and it remains the industry's longest-running DAO. Created in 2016, Dash was the first DAO entity built on the Ethereum blockchain. It raised roughly $150 million in a matter of weeks to create a platform for collective investment in blockchain projects. It was closed shortly afterwards, however, after hackers stole most of the funds that had been raised. To avoid a repeat of such a debacle, new platforms for creating DAOs and facilitating voting and security protocols for code-auditing have been established, including Snapshot, Aragon, and DAOStack. The DAO ecosystem accelerated in 2020 as DeFi platforms, such as Uniswap and Aave, took off with DAO structures.[25] In 2021, the total value of assets held in DAO treasuries surged from $400 million to $16 billion, and the number of DAO participants rose from 13,000 to 1.6 million (Quarmby, 2021). According to SnapShot, a voting platform for DAOs that also provides analytic data, the number of DAOs increased from about 700 in May 2021 to about 6,000 as of June 2022.

DAOs offer several advantages over traditional corporations. First, DAOs provide their members with more direct control over an entity's operations without relying on agents such as managers and directors, mitigating agency issues. Second, DAOs can enhance operational transparency. Every transaction, modification, or audit is recorded instantly on the blockchain, providing an immutable and easily accessible online record to every member, making it difficult for any single member to hide a fraudulent transaction or other illicit activity. Third, DAOs also enhance efficiency as they can be created more quickly than traditional companies, have instant access to prospective investors, and run without significant overhead costs. In addition, DAOs typically feature online governance forums that enable discussion of issues by, and receive feedback from, various stakeholders, potentially leading to better decision-making (e.g.,

[25] A DeFi platform is a peer-to-peer financial network that uses blockchain technology to manage financial transactions without third-party intermediaries such as banks and brokerages. Almost all of the major DeFi platforms are run by DAOs.

high-quality proposals). With respect to voting, a sponsor initiates the voting process essentially unassisted. After a proposal passes, it typically will be implemented automatically by the associated smart contract. Blockchain-based voting systems can also streamline other steps in the voting process, as summarized in Section 3.1.

Despite their benefits, DAOs also face a number of challenges, including a lack of legal status and the potential for unlimited liability, security-law non-compliance, and governance issues.[26] First, without legal recognition, a DAO may by default be seen as a general partnership, with each member potentially having unlimited liability in bankruptcy.[27] As of March 2023, only a few U.S. states, including Vermont, Wyoming, Tennessee, Utah, and New Hampshire, had enacted statutes recognizing DAOs as legal entities. A DAO without legal status may find it more difficult and uncertain when entering into and enforcing contracts.

Second, the SEC generally treats DAO-issued tokens as securities that are subject to the registration requirements under U.S. securities laws (see Weinstein et al. (2022) for additional details). The decentralized structure of a DAO makes it unclear, however, how it can comply with registration, disclosure, or reporting rules.

Third, although without management teams the DAO organizational structure addresses principal-agent problems between management and shareholders that plague traditional companies, DAOs still face another fundamental trade-off that traditional firms also face: the potential for conflicts of interest between large token holders, commonly known as "whales,"

[26]See Harvey and Rabetti (2024) for a discussion of governance risk in the DeFi context.

[27]In March 2022, a U.S. District judge ruled that the founders of the bZx DAO, a DeFi protocol, had formed the organization with the intention of circumventing U.S. corporate law and that the DAO was effectively the equivalent of a general partnership. In June 2023, another judge decided that the DAO was an unincorporated association, a form of entity that generally does not provide limited liability to its members.

and small token holders (i.e., users). The term “whales,” which is borrowed from traditional finance, describes individuals or institutions with substantial holdings that lead to market power. Whales can swing a voting outcome using their large holdings whereas dispersed small token holders cannot do so individually. Therefore, open-market trading in governance tokens may enable whales to accumulate enough voting power to manipulate votes. Such manipulation, which often manifests in what are known as governance attacks, provide short-term gains at the expense of minority token holders.

In April 2022, for example, a whale used a flash loan worth $1 billion to gain a 67% voting stake in Beanstalk, a decentralized stablecoin protocol, and passed a malicious proposal to drain $182 million in crypto assets from Beanstalk’s asset pools. The attacker exploited a vulnerability in the governance module in virtue of which any individual with a simple supermajority stake can pass a so-called “Beanstalk Improvement Proposal” at any time. Specifically, the attacker was able to deceive the community by making members believe that the proposal involved only donating money to Ukraine. Once the attacker acquired a supermajority governance stake, he invoked a function that allowed him to circumvent the usual life cycle of a proposal and execute the proposal immediately after voting on it (see Immunefi (2023) and Everything Blockchain (2022) for additional details).

In addition, decentralized governance may not result in decision-making that is as beneficial or timely as decision-making by professional managers who have developed relevant expertise, particularly when complex issues are involved. In the following sections, we review research on governance issues that DAOs face.

4.2.2 Voting power and participation in governance

Appel and Grennan (2023) classify 151 DAOs into three broad categories: DeFi, blockchain infrastructure, and Web3. DeFi accounts for 61% of DAOs in their sample. Infrastructure DAOs, which create and manage tools that are used to scale the cryptocurrency industry (e.g., Ethereum Name Service), account for 7% of the DAOs. Web3 DAOs, which engage in a variety of activities related to new internet services (e.g., gaming, social media), account for 32% of the sample. Perhaps counter-intuitively, rather than democratizing decision-making (which was the main mission of DAOs), in most DAOs a small number of entities exert control. Appel and Grennan (2023) find that the average Herfindahl-Hirschman Index (HHI) across all three DAO categories is high, exceeding 0.29. On average, the top three token-holder addresses control more than 67% of the voting power. The top three token holders also tend to vote in unison: between 61% and 79% of votes cast by the top three holders in any DAO are unanimous. This high concentration of voting power is consistent with the pattern documented in Han et al. (2023), who show that the average HHI and top three owners of 179 major DAOs are 0.29 and 67%, respectively. Similarly, Laturnus (2023) finds that, for a large sample of DAOs, the average (median) Gini coefficient for token ownership is 0.39 (0.47), indicating high ownership concentration.[28] The average DAO's ownership structure has however become more diversified (decentralized) over time.

Several studies have analyzed voting power concentration for individual platforms. Goldberg and Schär (2023) find that, for Decentraland, an Ethereum-based virtual world platform, the largest holders' voting power ranges from 45% to 70%, depending on proposal

[28]The Gini coefficient is defined as $\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}|x_i - x_j|}{2n^2\bar{x}}$, in which n is the number of token holders, x_i is holder i's ownership share, and $\bar{x}$ is the average ownership share.

type (these are also whales, as mentioned above). Fritsch et al. (2022) examine the distribution of voting power for three DAOs, Compound, Uniswap, and Ethereum Name Service. They find that the Gini coefficient for voting power distribution is above 0.9 for all three DAOs, implying very high concentration. Taken together, the evidence suggests that voting power is quite concentrated in the average DAO, which, ironically, defeats the end goal of distributing governance power.

Makarov and Schoar (2022) observe that an entirely decentralized organization often struggles to make decisions efficiently. When ownership is dispersed, token holders have weak incentives to participate in governance activities because their votes are not likely to be pivotal, corresponding to shareholder apathy in standard corporations (e.g., Shleifer and Vishny, 1986; Grossman and Hart, 1980; Brav et al., 2022). DAOs generally exhibit low participation rates. Laturnus (2023) shows that, for a typical vote conducted off-chain (via Snapshot), 24% of token holders cast votes. On average, only 11% of token holders participate in on-chain voting, likely because of gas fees,[29] which can run as high as $170 for on-chain voting (Tally, 2021).[30] Similarly, Fritsch et al. (2022) find that, for Compound and Uniswap, fewer than 15% of circulating tokens participate in voting on proposals. Such numbers are substantially lower than the average voting turnout in the stock market, which is around 80% for institutional investors and 30% for retail investors (Brav et al., 2022, 2024).

Because governance tokens are issued for the purpose of granting holders the right to participate in the decision-making process on a decentralized protocol or platform, platform

[29]On a blockchain, the term "gas fees"denotes the cost associated with executing transactions or smart contracts on that blockchain. The term "gas" itself represents the unit used to measure the amount of work required to execute a transaction or contract operation.

[30]One caveat with these analyses is that some token holders may own multiple addresses and delegate voting to only one address, which will bias estimated wallet-level participation rates downward.

valuation and governance-token returns are related to voting participation rates. Interestingly, Laturnus (2023) shows that the relationship is convex, suggesting that the effect of participation turns strongly positive when the majority of DAO members become involved.

4.2.3 Conflicts of interest among token holders

To study the potential for conflicts of interest to arise between whales and small holders of DAOs formally, Han et al. (2023) base an equilibrium model of a DAO platform largely on token-based voting and dynamic token trading. A whale that controls the platform in the model garners private benefits (e.g., the passage of value-destroying proposals). The whale weighs private benefits against the cost of manipulating voting outcomes, with the cost including a loss in public value and trading costs involved in token illiquidity. The authors show theoretically and empirically that voting power concentration, empirically proxied by the HHI of voting power, harms platform growth but that harm can be mitigated by platform size, token illiquidity, and long-term incentives for whales. In particular, illiquidity shields users against negative effects of poor governance by increasing the cost a whale pays to acquire additional tokens, thus making manipulation of voting outcomes less likely. This liquidity effect on governance wears off quickly, though, with greater ownership concentration because, under high illiquidity, selling off a large stake after voting would entail a substantial price impact. Therefore, the whale prefers early liquidation, avoiding the need to implement proposals.

The apparent paradox involved, in virtue of which DAO governance can benefit from illiquidity, reflects the absence of active monitoring of management in light of DAO autonomy. We know that liquidity benefits governance in traditional corporations by encouraging active monitoring when principal-agent problems between management and shareholders arise(e.g., Maug, 1998; Bolton and Von Thadden, 1998). The finding that token illiquidity benefits DAO governance is consistent with recent theoretical developments, notably in Levit et al. (2024), who show that trading frictions can improve shareholder welfare by discouraging an firm's shareholder base from extreme behavior in the context of traditional corporate governance.

Even though it is possible for token illiquidity to discourage whales from exploiting a platform, there is considerable cost involved in the sacrifice of general token liquidity, making the market inefficient and raising transaction costs (Han et al., 2023). Consequently, "targeted illiquidity" has emerged as a prevalent practice adopted by contemporary DAOs. The imposition of a lock-in period, not unlike imposing a vesting schedule on equity shares, generates positive multiplier effects as more users participate but fails to generate side effects that often accompany illiquidity. Lock-in periods give whales less time to liquidate positions after voting while leaving (patient) users' welfare unaffected. Such intensified time pressure raises the cost to whales of implementing value-destroying proposals, thereby enhancing governance and promoting user participation. Voting models based on vesting schedules, often through "vote escrow" systems, are analogous to tenure-based voting systems and Loyalty Shares (L-shares) in the stock-market setting, as proposed by Edelman et al. (2018) and Bolton and Samama (2013), respectively. We note that Curve Finance, a DEX designed for trading stablecoins, pioneered vote escrow tokens, whose voting weights and shares of rewards are generally proportional to the preset locked-in time periods.

Another mechanism that can increase decentralization is airdrops, which are distributions of free governance tokens to current (and prospective) community members. In a standard airdrop, all current (and prospective) platform users are eligible to receive new tokens while a holder airdrop distributes new tokens to wallets that already hold some tokens. When airdrops distribute the same number of tokens to all eligible users, they are likely to advance decentralization, which is true even for holder airdrops, as it should reduce ownership concentration. Such airdrops may also "stimulate" demand as these events are typically used as marketing tools to raise awareness of a token. Non-pro-rata distributions can, however, be dilutive for existing (large) token holders, triggering objections by these holders, especially when token prices are not expected to rise sufficiently to compensate for the dilution. This trade-off suggests that airdrops are particularly effective for early-stage platforms whose governance tokens are not yet listed or widely held.

Anecdotal evidence supports the above prediction. For example, Uniswap, a leading DEX, airdropped at least 400 UNI tokens in September 2020 to each of the 250,000 addresses that had previously interacted with the protocol. This event appeared to have generated significant interest in UNI, which opened trading around \$3.50 shortly after the airdrop. The token price kept climbing over the next eight months, rising above \$40 in May 2021. Using a sample of 51 cryptocurrency exchanges, Makridis et al. (2023) find that airdrops are positively correlated with growth in token valuation and trading volume, but these benefits are concentrated among DEXs. Specifically, a DEX that conducts an airdrop experiences a 13 percentage point increase in the growth rate of its tokens' market capitalization. This evidence is consistent with the finding reported in Han et al. (2023) according to which ownership concentration has a negative effect on platform growth.

Instead of capturing control outright, a token holder can also bribe his peers to generate a favorable voting outcome. To study such collusion in voting, Braun et al. (2022) build a simple model of a DAO that is owned by a whale (e.g., a service provider who maintains the DAO) and many token holders. The whale obtains a private benefit by manipulating the protocol. If a majority of the token holders vote to convict the whale, its stake will be confiscated. Before the vote, however, the whale can bribe token holders to prevent the vote from passing. The authors show that ownership concentration and a stochastic voting scheme, under which a single decisive vote is drawn from the voter pool with a probability that is proportional to a voter's token holdings (i.e., the probability that a large holder's vote is adopted is higher than that for a small holder), make the DAO collusion-proof. The authors highlight the importance of ownership concentration. When voting is stochastic but each voter holds only a small number of tokens, it will still be almost costless for the whale to bring about an acquittal decision. A concentrated voter base, in contrast, is incentivized to refuse bribes.

4.2.4 Optimal voting systems for DAOs

Several studies have focused on studying the optimal voting systems for DAOs. Most DAOs have implemented stake-weighted voting, which is equivalent to the one-share-one-vote system used in shareholder voting, to incentivize information crowdsourcing from their users. These systems aggregate information through users' votes, where each user's vote is weighted by her token holdings. These systems work on the principle that owning more tokens gives users a greater skin in the game, incentivizing them to cast higher-quality votes.

Contrary to popular belief, however, when voters are strategic insofar as they vote to maximize the expected value of their tokens by taking others' votes into account, stake-weighted voting generally discourages truthful voting behavior and reduces a platform's predictive accuracy (Tsoukalas and Falk, 2020). Such "insincere" voting behavior is consistent with findings reported in the voting literature, including in studies of shareholder voting. Austen-Smith and Banks (1996) and Feddersen and Pesendorfer (1996) explain that voting based on one's own private signal (i.e., sincere voting) is inconsistent with rationality. Since token holders (shareholders) change voting outcomes only in scenarios in which they are pivotal, they vote strategically rather than sincerely and place a heavy weight on the information others must hold (e.g., Maug and Rydqvist, 2009; Matvos and Ostrovsky, 2010).

DAOs fail to attain the first-best accuracy that a centralized platform makes possible. In many cases, a platform could achieve equal or sometimes greater accuracy by pursuing an alternative aggregation strategy and/or by limiting token dispersion across users. A solution that might succeed in addressing the suboptimality of stake-weighted voting is quadratic voting, where the cost of acquiring voting power is convex. From a weighting perspective, this is equivalent to aggregating user votes based on the square roots of their stakes. In other words, the cost to a voter is a quadratic function of the number of votes cast, which implies that the number of votes equals the square root of the voter's stake.

Quadratic voting has been shown to restore optimality when voters hold perfect information (but diverse preferences) on the proposals on which they are voting (Lalley and Weyl, 2018). Benhaim et al. (2023b) compare quadratic voting and stake-weighted voting in the crowdsourcing setting, where voter incentives are aligned but voters possess imperfect information. The authors find that quadratic voting can be inferior to stake-weighted voting because it disincentivizes voters holding more information from casting sufficiently many votes to instill their beliefs. Both voting mechanisms approach optimality when the number of voters approaches infinity. Benhaim et al. (2023b) suggest that enhancing voting efficiency for DAOs requires boosting voter participation.

Benhaim et al. (2023a) analyze committee-based consensus protocols, which are used by some blockchain platforms, including Binance and Cosmos. These protocols require token holders to elect a committee of block producers who verify and add transactions to blocks.[31] This approval-voting method allows voters to approve multiple candidates. The authors find that the approval-voting mechanism converges on optimality quickly when the number of voters increases, even when it is relatively difficult to distinguish between honest and malicious candidates, the latter of whom may censor transactions or include invalid transactions in a block (e.g., minting tokens to their own addresses). In addition, the voting mechanism could outperform other mechanisms, such as single-choice protocols, that are in widespread use.

4.2.5 Optimal decentralized governance designs

An emerging body of literature has examined the conditions under which decentralization is optimal in comparison with the benchmark of a centralized platform or a social planner who maximizes total user surplus. Arruñada and Garicano (2018) explain that hold-up problems are common for centralized platforms. Once participants (e.g., application developers) have committed to a platform, switching is costly. This allows the platform to hold up participants

[31] Amoussou-Guenou et al. (2023) and Halaburda et al. (2021) study the means by which strategic committee members can reach consensus once they are part of a committee.

by implementing changes, such as increasing fees, that are costly to those participants. This hold-up risk leads to underinvestment. Decentralized platforms can resolve the hold-up problem because of the threat of a hard fork (by some participants), which would split a blockchain network into two separate chains. This solution, however, comes at the cost of weakening coordination in the adoption of new innovations. Consistent with this theory, Chen et al. (2021) find an inverted U-shaped relationship between the degree of decentralization and platforms' market capitalization, developer attention, development activity, and social media followers, suggesting the optimality of modest decentralization.

How would an optimal decentralized platform issuing governance tokens compare with a centralized platform in the context of personal data-sharing? Bena and Zhang (2023) show that, when data enter the production function, decentralized platforms yield a greater user surplus than centralized platforms. For "data-heavy" platforms, which require highly advanced technology, adopting a token-buyback mechanism can achieve optimality. Implementing a buyback mechanism for governance tokens would enable a platform to promote early adoption by committing to the repurchase of tokens in the future. Therefore, a decentralized platform can achieve greater output than a centralized platform. This finding provides a rationale that encourages a founder to set up a platform with decentralized token-based governance rather than a traditional corporate governance structure.

For a typical token-based platform, users who hold tokens for transactions and speculators who hold tokens for returns coexist. Speculators affect users through two opposing effects: speculators harm users and platform adoption by driving up token prices in good times (a crowding-out effect), but benefit them by providing liquidity, especially in bad times. Mayer

(2021) suggests that a natural approach to mitigating the crowding-out effect and thereby promoting adoption is to unbundle the investment and utility functions of tokens. This can be achieved using a dual token structure that comprises a governance token and a stablecoin. The governance token is held for financial returns while the stablecoin serves as a transaction medium and holding it brings no return.

In theory and practice, a distributed ledger can be centrally managed by a single authority or a committee of "validators." Which design leads to optimality, where optimality is defined as maximizing the surplus from token trades net of the validation costs? Auer et al. (2021) find that decentralized record-keeping with multiple validators is generally more efficient than relying on a single authority. A single validator is optimal only in the presence of trustworthy validators. This occurs when strong intertemporal incentives, which involve the present values of future validation rewards, raise the cost of misbehaving (e.g., adding invalid transactions to a block) intolerably high for validators. Weak intertemporal incentives, however, make preventing a single validator from misbehaving too costly. The authors also show that a "stakeholder economy," in which participants manage record-keeping, can result from decentralization: "internal" validation is the only way to support trading in equilibrium with multiple validators. In other words, having validators who also participate in the market and thus have an intrinsic interest in keeping it functioning smoothly facilitates the achievement of good governance and honest record-keeping.

5 Conclusion and Future Research

The intersection of corporate governance and technology is a dynamic and multifaceted landscape that continues to evolve rapidly. Data and technology have undeniably transformed our financial markets and corporations, ushering in both promising solutions and complex challenges to their governance. Like technology and institutional innovations in the past, new technologies embodied in big data, AI, and blockchains have the potential to solve problems, enhance efficiency, and level the playing field in corporate governance; however, they also give rise to new inequalities and governance dilemmas. The traditional board-centric model and its associated shareholder monitoring and regulatory scrutiny, which have long been the cornerstone of corporate governance, must adapt to the changing structure of information, preference aggregation, and contractual feasibility in the digital age. This adaptation is essential to ensure that governance structures remain effective and responsive to the needs and expectations of shareholders, stakeholders, and the broader society.

Looking ahead, we see numerous exciting avenues for future research in the realm of corporate governance and technology. Upcoming topics include analyzing the potential of blockchain technology and smart contracts to enhance transparency, trust, and automation in corporate governance processes; examining how AI and advanced analytics can be leveraged to improve decision-making, risk assessment, and compliance within corporate boards and management; and exploring innovative ways in which technology can facilitate meaningful engagement between shareholders and companies. We can also count on IoT technologies and decentralized verification systems to hold firms to account for their ESG commitments. Finally, "RegTech" is catching up with updated regulatory frameworks that address the unique challenges posed by technology-driven corporate governance while striking a balance between innovation and oversight.

In conclusion, the ongoing interplay between corporate governance and technology presents both opportunities and challenges that require careful examination and adaptation. As technology continues to evolve, researchers, policymakers, and practitioners must collaborate to ensure that corporate governance remains effective, equitable, and responsive to the changing business world.

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