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 the way a corporation is directed, administered, or controlled. Technology both enhances and disrupts the traditional board-centric corporate governance system, offering efficiency gains and transparency improvements while introducing new challenges and risks. This paper presents a comprehensive examination of three key themes: the redefinition of information and information asymmetry through the generation of and access to big data; blockchain's transformative potential in aggregating preferences and exercising shareholder voting rights while blurring the lines between securities and tokens; and the impact of smart contracts and their underlying infrastructure in expanding contracts and enabling decentralized governance through DAOs. These innovative technological solutions empower stakeholders to exercise governance rights effectively, but their complexity also give 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 dynamic business environment.

Keywords: Corporate Governance, Technology, Blockchain, Big Data, AI, DAO

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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 ESG 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 between those in control and the large and diverse group that owns the firm naturally gives rise to conflicts of interest. The second force is the information asymmetry between insiders and outsiders, as described in the long literature pioneered by Leland and Pyle (1977). There exists a gap between what insiders, especially senior management, know about the current condition and prospects of the firm, and what outsiders are informed of. Uninformed outsiders are, nevertheless, eager to infer some of the unknown based on the actions taken by the former (e.g., capital structure adjustment or securities issuances) and are

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

often intelligent in doing so, giving rise to motives by the firm to signal their quality (Myers and Majluf, 1984). Such a game of information inference often generates additional moral hazard and information frictions.

These two factors have led to widespread adoption and establishment of a board-centric governance structure in the United States. While CEOs and senior managers serve as the 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 facets to the realm of corporate governance and research in this domain. Firstly, data and technology have the potential to reshape the way corporations are governed. Real-time access to new information, improved infrastructure, and innovative toolkits can either enhance traditional systems or give rise to entirely new ones. Secondly, the governance of data and technology presents pressing issues. Questions arise about data ownership, privacy rights, data monopolies, biases associated with algorithms, and the ethics of artificial intelligence (AI). Thirdly, the incorporation of big data and machine learning techniques into corporate governance research has swiftly transitioned from being a new trend to becoming a mainstream methodology. Machine learning-based measures, analyses, and newer tools that use generative AI have revolutionized the approach to conducting corporate governance research.

Each of these three aspects deserves its own in-depth examination. In this context, we have chosen to focus on the first part, how data and technology are reshaping the corporate governance system that we have been familiar with. Under this overarching theme, we aim to 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 like blockchain, on ownership and governance. Third, the role of smart contracts and their underlying infrastructure in expanding the contractual landscape by altering mechanisms for verification and enforcement.

Technology has led to an explosion of data in the corporate world. Real-time information, big data analytics, and artificial intelligence have revolutionized the way corporations access, process, and use information. Shareholders and other stakeholders now have access to a wealth of data, allowing them to monitor company performance more closely and make more 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 the firm, such information asymmetry is fundamentally different from the classic definition based on the dichotomy of insiders vs. outsiders. Exploring how technology shapes this changing information structure and its impact on corporate governance is crucial to understanding the governance of data-intensive businesses. For details, see Section 2.

Distributed ledger technology, such as blockchain, 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. The transparency and immutability of the blockchain can enhance trust among stakeholders by providing a single source of truth for ownership and transaction records and corporate actions (Yermack, 2017). This can streamline processes such as shareholder voting and proxy management. Additionally, blockchain enables the creation of digital assets and tokens that can represent ownership in new ways, such as tokenized securities and governance rights. These innovations have expanded the scope of ownership and corporate governance that have mostly been based on securities and their trading in the marketplace, including exchanges and over-the-counter. 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). They mitigate some, and create more, governance issues associated with the separation of ownership and control, and information or preference aggregation. For details, see Section 3.

Smart contracts are self-executing contracts with the terms of the agreement directly written in code. These contracts automatically execute 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 help minimize transaction costs and prevent fraudulent and unethical behavior. By enforcing pre-agreed 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 contrasts also give rise to additional limitations, such as the need for and challenge in online-offline interactions. Smart contracts may also facilitate collusive behavior. Therefore, exploring how smart contracts change the verification and enforcement mechanisms and their implications for corporate governance is crucial in a digital business landscape. For details, see Section 4.

These three areas represent critical facets of the evolving relationship between technology and corporate governance, each with its 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 Flow of information from the firm 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 serves as a critical tool for enhancing corporate governance by providing the necessary information and visibility for stakeholders to make informed decisions and exercise proper oversight of a company's activities. We believe that "sunlight is the best disinfectant," which is, if there were more transparency and more publicly available information, many governance issues would have gone away or had been significantly mitigated.

One of the most important paradigms of asymmetric information is from Myers and Majluf (1984) and the work that follows (e.g., Viswanath, 1993; Healy and Palepu, 2001; Hennessy et al., 2010), which is the idea that firms have information that investors do not, and yet investors are eager to gain or infer information from firms' disclosures or actions (e.g., securities issuances). A more recent literature (Chen et al., 2007; Edmans et al., 2015) and a survey by Bond et al. (2012) acknowledge that the information flow between insiders and outsiders could go in both directions: Stock prices give managers incremental information to make strategic decisions. For example, reactions in the stock market and changes in company valuation enable managers to make more informed 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 incremental to managerial private information.

2.2 Data generation and new information asymmetry

Data generated as well as 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 more informed than outsiders. By collecting and analyzing data from various sources, including internal operations, customer behavior, market trends, and industry benchmarks, firms can uncover patterns, trends, and correlations that outsiders may not have access to.

New software to predict supply chain and sales enables firms to stay informed about imminent issues 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 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 potential problems arise. These innovative technology solutions empower firms to stay ahead of challenges and capitalize on opportunities, and also provide firms more time and space between when and what they know and when and what they are required to disclose.

On the other hand, a significant portion of the 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 metaphorical (such as credit card transactions, internet traffic, and social media posts). Individuals with timely access to such data may gain insights into the performance of businesses of a Starbucks store or the reception of a new car model of Toyota long before the CFOs of these companies receive official reports. It is important to note that this information is not only universal—available to anyone with the requisite technology or a fee—but also uneven in accessibility due to the expertise and resources needed for data collection and analysis. This dynamic introduces a new form of asymmetry among outsiders rather than solely 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 gain information and make informed decisions. This data is considered "alternative" because it goes beyond the more traditional sources of information, such as financial reports, surveys, and government statistics. Instead, it encompasses a wide range of data, often unstructured or semistructured, 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, which can be used for purposes such as tracking supply chain activity, monitoring external conditions (e.g., whether), 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, which is used to analyze public sentiment, monitor brand mentions, and predict market trends.

Satellite Imagery: High-resolution satellite images used for applications ranging from monitoring 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, which is used to gauge public sentiment and assess market sentiment.

Alternative data holds significant value as it can furnish 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 its origin and distribution, as a substantial portion of it is generated and disseminated beyond the confines of any given firm. In cases like satellite images or social media chats, the data is 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 information asymmetry that has traditionally separated insiders from outsiders.

The initial wave of research on alternative data demonstrates its potential to predict 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 raises governance concerns, 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. The introduction of such data reduces the cost of acquiring information, especially in firms where sophisticated investors have strong incentives to uncover hidden insights. This increased integration of information into stock prices curtails opportunistic managerial trading. Simultaneously, managers are incentivized to make more efficient investment and divestment decisions, aligning their actions with the enhanced information signals embedded in stock prices.

A crucial insight from Zhu (2019) highlights that the large volume of externally generated data improves governance through two distinct channels, both of which revolve around the theme of information. Firstly, alternative data, often unstructured and requiring advanced technologies such as natural language processing (NLP) and machine learning for analysis, serves to level the playing field of information between firms, as security issuers, and investors of those securities. This effect not only curtails insider rents, but also alleviates deadweight losses in signaling games arising from information asymmetry. Secondly, big data manage to find their way into security prices, enhancing the latter's informativeness, thereby rendering them more efficient signals for guiding investment decisions and acquisitions, and incentivizing effective management.

In a recent study, Cao et al. (2023) further quantify the impact 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 to the benchmark of an "AI analyst" who solely relies on processing the firm's disclosed information. However, this improvement is contingent on the affiliation of the analyst with a brokerage that possesses AI capacity, defined as those firms that hire 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 bridges the information gap between firms and their investors, but only with the help of technology needed to extract and synthesize big data.

2.4 Data, technology, and "public information asymmetry"

The demand for specialized talent and the need for financial and technical resources, including cloud computing, to acquire and process data that should, in theory, be accessible to all 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 from the most publicly available information, such as data collected and disseminated by regulatory authorities like the SEC. One prime example is EDGAR, the Electronic Data Gathering, Analysis, and Retrieval system, established in 1992. EDGAR's functions encompass the automated collection, validation, indexing, acceptance, and forwarding of submissions made by companies and others who are legally obligated to file forms with the SEC. Designed as a central hub for investors and other stakeholders to access corporate information, EDGAR was originally envisioned to level the playing field of information and promote broad market participation. However, the hurdles associated with accessing and effectively utilizing this wealth of data have inadvertently contributed to a disparity in information access.

EDGAR estimates an annual download volume of approximately 3,000 terabytes of data from its website. On the contrary, computational neuroscientists generally posit that the human brain stores between 10 and 100 terabytes of data.[2] This marked disparity suggests that the majority of the document processing is carried out by machines. According to research 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, Deputy Chief Economist and Deputy Director of the Division of Economic and Risk Analysis at the SEC, estimated in 2018 that approximately 85% of the documents accessed are 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 underscores that while the information is technically "public," disparities in the ability to process these data could give rise to information asymmetry – a situation similar to "equal rights, differential power."

The greater the deployment of algorithms and AI in the retrieval and processing of information, the faster the response from well-equipped investors, leading to a more rapid incorporation of information into stock prices. This relationship is examined and validated in the study by 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 expected to be profitable based on the stock price 15 minutes later) occurs nearly 12 seconds sooner. These

[2] Source: https://aiimpacts.org/information-storage-in-the-brain/.
[3] Source: https://www.sec.gov/news/speech/speech-bauguess-050318.

results strongly suggest that technology facilitates the expeditious incorporation of information into stock prices, thereby enhancing their informativeness in relation to firm disclosures.[4] This effect is generally considered positive for both market efficiency and corporate governance.

There is the other side of the same story. The growing integration of machines and AI into research and trading processes is also amplifying informational 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 the stock is extensively traded 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, designed to level the playing field, also fuels a widening information gap among its intended recipients. Such information asymmetry cannot be rectified solely through the implementation or spirit of regulations such as Regulation FD.[5]

2.5 Feedback effect from technology to corporate decisions

The awareness that machines are increasingly processing corporate disclosures, press releases, and earnings calls underscores the motive for firms to adapt their communication strategies. In the past, these communications were primarily tailored for human consumption,

[4]The aggregate impact of AI-controlled or assisted trading on stock price informativeness is not clear; see the model by Dou et al. (2023). In particular, AI-powered trading can decrease the informativeness of stock prices, as informed AI speculators can autonomously learn 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. Regulation FD's objective is to ensure comprehensive and equitable disclosure.

but the changing audience calls for a shift in communication strategies. Firms should have the incentive 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 by AI readers and listeners. The study by 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 sentiment) by Loughran and McDonald (2011) and the advent of BERT by Google in 2018.[6] The findings reveal that companies whose filings are more 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, though not necessarily by the earlier psychological Harvard-IV dictionary. Furthermore, companies with a higher proportion of AI-powered institutional investors also demonstrated a greater propensity to transform their disclosure materials to reduce the likelihood of being perceived negatively by the BERT algorithm after its launch.

Disclosure serves as just one illustrative example of how evolving technology molds companies into adaptation, a phenomenon of a "feedback effect" from technology. That is, while financial markets reflect firm fundamentals, market perception (which is now powered by AI) also influences managers' information set and decision making (see the survey conducted by Bond et al. (2012)). 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 reverse-

[6]Bidirectional Encoder Representations from Transformers, or BERT is a natural language processing (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.

engineerable to varying degrees), agents affected by these decisions may have 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 the work of 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 research by Calvano et al. (2020). As technology continues to advance, it becomes increasingly imperative for further studies to explore the impact of AI and the behavior it induces in the realms of financial economics and society at large.

3 Governance via Blockchain

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 the company on behalf of shareholders, who expect to receive residual cash flows based on their ownership of the business. Because corporate directors are elected by shareholders, voting by the latter is a crucial mechanism to influence company management and operations. Under the current proxy voting system, however, shareholders cast their votes through intermediaries,[7] which can result in inefficiencies such as "over-voting" (Hu and Black, 2005; Smith, 2013), management manipulation (Bach and Metzger, 2019), and inaccurate vote tallies and incomplete distribution of ballots (Kahan and Rock, 2007).

These issues are especially problematic during proxy contests, i.e., contested elections by shareholders for corporate control changes including M&A and contested board elections. They are ex-ante pivotal voting events in which both incumbent management and a challenging dissident expect a meaningful chance of prevailing (Brav et al., 2020, 2024). The proxy contest between Procter & Gamble (P&G) and Trian Fund Management, a leading activist investor, best exemplifies such inefficiencies. Shortly after the October 2017 shareholder meeting, P&G claimed a narrow victory. The winning side, however, kept flipping with each subsequent count due to 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. However, a month later, the final vote tabulation indicated P&G nominees won by a margin of 0.025% of the votes cast.

Over-voting refers to some shares being voted multiple times, and in extreme cases, it could lead to more votes cast by shareholders than there are eligible shares to be voted. This situation typically arises due to 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 a pro-management bias. When exercising their

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

appraisal rights (Jiang et al., 2016, 2020), due to the same inefficiencies, dissenting shareholders may also "over-surrender" shares to the 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.[8]

In addition, Listokin (2008) and Bach and Metzger (2019) present evidence that close votes on management proposals, such as director elections and Say-on-Pay votes, and shareholder proposals are disproportionately more likely to be won by management than by shareholder activists, suggesting that vote outcomes are subject to manipulation. Bach and Metzger (2019) write 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 for managers under normal circumstances (Fos and Jiang, 2015). Such a sorry state of the current shareholder voting landscape led prominent Delaware attorney Gil Sparks to famously say in 2018 that "in a contest closer than 55% to 45%, there is no verifiable answer to the question 'who won?"'[9]

[8]See Brown (2018) for details.

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

3.1.2 How blockchains reshape shareholder governance?

Blockchain is a distributed digital ledger technology that is used to record and secure transactions across a network of computers. Its defining features 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 redoing the work required to add subsequent blocks to the chain. 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. 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 is still at an experimentation stage. A notable project was the 2016 Nasdaq pilot program that used blockchain voting in shareholder 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 if necessary, and review previous meetings and votes. In April 2018, Dutch company KAS Bank tested an Ethereum-based blockchain service for shareholder voting at its annual meeting. The experiment intended 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 enhance shareholder rights. Here are a few examples. First, 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 compared to 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). Such an idea has been in implementation by the Long Term Stock Exchange (LTSE) (https://ltse.com/) founded in 2015.

Second, blockchain technology allows for the creation of different classes of shares 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 different 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 of insiders, backed by legal enforcement.

Third, blockchain can help improve the traditional dual-class share system. While the literature has been mostly negative on dual class as it violates the general principles of shareholder governance, recent research suggests that such a system could help early-stage firms but it often times overstays (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 could also empower retail investors by allowing them to set up decentralized autonomous organizations (DAOs) that serve as self-sufficient proxy advisories. DAOs are entities without 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 Section 4.

3.2 Governance on the blockchain: Coins and tokens

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 that of token-based financing activities and transactions, the latter is still in the early stages of defining the appropriate legal/regulatory frameworks and best practices. Within this context, a burgeoning body of literature has rapidly developed, encompassing both theoretical and empirical research.

3.2.1 Governance of startups on blockchain

(i) Institutional background and taxonomy

An ICO is 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 for an ecosystem, and the right to cast a vote on governance issues (for start-ups organized as decentralized autonomous organizations, or DAOs). We refer the 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 initial coin offerings (ICOs). We will instead focus on governance issues.

A typical offering begins with the presentation of a white paper, which describes the business idea and model, the team, and the technical specifications of the underlying project. The entrepreneurs lay out a timeline for the project and describe how the funds raised will be spent, such as on marketing and research and development. They often specify a "soft cap" that is the minimum amount received at which the initial offer will be considered successful. Startups usually also specify a "hard cap," which is the maximum fundraising goal for a crowdsale. Investors who purchase tokens early may be given preferential terms, in the form of an "early bird" bonus or discount. One purpose of the bonus or discount is to compensate for the higher risks that early buyers bear. Some ICOs include a presale period, also known as a pre-ICO. Presales generally target larger investors, including institutional investors. The fundraising targets for presales are usually lower than those for the main sales, and tokens are typically sold at steep discounts.

By industry convention, an ICO is considered a success if the amount it collects exceeds the soft cap. If a token sale does not reach its soft cap, funds are usually returned to investors.

This is the "all-or-nothing" arrangement commonly used in ICOs. In rare cases, a team may decide to move forward regardless. If the hard cap is reached, additional subscriptions will be rejected and the funds will be returned.

After an ICO is successfully completed, the entrepreneurs typically begin to plan for an exchange listing. Most centralized cryptocurrency exchanges require an application and a listing fee and, depending on each case, the period preceding a listing can last from several days to several months. Secondary market trading starts immediately after listing. If a project is implemented successfully and more capital is needed, a startup may return to the ICO market for a seasoned offering. See Lee et al. (2022) for the timeline for a typical ICO.

Regulatory scrutiny, high-profile fraud cases, and the fall in digital currency prices likely contributed to the dramatic cooling of the ICO market in recent years.[10] 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., in SEC v. Ripple, may be deemed securities and hence should be subject to equivalent laws and regulations governing securities issuance.[11] The two new forms navigate securities regulations better than ICOs, primarily because they are specifically designed 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

[10] 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, there were only 29 ICOs seeking to raise $50.2 million. See `https://coinmarketcap.com/ico-calendar/` for details.

[11] 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.

investor protections, such as adherence to Know Your Customer (KYC) and Anti-Money Laundering (AML) regulations, similar to those 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 lacked.

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 a standard token (with a capped total supply and the ability to burn tokens) within minutes. 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 of which determines the price of the token (see Li et al. (2022) for more details on these steps). Unlike listing on a CEX, where the token needs to pass through the exchange's screening process, all the steps for DEX listing are automated.

Because ICOs do not go through the due diligence, road shows, and regulatory filings typical of IPOs, there are naturally concerns about the adverse selection issues that have plagued the market for token offerings. 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 experience higher employment and avoid failure (Howell et al., 2020), and those that disclose information on the team or insider ownership have a higher likelihood of a successful fundraiser (e.g., Bourveau et al., 2022). The next sections will go into more details about these mechanisms.

(ii) Tokenization vs. traditional financing

A growing theoretical literature has studied the benefits and costs associated with token offerings, compared to traditional financing schemes. Among them, Sockin and Xiong (2023) examine tokenization as an innovation to 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 are reminiscent of the classical corporate governance issue: separation of ownership and control which leads to agency conflicts.

Tokens, which usually refer to "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 for 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 amount of 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 profits (or residual cash flows) as in the case of equity. It turns out that this feature of token financing helps mitigate certain agency conflicts in the traditional financing model while creating new ones.

It is well understood that equity financing leads to underprovision of effort by an entrepreneur in the spirit of Jensen and Meckling (1976), since the entrepreneur internalizes the full cost of his effort but only part of the platform's profit. Token financing also leads to effort underprovision because the founder's claims are partial. However, this aspect of moral hazard is less severe due to the fact 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.

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

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 occurs because, after selling a fraction of tokens to investors, the entrepreneur internalizes only a portion of the platform's revenue, while bearing the full burden of production costs. The underproduction issue becomes more pronounced when the marginal production cost remains high even as production volume increases. 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 underprovision of effort. Consequently, it dominates equity financing as a more efficient funding method due to inherent governance alignment.

Another advantage of token financing, relative to equity financing, is that tokenization can act as a commitment device to prevent a platform from exploiting its users, such as selling user data to third parties (Sockin and Xiong, 2023). For example, Amazon was investigated by the European Union in 2018 for using its merchants' transaction data to launch private label products that directly competed with those merchants. Equity owners would choose this action when the transaction fees from the platform fall below the gains 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 the 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 collectively would not act to exploit themselves. Allocating control of the platform to users through decentralization is a key appeal of tokenization, which we will come back to when discussing DAOs.

The downside of tokenization analyzed in Sockin and Xiong (2023) is that there is no equity owner who would subsidize user participation to maximize a platform's network effect. In the digital era, centralized platforms typically devote substantial resources to subsidize user participation to increase 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, shareholders of these platforms bear the costs of subsidizing user participation to maximize future profits, which increases with the size of the user base. This trade-off makes utility tokens a more appealing funding scheme than equity for platforms with relatively weak fundamentals, measured by users' aggregate transaction needs. This is because the concern about equity owners exploiting users is high when transaction fees are low, which makes the commitment created by tokenization particularly 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, the platform may need to provide them with an initial subsidy. Because providing such a subsidy requires additional outside financing, it further dilutes the entrepreneur's stake in the platform, exacerbating effort underprovision under equity financing. Through selling tokens with voting rights, the entrepreneur can credibly relinquish her power to increase the transaction fee once the platform becomes operational, as in Sockin and Xiong (2023). Tokenization thus eliminates the threat of hold-up, which makes users reluctant to pay a fee (i.e., an investment) to join the platform ex ante because they become vulnerable once they join the platform and their cost of joining becomes sunk. 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.[12]

[12]Lee and Parlour (2022) and Goldstein et al. (2019) show that token financing can improve efficiency (i.e., mitigate 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 relative to utility tokens?[13] 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 as long as profit sharing can be credibly implemented (through smart contracts). Gryglewicz et al. (2021), however, show that dividend rights granted to security token holders spur platform adoption but dilute developers' equity stake and therefore undermine incentives. As a result, an increase in financing needs or in agency conflicts leads to a decrease in token security features. 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 different contracting possibilities under the two financing methods (which we will discuss in Section 4).

The ability to commit to revenue (or profit) sharing reflects a distinguishing feature of tokens: algorithmic commitment (see Cong et al. (2022) for a discussion of blockchain commitment). Smart contracts enable commitment and automated implementation of certain contracts. However, blockchain-enabled commitment is not a panacea. As we detail in Section 4, the commitment space is limited and smart contracts can incorporate only limited contingencies, not to mention that one needs oracles to feed market signals onto blockchains. A case in point is Quantstamp, a smart contract auditing platform, which was embroiled in controversy in 2018 when it did not adhere to a medium of exchange commitment to accepting its QSP token but instead accepting U.S. dollars and Ether for its services.

[13] A security token is the blockchain equivalent of a securitized asset traded on the stock market. 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 prone to scams, fraud, and abuse, primarily due to lack of regulation. In the absence of any "external" governance mechanisms (such as rating agencies and 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 set 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 IPO, Brav and Gompers (2003) show that this commitment device to alleviate moral hazard problems is the best explanation for the normally 180-day lockups of insider shares in IPOs. Howell et al. (2020) find that these governance measures 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 experience higher employment, avoid failure, and be eventually listed on CEXs.

Most ICOs offer early-bird bonuses to attract investor subscriptions. However, excessively high bonuses may lead wary investors to conclude that such ICOs are overpriced or even potential 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 have 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 be 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 and $75 million 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 increased investor protection enhances confidence and encourages investor participation.

The relation between measured governance and ICO outcomes mirror 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 raised capital, and post-ICO listing. Johnson and Yi (2019) find that in countries with weak regulation, ICO issuers tend to voluntarily adopt more governance mechanisms, including voting rights and lockup agreements. These governance mechanisms are associated with less managerial shirking, a higher likelihood of fundraising success, lower underpricing, and more efficient 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 potential cash flows associated with its platform. The classic paper by Leland and Pyle (1977) analyzes this problem and shows 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, retaining a reasonably high fraction of tokens in an offering can send a signal to the market that the entrepreneur has more skin in the game, and thus is more likely to expend serious efforts in developing the platform.

Information asymmetry associated with ICOs is likely to be more severe than that in IPOs (Lee et al., 2022). First, blockchain ventures are much younger and less established compared with the typical IPO firms. The latter tend to have tangible assets and developed products for their customers. In contract, most ICOs offer only a blueprint of their future development, which is typically envisioned in white papers posted on the ICO webpages. Such information may not be sufficient for individual investors to understand the underlying venture. Second, most ICO investors are retail investors, who likely lack sufficient knowledge of the underlying project (especially when the project develops innovative technologies) and financial markets in general. In contrast, IPO investors are mostly institutional investors who are generally more sophisticated than ICO investors. Third, ICOs lack a traditional underwriting process that IPOs employ. Therefore, a significant stake retained by the entrepreneur could play a crucial governance role to align incentives of the entrepreneur and token holders. 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 prediction above, Lee et al. (2022) find that when a smaller fraction of tokens is offered to investors (i.e., more 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 ones, with the difference being statistically significant. The fraction of tokens for sale is also positively associated with an ICO removing its white paper (which usually happens for compliance reasons or a lack of progress) or being charged for fraud. Davydiuk et al. (2023) also find that token issuers retaining a larger fraction of their tokens are more successful in their fundraising efforts, measured by funds raised and exchange listing, and more likely to develop a working product. Moreover, they show that retention is a stronger signal when markets are crowded or investors do not have as much time to conduct due diligence. Overall, empirical evidence suggests that investors favor ICOs in which entrepreneurs' and investors' incentives are more aligned through higher insider stakes.

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 one), signaling is possible with both tokens and equity. When this happens, the low-quality entrepreneur's incentive to imitate decreases and the high-quality one is able to sell a larger stake in the platform without the risk of being imitated. On the contrary, when platform heterogeneity is high, the low-quality entrepreneur's incentives to imitate are so strong that it is impossible for the high-quality entrepreneur to signal with either equity or token retention while raising sufficient funds. Finally, for moderate values of platform heterogeneity signaling is possible with tokens but not with equity. As shown in Section 3.2.1 (ii), the entrepreneur is able to retain a larger share of the platform's future cash flows by issuing tokens, relative to the case where equity is issued. A larger retention rate sends a more credible signal about platform quality. As a result, token financing expands the parameter space in which signaling to investors is possible.

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 webpages, to mitigate information asymmetries between issuers and investors during token offerings. One likely reason is that there were few investor protection rules or disclosure regulations, hence voluntary disclosure serves a complementary governance role, consistent with the large literature on public firm voluntary disclosure (e.g., Verrecchia, 1983; Eng and Mak, 2003). However, these disclosures are generally unaudited and largely unverifiable, which raises investor protection issues and questions about their effectiveness. Lee et al. (2022) and Bourveau et al. (2022) find that nearly all ICOs have published a white paper, which is the primary means that blockchain startups communicate with potential investors before an offering takes places. However, some platforms pull their white papers immediately after the sales are concluded or even during a sale, and such behavior is highly correlated with fraud. Lee et al. (2022) find that 7.7% of all ICOs do not have a downloadable white paper, and Howell et al. (2020) show that only 86% of issuers have a non-missing 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 on 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, exposing the fact that most ICOs are offered on the basis of inadequate disclosure of information. The authors also show that an even greater share of ICOs do not elaborate on the applicable law, segregation or pooling of client funds, or the existence of an external auditor. In addition, Bourveau et al. (2022) find that few white papers make risk or financial disclosures, and only 14% include information on future dividends or distributions.

Though traditional firms have more requirements and channels for disclosure, an alternative disclosure channel is through GitHub, which is a powerful tool for blockchain developers 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 amount 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 development progress of the platform in real time, which is not available for investors in traditional firms. Howell et al. (2020) and Bourveau et al. (2022) find that 53% of their sample ICOs post their source code to a GitHub repository.

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

3.2.2 Governance void: The dark side of the blockchain

Many people, entrepreneurs and investors alike, often 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. However, this perception overlooks the crucial role that governance plays in ensuring accountability, sustainability, and ethical practices within these ventures. The risk of unchecked power and information asymmetry does not spare high-tech entities or systems. The collapse of the FTX cryptocurrency exchange is a case study. 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."

Nicolle (2023) surveys 60 blockchain/cryptocurrency companies and finds that only half of the businesses engaged an independent auditor to assess their finances and 63% of the companies had an independent board of directors, although nearly all of the 60 firms had raised outside investments. Among those without independent boards were major exchange operators, such as Binance and Huobi, and Tether, issuer of the largest stablecoin. This is in stark contrast to (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 pervasion still unknown. We proceed to review studies on these topics in this subsection.

(i) Misreporting and manipulation

Misreporting and manipulation by and on cryptocurrency exchanges have been a major concern by regulators and investors. Fusaro and Hougan (2019), in their Bitwise report presented to the SEC, indicate that 95% of trading volume on unregulated centralized exchanges (CEXs) appears to be fake 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. (2023) use statistical and behavioral patterns in trading to detect washing trading on 29 centralized exchanges. They find that wash trading is prevalent on unregulated exchanges, which generally lack effective corporate governance, but is absent on 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 for 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. (2023). Amiram et al. (2020) show that competition among exchanges leads to volume inflation.

Wash trading is not restricted to centralized exchanges. Victor and Weintraud (2021) find that wash trading worth $159 million has taken place on small decentralized exchanges, such as EtherDelta and IDEX, which lack governance oversight by any party. It is perhaps not surprising that wash trading also plagues the non-fungible token (NFT) market,[14] which is generally much less liquid than the cryptocurrency market. Wash trading makes the market appear more liquid, thus attracting potential buyers. Work by von Wachter et al. (2022) and Oh (2023) documents significant NFT wash trading volume on the Ethereum blockchain, consistent with findings in industry reports.[15] In addition, CryptoFisher (2018) estimates that a 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 Bitcoin price during the sample period. Specifically, two actors' suspicious trading

[14]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.

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

activity is associated with a 4% rise in 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, these price-support activities occur more aggressively immediately below salient round-number price thresholds where price support may be most effective. Both studies support the view that price manipulation can have substantial distortive effects on cryptocurrency prices.

Pump-and-dump schemes (P&Ds) are a form of price manipulation that involves artificially inflating an asset's price before selling. Securities regulators deem these schemes illegal. However, P&Ds are pervasive on CEXs as they lack incentives to police and report these incidences. These events also take place frequently on DEXs that feature high speed and low costs, such as PancakeSwap, as a typical P&D scheme concludes within several minutes (Li et al., 2018). Li et al. (2018) find that most P&Ds lead to short-term episodes where prices, volume, and volatility increase dramatically followed by quick reversals. The documented evidence, including price run-ups before P&Ds start, implies that significant wealth transfers between insiders and outsiders occur. Furthermore, the authors exploit two natural experiments to study 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 to randomly pump cryptocurrencies listed on the exchange in October 2018. The authors conclude that P&Ds are detrimental to 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.

"Hostile takeovers" have their analogies on blockchain except that such endeavors on the blockchain have so far been malicious in nature. Governance attacks refer to situations where players manipulate blockchain platforms that use decentralized governance structures by gaining enough voting rights to reshape the rules or influence enough token holders to cast biased votes on a 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, the large 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 more 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 more 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 interest (Buterin, 2021).

Another type of governance attacks launch through the proof-of-work systems, the most common system for validating on-chain transactions. It can occur when a single entity or a coalition of entities gains significant control over the mining power or computational resources of the network, allowing them to influence decision-making processes. The system may lead to a situation where blockchain conglomerates, which are firms that operate in multiple businesses of the blockchain industrial ecosystem, "control" the governance of the blockchain (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 the blockchain network.

(ii) Misappropriation

Misappropriation is a major corporate governance risk, referring to the illegal or unauthorized use of funds, assets, or resources for personal gain or purposes other than those intended. It typically involves someone entrusted with managing or handling financial resources diverting them for their own benefit or for purposes unrelated to their designated use. In the blockchain world, misappropriation takes an elementary format in that 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 whether an ICO removes its white paper as a proxy for potential 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 Know Your Customer procedure.

On DEXs, issuers can create and list tokens and profit from such issuances, primarily through exit scams which are also called "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 an equal value of both tokens to the pool. In return, the LP receives a pool-specific token called LP token, and can withdraw her share of the pool by redeeming her LP tokens. When traders swap their numeraire token 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 or utility, were issued, with a total trading volume of more than $30 billion.[16] On average, about 94% of creators' profits during the first 30 days after issuance are generated through rug pulls.

[16]The authors also explore why investors trade meme tokens despite their average negative profit. 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 would be willing to participate in meme-token trading. Second, although the average short-term return is negative, the return distribution is right-skewed, which suggests that investors with gambling preferences who overweight high short-term returns may participate in meme-token trading.

4 Smart Contracts and DAO as Governance Implementation

4.1 Smart contracts: Implementation and commitment

4.1.1 Smart contracts: Basics

We have briefly touched upon the concept of smart contracts in previous sections as decentralized governance, token offerings, and DeFi protocols are all enabled by smart contracts. In this section, we explain the basic mechanics of smart contracts and explore the governance problems smart contracts can solve and create.

Smart contracts are 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 enable "terms contingent on decentralized consensus that are tamper-proof and typically self-enforcing through automated execution." Decentralized consensus has the potential to expand the contracting space by reducing the scope of non-contractible contingencies, which is at 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" of miners is effectively observable by tracking the frequency at which a miner solved mathematical puzzles that are lower-tier to those used in proof-or-work. A few 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 quite many advantages, such as speed, efficiency, transparency, accuracy, trust, security, and cost savings, all of which are relevant for 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 will 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 discourage a major issue in classic contracting, i.e., strategic ex-post renegotiation. By enforcing pre-agreed rules and conditions, smart contracts mitigate adverse selection and moral hazard issues.

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 commitment ex ante takes precedence over ex-post renegotiation and where discretion in implementation is not valued or may even be detrimental due to its potential to invite 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 primarily draw from earlier literature within the traditional governance framework. Nonetheless, the inherent properties of smart contracts allow 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 a 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 and platforms 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 contingencies are hard to specify or where ex-post risk sharing is desired.

The trade-off between mandatory and discretionary triggering of contractual terms could be intriguing. As we discussed in Section 4.1.1, algorithm-based decision making is transparent or could potentially be reverse-engineered, thus inviting behavior that could trigger the algorithm for unintended consequences. Smart contracts, due to their mechanical nature, are unable to handle contingencies with "feedback effects." This issue is illustrated well by 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, such as that based on market prices, or at the discretion of regulators (Avdjiev et al., 2020). While the discretion of triggering typically carries the risk of inviting moral hazard due to the possibility of renegotiation (even if implied), mandatory triggering could potentially lead to a "death spiral" (Sundaresan and Wang, 2015). This is because the anticipation of breaching the condition may lead to selling, which, in turn, accelerates the breach. In other words, the use of smart contracts for CoCos may not provide robust risk management. 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 have several additional limitations, some of which are directly related to their technical features. For example, smart contracts are highly dependent on programmers and vulnerable to bugs and logical errors in the code. Any errors could result in significant risks for all parties involved.[17] What we focus here are elements that have direct sources from or implications for governance. First, it is challenging for decentralized governance mechanisms to reconcile competing objectives among different parts, resulting in system instability when facing governance disputes within blockchain communities, especially when it comes to making critical decisions about protocol upgrades or changes to contract rules. Such a limitation was responsible for the eventual collapse of the Terra-Luna system in May 2022 (Liu et al., 2023).

[17]For example, in an incident involving DeFi platform YAM Finance, the developers behind the project created a bug in the smart contract that caused the entire project to collapse and resulted in significant losses for investors. Lehar and Parlour (2023) also describe a flash loan attack that exploited a decentralized platform's coding mistake.

Second, smart contracts primarily operate 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 for 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.[18] The connection with the latter exposes smart contracts to the mundane governance issues in the offline world. Oracles, for example, can be manipulated through arbitrage (that utilizes flash loans), especially via DeFi protocols.[19] Moreover, in transactions that involve physical assets, smart contracts need to be integrated with conventional legal structures.

Third, though 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 of the collusive behavior is no different in nature from the strategic behavior which extends from offline to the online world under somewhat different covers. For example, token concentration may result in 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 precisely encouraged by the transparency that decentralized consensus provides, which would have been deterred by information asymmetry or a lack of commitment. Cong and He (2019) have shown that smart contracts can encourage collusion among interested

[18] Oracles could be APIs and webpages. See Beaver Finance (2022) for various types of oracles.

[19] 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 more examples on oracle attacks.

parties as the transparency and commitment help 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 for the trade-offs under incomplete contracting comes from Chen et al. (2023). Using staggered adoption of U.S. state laws that increased firms' in-state ability to use blockchain technology, the authors find that firms that are more exposed to blockchain technology experience significant improvement in performance. Most relevant to blockchain technology, the authors show that such firms become less reliant on vertical integration, form more strategic alliances, and develop new customers beyond geographical proximity.

4.2 Governance of DAOs

4.2.1 Institutional background

A Decentralized Autonomous Organization (DAO) is a new kind of organizational structure, built with blockchain technology, which is governed directly by members who have invested in it. Unlike corporations, DAOs do not have physical headquarters or offices, directors, management, or employees. 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 that the group votes on during a specified period, with voting rights similar to those by shareholders in traditional companies. Furthermore, the token holders are also users of its services. All of the DAO's transactions are immutably recorded on the blockchain, which provides transparency to its members.

The first references to DAOs emerged in the 1990s when Dilger (1997) described a decentralized autonomous organization that would be integrated as part of the Internet of Things. However, the modern meaning of DAOs can be traced back to the concept of a decentralized autonomous corporation (DAC), coined shortly after the Bitcoin network was born. The term "DAO" became more widely adopted by blockchain enthusiasts and developers in 2013, most notably 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 to be the first DAO that has a self-funding, self-governing protocol. Dash pioneered decentralized governance by blockchain, and it remains the industry's longest-running DAO to date. The DAO, created in 2016, 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 raised funds. To avoid a repeat of such debacle, platforms for creating DAOs and facilitating voting and security protocols for auditing code have been established, including Snapshot, Aragon, and DAOStack. The DAO ecosystem accelerated in 2020 as decentralized finance (DeFi) platforms, such as Uniswap and Aave, took off with DAO structures.[20] 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

[20] DeFi 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.

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 can offer members benefits through increased transparency and democratic decision-making. They also increase efficiency as DAOs can be created more quickly than traditional companies, have instant access to potential investors, and run without significant overhead costs. However, DAOs also face a number of challenges, including a lack of legal status and potential for unlimited liability, security law non-compliance, and governance issues (see Weinstein et al. (2022) for more details).[21] In the rest of this section, we focus on potential governance issues DAOs face.

4.2.2 Voting power and governance participation

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 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 (whic was the main mission of DAOs), a small number of entities exert control in most DAOs. 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 addresses control more than 67% of

[21] As of March 2023, several U.S. states, including Vermont, Wyoming, Tennessee, Utah, and New Hampshire, have enacted statutes recognizing DAOs as legal entities.

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 are unanimous. The high concentration of voting power is consistent with the pattern documented in Han et al. (2023), which shows that the average HHI and top three ownership for 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.[22] However, the average DAO's ownership structure has 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 whale's voting power ranges from 45% to 70%, depending on proposal type. 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 more than 0.9 for all the three DAOs, implying very high concentration. Taken together, the evidence suggests that voting power is quite concentrated for the average DAO, which, ironically, defeats many DAOs' end goal to distribute governance power.

As noted by Makarov and Schoar (2022), decision making in a fully decentralized organization can be inefficient. 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 regular 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.

[22] 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, and $\bar{x}$ is the average onwership.

On average, only 11% of token holders participate in on-chain voting, likely attributable to gas fees[23] as high as $170 required for on-chain voting (Tally, 2021).[24] Similarly, Fritsch et al. (2022) find that for Compound and Uniswap, less than 15% of circulating tokens participate in voting on proposals. Such numbers are substantially lower than the average voting turnout around 80% for institutional investors and 30% for retail investors (Brav et al., 2022, 2024).

Because governance tokens are issued to grant holders the right to participate in the decision-making process of a decentralized protocol or platform, platform 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 becomes strongly positive when the majority of DAO members become involved.

4.2.3 Conflicts of interest among token holders

By eliminating the management team, DAOs' organizational structure addresses principle-agent problems between management and shareholders that plague traditional companies. However, they still face another fundamental trade-off as traditional firms: the potential conflicts of interest between large token holders, commonly known as "whales," and small token holders (i.e., users). Whales can swing the vote outcome using their large holdings whereas dispersed small token holders cannot individually. Therefore, open-market trading of governance tokens may enable whales to accumulate enough voting power to manipulate votes, leading to short-term gains at the expense of minority token holders. In April 2022, for

[23]"Gas fees" on a blockchain refers to 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 computational work required to execute a transaction or contract operation.

[24]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.

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 of cryptoassets from Beanstalk's asset pools. The attacker exploited a vulnerability in the governance module that any individual with a simple supermajority stake can pass a so-called "Beanstalk Improvement Proposal" at any time. Specifically, the attacker managed to deceive the community by making them believe that the proposal was only meant to donate money to a Ukraine donation address. Once the attacker acquired a supermajority governance stake he invoked a function that allowed him to circumvent the usual lifecycle of a proposal and execute the proposal immediately after voting on it (see Immunefi (2023) and Everything Blockchain (2022) for more details).

To formally study potential conflicts of interest between whales and small holders of DAOs, Han et al. (2023) develop an equilibrium model of a DAO platform featuring token-based voting and dynamic token trading. In the model, a whale enjoys private benefits through controlling the platform (i.e., passing value-destroying proposals). The whale weighs private benefits against the cost of manipulating vote outcomes, the latter of which includes a loss in public value and trading costs due to token illiquidity. The authors show theoretically and empirically that voting power concentration, empirically proxied by the HHI of voting power, has a negative effect on platform growth, but platform size, token illiquidity, and long-term incentives for whales can mitigate the negative effect. In particular, illiquidity shields users against negative effects of bad governance by increasing the cost for a whale to acquire additional tokens, thus reducing the potential for manipulating vote outcomes. However, the beneficial effect of illiquidity on governance wears off rapidly as ownership concentration increases because under high illiquidity, selling off a large stake after voting would induce a substantial price impact. Therefore, the whale prefers early liquidation, avoiding implementing proposals.

This seemingly paradoxical result, where illiquidity can benefit the governance of a DAO, hinges on the fact that active monitoring of management is absent due to DAO's autonomous nature. Liquidity is known to have a beneficial effect on the governance of traditional corporations by facilitating active monitoring in the presence of principal-agent problems between management and shareholders (e.g., Maug, 1998; Bolton and Von Thadden, 1998). The beneficial effect of token illiquidity on DAO governance aligns with recent theoretical developments, notably Levit et al. (2019), which demonstrates that trading frictions can enhance shareholder welfare by preventing the shareholder base from becoming too extreme in a traditional corporate governance framework.

Although token illiquidity can deter whales from exploiting a platform, sacrificing general token liquidity can still be costly, leading to market inefficiency and high transaction costs for users (Han et al., 2023). As a result, "targeted illiquidity" has emerged as a prevalent practice adopted by contemporary DAOs. That is, imposing a lock-in period, similar to a vesting schedule for equity shares, achieves positive multiplier effects through user participation but does not generate side effects created by illiquidity. A lock-in period will provide a whale a shorter time frame to liquidate its position after voting while not affecting (patient) users' welfare. This increased time pressure makes it more costly for the whale to implement a value-destroying proposal, leading to enhanced governance, which in turn promotes user participation. Voting models based on a vesting schedule, often through "vote escrow" systems, are analogous to tenure-based voting systems and Loyalty Shares (L-shares) in the stock-market setting, proposed by Edelman et al. (2018) and Bolton and Samama (2013), respectively. We note that Curve Finance, a DEX for trading stablecoins, pioneered vote escrow tokens, whose vote weight and share of rewards are generally proportional to the preset time periods locked.

Another mechanism to increase decentralization is via airdrops, which are distributions of free governance tokens to current (and potential) community members. In a standard airdrop, all current (and potential) 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 amount of tokens to all eligible users, they are likely to increase decentralization, which is even true for holder airdrops as ownership concentration would decrease. Such airdrops may also "stimulate" demand as these events are typically used as marketing tools to raise awareness of the token. However, non-pro-rata distributions can be dilutive for existing (large) token holders, triggering objections by these holders, especially when token prices are not expected to rise 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 prediction above. 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 started trading around $3.5 shortly after the airdrop. The token price kept climbing over the next eight months, touching above $40 in May 2021. Using a sample of 51 cryptocurrency exchanges, Makridis et al. (2023) find that airdrops are positively associated with growth in token valuation and trading volume, but these benefits are concentrated among DEXs. Specifically, DEXs that conduct an airdrop exhibit a 13 percentage points increase in the growth rate of their token's market capitalization. This evidence is consistent with the finding in Han et al. (2023) that 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 vote 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 of adopting a large holder's vote 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 has small token holdings, reaching an acquittal decision will still be almost costless for the whale. 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, equivalent to one-share-one-vote 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 under the principle that users with more tokens have more skin in the game and are thus incentivized to provide higher quality votes.

Contrary to the popular belief, however, when voters are strategic in that they vote to maximize the expected value of their tokens by taking into account others' votes, 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 in the voting literature, including those on 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. Because non-pivotal votes do not affect vote outcomes and are thus payoff-irrelevant, optimal collective decision making requires that shareholders vote strategically (e.g., Maug and Rydqvist, 2009; Matvos and Ostrovsky, 2010). The DAO fails to achieve the first-best accuracy of a centralized platform. In many cases, a platform could achieve equal or sometimes better accuracy by pursuing a different aggregation strategy and/or by limiting token dispersion across users.

A possible solution to address 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 using the square root 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 have perfect information (but diverse preferences) on the proposals they are voting for (Lalley and Weyl, 2018). Benhaim et al. (2023a) compare quadratic voting and stake-weighted voting in the crowdsourcing setting, where voter incentives are aligned but voters have imperfect information. The authors find that quadratic voting can be inferior to stake-weighted voting because it disincentivizes voters with more information from casting enough votes to reflect their beliefs. Both voting mechanisms approach optimality when the number of voters approaches infinity. Benhaim et al. (2023a) suggest that enhancing voting efficiency for DAOs necessitates efforts to boost voters' participation.

Benhaim et al. (2023b) analyze committee-based consensus protocols, used by some blockchain platforms including Binance and Cosmos, which require token holders to elect a committee of block producers who verify and add transactions to blocks.[25] This approval voting method allows voters to approve multiple candidates. The authors find that the approval voting mechanism converges to optimality quickly when the number of voters increase, 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 has the potential to outperform other commonly employed mechanisms, such as single-choice protocols.

4.2.5 Optimal designs of decentralized governance

An emerging literature has examined under what conditions decentralization is optimal, relative to 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 by implementing

[25] Amoussou-Guenou et al. (2023) and Halaburda et al. (2021) study how strategic committee members can reach consensus once they are part of a committee.

changes that are costly to them, such as increasing fees. 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 the theory, Chen et al. (2021) find that the degree of decentralization has an inverted U-shaped relationship with platforms' market capitalization, developer attention, development activity, and social media followers, suggesting a modest level of decentralization is optimal.

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 more advanced technology, adopting a token buy-back mechanism can achieve optimality. A buy-back mechanism for governance tokens would enable the platform to promote early adoption by committing to repurchasing tokens in the future. Therefore, the decentralized platform can achieve a greater output than a centralized one. This provides a rationale for 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 price 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 mitigate the crowding-out effect and thereby to promote 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 entails 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 in terms of 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 when validators are sufficiently trustworthy. This is when intertemporal incentives, which are the present values of future validation rewards, are high and validators would have much to lose from misbehaving (e.g., adding invalid transactions to a block). When intertemporal incentives are weak, however, it becomes too costly to prevent a single validator from misbehaving. The authors also show that decentralization leads to a "stakeholder economy" in which the participants of the system are in charge of the record keeping: only "internal" validation can support trading as an equilibrium with more than one validator. In other words, achieving good governance and honest record-keeping is made easier by having validators who also participate in the market themselves and thus have an intrinsic interest in keeping it functioning smoothly.

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 blockchain 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, there are 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; 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 environmental, social, and governance (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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