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Decentralised Finance's timocratic governance: The distribution and exercise of tokenised voting rights

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A B S T R A C T

Ethereum's public distributed ledger can issue tokenised voting rights that are tradable on crypto-asset exchanges by potentially anyone. Ethereum thus enables global, unincorporated associations to conduct governance experiments. Such experiments are crucial to Decentralised Finance (DeFi). DeFi is a nascent field of unlicensed, unregulated, and non-custodial financial services that utilise public distributed ledgers and crypto-assets rather than corporate structures and sovereign currencies. The inaugural Bloomberg Galaxy DeFi Index, launched in August 2021, included nine Ethereum-based projects – non-custodial exchanges as well as lending and derivatives platforms. Each project is governed, at least in part, by unregistered holders of tokenised voting rights (also known as *governance tokens*). Token-holders typically vote for or against coders' *improvement proposals* that pertain to anything from the allocation of treasury funds to a collateral's risk parameters. DeFi's governance thus depends on the distribution and exercise of tokenised voting rights. Since archetypal DeFi projects are not managed by companies or public institutions, not much is known about DeFi's governance. Regulators and law-makers from the United States recently asked if DeFi's governance entails a new class of "shadowy" elites. In response, we conducted an exploratory multiple-case study that focused on the tokenised voting rights issued by the nine projects from Bloomberg's inaugural Galaxy DeFi index. Our mixed methods approach drew on Ethereum-based data about the distribution, trading, staking, and delegation of voting rights tokens, as well as project documentation and archival records. We discovered that DeFi projects' voting rights are highly concentrated, and the exercise of these rights is very low. Our theoretical contribution is a philosophical intervention: minority rule, not "democracy", is the probable outcome of token-tradable voting rights and a lack of applicable anti-concentration laws. We interpret DeFi's minority rule as *timocratic*.

1. Introduction

If the global financial system's governing elites are responsible for the crisis of 2007–2008, what we need is a new form of community-based governance – an alternative to both public institutions and private companies. This is a claim espoused by proponents of blockchain and Decentralised Finance (DeFi) [1–3]. DeFi projects are typically governed by coders together with unregistered holders of tokenised voting rights (also known as *governance tokens*) [4]. Coders issue a diverse array of *improvement proposals* that are subjected to voting rounds. Votes are cast by the token-holders. DeFi's tokenised voting rights can be bought and sold in a peer-to-peer manner or via crypto-asset exchanges. Anyone on Earth can henceforth purchase a right to vote, at a price determined by the global market. The mantra is not *one person, one vote*; individuals are free to purchase multiple voting rights and accumulate power over time, without needing to register their legal identity information.

Unlike shareholders' voting rights, issued by registered companies, DeFi's tokenised voting rights are typically issued by global entities that are unincorporated and non-liable [5,6]. Blockchain developers refer to these ambiguous global entities as Decentralised Autonomous Organisations (DAOs). DeFi's tokenised voting rights, issued by DAOs, are supposed to offer a more democratic and inclusive alternative to corporate governance [7–9]. According to Pandian et al. [9],

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"governance tokens ensure DeFi's democratic and decentralised governance"; but early empirical research reveals highly concentrated voting rights and an absence of applicable anti-concentration laws [10,11]. This tension between "democracy" and concentrated governance power piqued our curiosity.

The nascent field of DeFi mostly consists of unlicensed, unregulated, and non-custodial financial services that exist thanks to public distributed ledgers like the Ethereum Mainnet [6,12–15]. In January 2021, a non-custodial crypto-asset exchange named Uniswap became the first DeFi project to reach a total trading volume of USD $100 billion. In response to interest from investors and financial analysts, Bloomberg launched the Galaxy DeFi Index in August 2021. The DeFi projects from Bloomberg's index are not governed by private companies or public institutions. Each project is Ethereum-based, and each project is governed (at least in part) by a DAO.

In other words, the DeFi projects from Bloomberg's index involve unregistered token-holders' voting rights, not registered shareholders' voting rights. Unlike shares, voting rights tokens are not legal contracts, and they do not entitle holders to a share of a registered company's profits [6]. A community of voting rights token-holders – a DAO [16] – is not typically positioned as a *juridical person* [5]. The distinctions are clear.

In the context of DeFi's governance, *decentralised* specifically denotes independence from regulators, registered companies, and investor registration processes [6,10,13]. Hence the Democratic Senator Elizabeth Warren [17] referred to DeFi as "the Wild West of our financial system". The Financial Action Task Force (FATF), the Chair of the United States Securities and Exchange Commission (SEC), and Professor Kenneth Rogoff from Harvard University issued similar remarks [18–21]. According to Warren, DeFi replaces an old form of centralised control – the traditional financial system – with a new form of centralised control that is shadowy and unregistered [22]. She therefore associates DeFi not with a uniform, democratic distribution of power and resources but rather with "new concentration risks" [23; p. 3]. The Republican House Majority Whip, Tom Emmer [24], advanced an opposing view. According to him, *de*-centralised finance "shifts economic power from *centralised* institutions back into the hands of the people". The tension is obvious: DeFi is oligarchic according to Warren, and it is democratic according to Emmer.

Early socio-technical studies about DeFi's governance support Warren's assertion [10,11,14,25]. The new concentration risks and oligarchic governance structures are broadly labelled "Fake-DeFi" [26] and "the illusion of decentralisation" [27]. Barbereau et al. [10] studied the tokenised voting rights issued by five Ethereum-based DeFi projects: Uniswap, Maker, SushiSwap, Yearn Finance, and UMA. The authors discovered that, for all five cases, the distributions of tokenised voting rights are highly concentrated. Their study did not, however, examine the actual *exercise* of voting rights. In response to this notable gap and DeFi's contested *democratic/oligarchic* governance, we formulated three research questions.

1. How distributed (or, rather, concentrated) are DeFi's tokenised voting rights?
2. What portion of DeFi's token-holders actually exercise their voting rights?
3. What are the entitlements and the initial distribution strategies that pertain to DeFi's voting rights tokens?

DeFi's token-holder governance is a novel topic that cannot be subsumed under the well-known categories of corporate governance or State governance. It also cannot be subsumed under the blockchain researchers' esoteric category of *off-chain governance* [28–31] – specifically, the governance of an entire distributed ledger by parties such as the Bitcoin Core Developers and the Ethereum Foundation.

Motivated by the topic's novelty as well as the tension between "democracy" and concentrated power, we conducted an exploratory, longitudinal, multiple-case study [32–34]. The nine cases we selected are all Ethereum-based, non-custodial DeFi projects that include tokenised voting rights: Uniswap, Aave, Maker, Compound, SushiSwap, Synthetix, Yearn Finance, 0x, and UMA. As noted, these cases are all included in Bloomberg's inaugural Galaxy DeFi Index.

We quantitatively examined the "physical" artefact [34], namely the Ethereum Mainnet's ledger, which records all transactions that determine the possession and delegation of tokenised voting rights. We employed statistical methods to determine for each case: (a) the level of *decentrality* (uniformity) achieved by the token distribution strategy over time, and (b) how often voting rights are exercised over time. We also sourced qualitative data – project documentation, white-papers, and grey literature – to derive knowledge about voting rights tokens' entitlements and distribution strategies.

The article is primarily addressed to the critical sub-field of Information Systems research, which focuses on power relations instead of common theories about technology acceptance or transaction costs [35–37]. Hence the study's main subject is *voting power*, and its cases are all hosted on an *information system* (Ethereum). The article is also addressed to critical, interdisciplinary researchers that study socio-technical topics [4,38,39]. Our theoretical discussion is a philosophical intervention [40,41]: in response to platitudes about DeFi's "democratic" governance, we depict it instead as *timocratic* [42]. This is because the DeFi cases we examined each exhibit minority rule (specifically, concentrated voting rights and low participation rates in voting rounds), "shadowy" unregistered entities, and large crypto-asset treasuries. The theoretical contribution is novel for two additional reasons: (1) it does not entertain the false equivalence between corporate governance and DeFi's DAO-based governance (see Ref. [43]), and (2) it does not opportunistically import theories from New Institutional Economics, apply them to DAOs, and assume that technology principally causes or determines institutional structures (see Refs. [44–46]). Our treatment of DeFi's governance as unorthodox and "novel" follows Vergne [47; p. 18]: he held that "theories premised on a manager- or shareholder-centric view are of limited usefulness" when it comes to understanding governance by DAOs.

2. Background

The governance of Decentralised Finance (DeFi), as the name denotes, is tied to *decentralisation* – a topic that is irreducibly political, legal, and technical [39,48]. *Decentralisation* is an equivocal, polysemous, and often confusing word that is frequently used by crypto-asset developers and researchers [49,50]. The word variably denotes socio-political ideals [28], the elusion of centralised authorities and detachment from legal legitimacy [5,38,44], and the technical features of distributed computing systems [51]. DeFi's governance by DAOs is linked to each of these points; therefore a nuanced understanding of decentralisation is required.

Bitcoin's blockchain network is an exemplar of decentralisation [52]. So, too, is the Ethereum Mainnet [2] – the predominant host of DeFi projects. Bitcoin's native crypto-currency, BTC, is the fastest asset in history to reach a $1 trillion market capitalisation [53]. It achieved this feat with no legal entity attached to it as a manager or majority owner. Bitcoin transactions are not registered on central servers; the Bitcoin network is instead distributed across a global computing grid that consists of voluntary participants [54]. Because the Bitcoin network is not wholly grounded in any particular jurisdiction, it entails challenges for regulators [55,56]. The Bitcoin network is, in the legal parlance, an "unincorporated distributed ledger system" [6; p. 13]. The network can alternatively be described as a distributed financial market infrastructure (dFMI), since it can operate autonomously and it does not rely on conventional financial market infrastructures (FMIs) such as central banks, auditors, or intermediary payment systems [57].

Decentralisation is often treated as a synonym for *distribution*, but this is not always appropriate. There is no necessary link, for instance, between socio-political ideals of decentralisation (*qua* democratisation or egalitarianism) and an actualised, uniform distribution of capital (BTC) and governance power within the Bitcoin network [58–60]. As Kostakis and Giotitsas [52; p. 437] put it, "in theory you have equipotential individuals (that is, everyone can potentially participate in a project), but in practice what one gets is concentrated capital and centralised governance." The 2015 *block-size debate* (and subsequent revision to the Bitcoin protocol) revealed the governance power that is concentrated among the Bitcoin Core Developers and the Lead Developer [28,60].

The Ethereum Mainnet, inspired by the Bitcoin network, launched in 2015. Ethereum introduced a Turing-complete program execution layer – the Ethereum Virtual Machine (EVM) – on top of a blockchain layer, together with a native crypto-currency (ETH). The EVM can execute persistent scripts – so-called *smart contracts* or computerised transaction protocols [61,62]. Developers can use smart contracts to create DAOs [63] or other types of decentralised governance protocols [64]. Hassan and De Filippi [16; p. 2] defined a DAO as "a blockchain-based system that enables people to coordinate and govern themselves, mediated by a set of self-executing rules deployed on a public blockchain, and whose governance is decentralised".

This new form of governance by DAOs received attention in 2020, thanks to DeFi projects like Compound, SushiSwap, and Uniswap [12,13,15]. In the legal parlance, DAO-based governance is *non-liable*, simply because a DAO is not a liable legal entity [6,13]. DeFi projects that are non-custodial and governed by non-liable DAOs are thus distinct from custodial crypto-asset exchanges and lending platforms that are owned by liable companies like Coinbase and Celsius [15]. DeFi projects governed by non-liable DAOs are virtually free from applicable law and regulation. Proponents note that this reduces compliance costs [65]; whereas legal scholars claim that DeFi projects can potentially "undermine traditional forms of accountability and erode the effectiveness of traditional financial regulation and enforcement" [6; p. 1].

Regulators and law-makers deploy similar, critical rhetoric about DeFi's unorthodox governance [19,66,67]. Japan's FinTech Innovation Hub [68], for example, labelled DeFi a threat to the ability of the Financial Services Agency (FSA) to enforce existing regulations. Commissioner Dan Berkovitz from the United States Commodity Futures Trading Commission (CFTC) warned that DeFi could become a massive, "unregulated shadow financial market" [69]. In spite of regulators' and law-makers' concerns, the market capitalisation of DeFi's voting rights tokens (and consequently the tokens' prices) increased dramatically from 2020 to early 2021 (Fig. 1).

DeFi's voting rights tokens allow holders to vote for or against a diverse array of improvement proposals. Improvement proposals pertain to a project's rules, parameters, or features [4,70]. Ethereum-based voting rights tokens are typically ERC-20 format; so, like other ERC-20 tokens, they can be traded on non-custodial exchanges like Uniswap and SushiSwap or on custodial exchanges like Coinbase and Binance. Some DeFi projects allow token-holders to delegate their voting power to other wallet addresses. The delegation of voting power can be reversed by the original token-holder at any point.

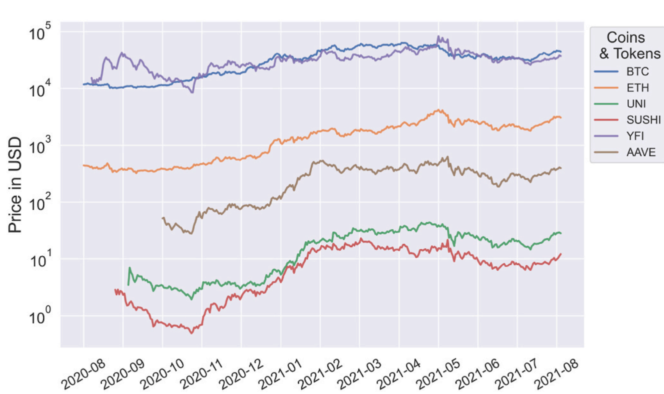


Fig. 1. Prices of voting rights tokens, together with BTC and ETH (data retrieved from CoinGecko on 13 August 2021).

DeFi's token-holder governance is a compelling research topic, especially following the concerns expressed by regulators and law-makers about DeFi's concentration risks and its new class of unregistered, "shadowy" elites [22]. These concerns contradict common, pre-theoretical assumptions about decentralised governance as democratic, inclusive, or empowering [2,9,24].

DeFi's token-holder governance is a novel topic as well. Klimon [71] reviewed governance options for organisational structures that historically preceded DAOs, such as unincorporated associations, trusts, trade associations, and other membership organisations. "Membership", wrote Klimon [71; p. 8], "is essentially the right to vote for the governing body". In contrast to DAOs, conventional membership organisations do not involve a global community of token-holders; but more importantly, they usually involve registered voting rights that are not purchased for speculative reasons. This reinforces the distinction made by regulators and law-makers: DeFi's voting rights are unorthodox, because they are tradable and unregistered, and their distribution is not confined to any particular jurisdiction.

Since our study focuses on DeFi's tokenised voting rights, it is distinct from prior research that measured the concentration of wealth or the concentration of mining power in the Bitcoin and Ethereum networks (see Refs. [51,58,72,73]). The closest precedent text is a conference paper by Barbereau et al. [10].[1] As noted, Barbereau et al. [10] studied five out of nine cases that Bloomberg eventually chose for their inaugural Galaxy DeFi Index: Uniswap, Maker, SushiSwap, Yearn Finance, and UMA. The authors used multiple statistical metrics to analyse the five cases' distributions of tokenised voting rights; but they did not, we repeat, examine the exercise of voting rights over time.

Our contribution is unique, since we studied all nine cases from Bloomberg's inaugural Galaxy DeFi Index, and we examined both the concentration and exercise of tokenised voting rights. Following Barbereau et al. [10], we chose a complementary array of statistical metrics (or, simply put, we did not exclusively rely on the Gini coefficient), a combination of qualitative and quantitative sources [74,75], and a longitudinal multiple-case study design [34].

3. Methods

Since DeFi's governance is a novel topic for critical, socio-technical research [6,12,13,76], we designed an exploratory multiple-case study [32,33,77]. To account for the distribution and exercise of tokenised voting rights over time, our multiple-case study is longitudinal [34]. Our total data set spans a period of 1,466 days. It draws on both quantitative and qualitative sources to comprehensively address our three research questions [74].

To reach a representative sample of our target site, we created a list of 25 tokens from the field of DeFi, sorted by market capitalisation. From this list, we selected cases that satisfy three conditions: (1) the token is issued exclusively in Ethereum's ERC-20 format, (2) the token attributes voting rights (or, more specifically, the token denominates voting units), and (3) the project that issued the token is governed by a DAO (at least in part). The first criterion excludes voting rights tokens that are issued on blockchains other than Ethereum, namely Terra Luna, BNB Chain, and THORChain. These blockchains are not as widely adopted as Ethereum, so we excluded them. The second criterion excludes crypto-assets like tokenised collateral and stable-coins; hence it allows us to focus on tokenised voting rights. The third criterion excludes only Nexus Mutual. Nexus Mutual is primarily governed by a registered company, and its

[1] The secondary precedent texts are pre-prints by Sun and Stasinakis [11], Jensen et al. [25], and Nadler and Schär [14].

tokenised voting rights uphold the principle of *one person, one vote*. Nexus Mutual's token-holders are required to register and complete a Know Your Customer (KYC) check. We excluded Nexus Mutual because of its proximity to conventional, corporate governance and its registered voting rights.

Table 1 presents the case selection. Nine cases qualified (highlighted in grey): Uniswap, Aave (formerly named ETHLend), Maker, Compound, SushiSwap, Synthetix (formerly named Havven), Yearn Finance, 0x, and UMA. Incidentally, the inaugural version of Bloomberg's Galaxy DeFi Index consists of these same nine cases.[2]

3.1. Data collection

There are six typical evidence sources for case studies: interviews, documentation, direct observations, participant observations, archival records, and "physical" artefacts [34]. We collected data from three typical sources: documentation, archival records, and a "physical" artefact. This allowed us to triangulate findings [75].

Documentation provides knowledge about the particular entitlements of each case's voting rights tokens and each case's token distribution strategy. This knowledge is required to address our third research question. Documentation also provides details about each case's improvement proposals [4]. We retrieved documentation from the cases' websites and file repositories (GitBook). Some of our cases have changed and developed significantly since their date of inception; hence we also considered archival records. Archival records allowed us to gauge the differences between project versions.

We retrieved documentation and archival records via a structured, two-stage process. First, in a scouting phase, we mapped out the available data sources for various, open-source DeFi projects: blogs, forums, developer repositories (GitHub), and Wikis. We evaluated these sources based on the number of available documents, descriptive richness, and technical depth. In the second stage, we selected the qualitative data sources that describe the project's governance.

Our third source of evidence is a "physical" artefact that is common to all nine cases: Ethereum's public ledger. Previous studies treated public ledgers as "physical" artefacts: for example, research dedicated to blockchains' throughput, fees, and transaction volumes [78–80], Bitcoin miners [81], and the performance of Uniswap's Automated Market Maker (AMM) protocol [82]. Additional examples include: studies about the feasibility of de-anonymisation [83,84], transaction *front-running* [85,86], and blockchain performance or improvement opportunities [87,88].

Ethereum's public ledger records a variety of transactions that pertain to each case's voting rights tokens, from their creation and initial distribution to buying, selling, and staking. Ethereum's public ledger is thus an eligible and crucial data source for our multiple-case study [34]. We used Dune's analytics platform and Structured Query Language to extract data from Ethereum's public ledger. Table 2 presents the quantitative data collection.

3.2. Data preparation

Following the data extraction process, we used Etherscan to identify relevant token-holders' wallet addresses and to prepare our quantitative data sets. The quantitative data sets help us answer our first two research questions, since they account for: (1) the distribution of voting rights over time, and (2) the exercise of voting rights over time (Fig. 2).

Gochhayat et al. [51] refer to statistical analyses of token distributions as assessments of *decentrality*. We retrieved all the Ethereum wallet addresses that hold relevant, tokenised voting units at 24-hour intervals. For the cases that allow wallet addresses to deposit tokens in smart contracts (e.g., SushiSwap's MasterChef staking contract) but retain their voting power, we traced these tokens back to the original holders' addresses.

We discovered that wallets controlled by custodial crypto-asset exchanges and lending platforms like Binance and Celsius hold a significant portion of our nine cases' voting rights tokens. These parties did not exercise any of their voting rights during our analysis period; but it is worth noting that, on 19 October 2022, Binance accidently delegated a substantial number of Uniswap voting rights [89]. The accident demonstrated that Binance at least has the technical capacity to delegate voting power, if not the political or professional will to do so. For the sake of a comparison, we created a second data set that excludes wallets controlled by custodial exchanges and lending platforms. This second data set accounts for a hypothetical scenario in which companies like Binance and Celsius preserve the current trend and choose to *not* exercise or delegate their voting rights. We excluded the following addresses from both data sets.

1. We excluded automata's smart contract addresses. Although automata's smart contract addresses can hold voting rights tokens and potentially participate in governance processes [90], we did not observe this in our nine cases. Hence we do not consider the automata's smart contract addresses relevant to our study.
2. We excluded wallet addresses that hold tokenised voting units (or portions of voting units) valued at less than $1. These wallet addresses very rarely participate in governance processes. This is not surprising, given the fact that the transaction fees required to exercise votes are frequently greater than $10.
3. We excluded addresses like 0x000…0000. These addresses are used to *burn* tokens, which renders tokens inaccessible and unable to attribute voting rights. We identified these addresses using the public labels from Etherscan.

We created a sum of the voting units held by all these excluded addresses, then we subtracted this sum from the overall token supply. For the first data set, we also bundled together addresses that have the same well-known controller (e.g., a custodial crypto-asset exchange or lending platform). The first data set yields the upper boundary for each case's decentrality. (Appendix B provides a mathematical proof of this argument.) It assumes that addresses not controlled by known entities (like crypto-asset exchanges) are controlled by unique individuals. (This assumption may not be correct, of course, because unregistered individuals can control more than one wallet address.)

Our second research question requires us to examine the exercise of voting rights over time. We considered on-chain voting activity as well as activity that occurs via off-chain voting mechanisms like Snapshot. We excluded activity that pertains to minor improvement proposals, such as proposals that do not have binding effects. To examine the voting activity provoked by major improvement proposals, we retrieved every wallet address that cast at least one vote. We excluded wallet addresses that only voted for or against anomalous improvement proposals that were cancelled in the middle of the designated voting period. Unsurprisingly, cancellations correspond to extremely low rates of exercised voting rights. We excluded this data, so that it would not distort our perception of the token-holders' normal participation rates.

To account for projects that permit the delegation of voting rights, we created a third data set to represent the delegates' active participation plus a fourth data set to represent the delegators' passive participation. For the third data set, the exercised voting power is treated as if it were held by the delegates' addresses. For the fourth data set, the exercised voting power is treated as if it were held by the delegators' addresses. The third data set also represents the active participation of token-holders from projects that do not permit the delegation of voting rights.

[2] We almost included Bancor's BNT token and SushiSwap's xSUSHI token in our case selection; but strictly speaking, these tokens do not denominate voting units. The respective voting units are denominated by two different tokens: vBNT and SUSHI.

Table 1
Case selection overview (market data derived from CoinGecko on 9 August 2021).

#	Name	Token	Token price	Token market cap.	DAO-governed	Token format	Denominates voting units
1	Uniswap	UNI	$28.42	$14,573,644,345	Yes	ERC-20	Yes
2	Chainlink	LINK	$24.27	$10,660,779,664	No	ERC-20	No
3	Terra	LUNA	$13.96	$5,730,458,699	Yes	Native	Yes
4	Dai	DAI	$1.00	$5,532,087,205	Yes	ERC-20	No
5	Compound USD Coin	cUSDC	$0.022	$5,137,739,177	Yes	ERC-20	No
6	Aave	AAVE	$374.75	$4,817,712,614	Yes	ERC-20	Yes
7	Compound Ether	cETH	$63.38	$4,659,745,677	Yes	ERC-20	No
8	Compound Dai	cDAI	$0.022	$4,456,149,064	Yes	ERC-20	No
9	PancakeSwap	CAKE	$18.37	$3,786,938,059	Yes	BEP-20	Yes
10	The Graph	GRT	$0.708	$3,163,453,402	No	ERC-20	No
11	Maker	MKR	$3357.32	$2,989,256,505	Yes	ERC-20	Yes
12	Amp	AMP	$0.061	$2,912,536,380	Yes	ERC-20	No
13	Compound	COMP	$468.40	$2,540,146,333	Yes	ERC-20	Yes
14	Lido Staked Ether	stETH	$3135.77	$2,317,693,291	Yes	ERC-20	No
15	THORChain	RUNE	$6.83	$1,889,788,372	Yes	Native	No
16	SushiSwap	SUSHI	$9.82	$1,885,006,157	Yes	ERC-20	Yes
17	1inch	1INCH	$2.77	$1,800,821,120	Yes	BEP-20, ERC-20	Yes
18	Synthetix	SNX	$10.16	$1,690,978,613	Yes	ERC-20	Yes
19	Yearn Finance	YFI	$33,865	$1,197,635,194	Yes	ERC-20	Yes
20	Bancor	BNT	$3.99	$937,888,541	Yes	ERC-20	No
21	xSUSHI	xSUSHI	$11.55	$820,466,370	Yes	ERC-20	No
22	Nexus Mutual	NXM	$120.30	$808,684,814	No	ERC-20	Yes
23	0x	ZRX	$0.954	$800,108,188	Yes	ERC-20	Yes
24	UMA	UMA	$11.49	$700,893,630	Yes	ERC-20	Yes
25	Perpetual Protocol	PERP	$15.94	$694,385,701	Yes	BEP-20, ERC-20	Yes

Table 2
Overview of quantitative data collection.

Case	Extracted addresses	Extraction period	Addresses used in the analysis	Addresses with (passive) governance participation
Uniswap	527,258	2020-09-14 – 2021-08-15	486,421	1,113 (9,012)
Aave	182,556	2020-10-02 – 2021-08-15	171,424	660 (724)
Maker	144,599	2017-11-25 – 2021-08-15	135,369	–
Compound	274,803	2020-03-04 – 2021-08-15	253,861	970 (6,519)
SushiSwap	143,915	2020-08-28 – 2021-08-15	126,370	5,458
Synthetix	164,003	2018-06-11 – 2021-08-15	161,426	391
Yearn Finance	96,227	2020-07-17 – 2021-08-15	86,752	7,566
0x	385,257	2017-08-11 – 2021-08-15	359,067	–
UMA	34,098	2020-01-09 – 2021-08-15	32,297	370

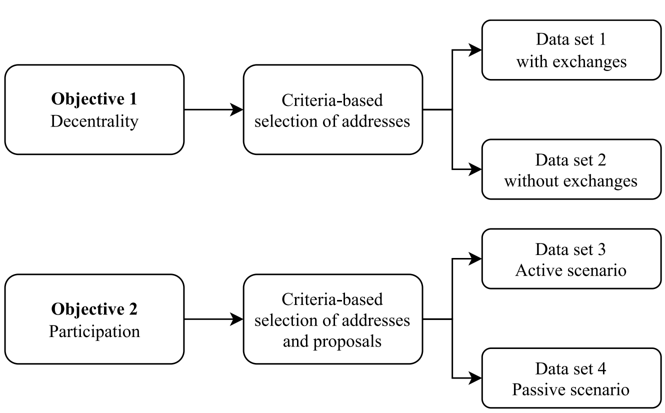


Fig. 2. Four data sets prepared in accordance with two objectives.

To reiterate, we created four data sets. The first and second data sets represent wallet addresses that hold voting rights tokens; the third and fourth data sets represent wallet addresses that exercise voting rights. We retrieved a total of 1,527,643 distinct addresses.

3.3. Data analysis

Data about voting rights tokens are irreducibly social and technical, electoral and financial; hence we used a mixed methods approach to analyse our three sources [74,77]. For the documentation and archival records, we used qualitative analysis techniques; and for the “physical” artefact, we used multiple statistical measures to assess decentrality and governance participation. We coded the project documentation and archival records by following the two-stage process proposed by Miles et al. [91]. During the initial stage, we considered each case’s documentation separately and assigned codes using the software MAXQDA [92]. As a group of researchers, we regularly reviewed the emerging concepts and ensured consistency in the coding system [93]. During the second stage, we clustered codes and assigned them to higher level themes that emerged contingently via data collection (inductive coding) or else pertained to an existing hypothesis (deductive coding). Since our study is not normative, we did not interpret the cases’ improvement proposals and judge whether or not they successfully uphold stakeholders’ values.

To analyse the “physical” artefact and examine decentrality for our first and second data sets, we selected statistical measures from two categories: (1) dimensionless dispersion measures, and (2) distance measures. We identified the possible candidates following a review of key texts [94–100]. These texts provide a list of multiple measures and their properties.

We first eliminated the measures that do not apply to our first and second data sets. The coefficient of variation was excluded, for example, because our data sets have heavy outliers. From families of measures (namely, the Minkowski distance family and the *f*-divergence family), we selected just one measure per family. From groups or pairs of measures that exhibit strong correlation by design, we again selected just one measure. Since, for example, the normalised Euclidean distance (NED) measure and the cosine similarity measure are strongly correlated, we selected just the NED. To determine the level of correlation by design, we calculated the measures using pseudo-random data sets and the Pearson correlation coefficient [101]. We consider the measures to be strongly correlated when the absolute value of the Pearson correlation coefficient is larger than 0.7. At the end of these selection processes, we had two dispersion measures and two distance measures. These four measures are described below.

3.3.1. Gini coefficient (G)

Originally developed to assess the income and wealth inequality of different countries, the Gini coefficient [102] has found applications in multiple areas from chemistry [103] and education [104] to blockchain networks [51,73]. The coefficient takes values in [0,1]. A higher value indicates higher inequality. This allows for efficient interpretation and comparison of the results. The Gini coefficient should not, however, be treated as a single source of truth about inequality, as it is not possible to reduce information generated by thousands or millions of data points to a single value without losing relevant information. For our cases, the Gini coefficient is a suitable estimator of the decentrality of voting rights tokens, because an electronic voting system in which few wallet addresses hold a large portion of the tokens will exhibit high inequality. The Gini coefficient's results should not, however, be interpreted in isolation [105]. The Gini coefficient is given by

$$G = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}|p_i - p_j|}{2N\cdot\sum_{j=1}^{N}p_j}, \tag{1}$$

where p_i corresponds to the share of voting rights tokens held by address i and N is the total number of addresses. It is maximised through the Dirac distribution δ_{i_0}, i.e., $p_{i_0} = 1$ for some $i_0 \in \{1, \ldots, N\}$ and $p_i = 0$ for all $i \neq i_0$, and minimised through the uniform distribution, i.e., $p_i = \frac{1}{N}$ for all i.

3.3.2. Normalised Shannon's entropy (NSE)

Shannon [106] initially designed the NSE to quantify lost information in phone signals. More broadly, the NSE determines the unpredictability of a distribution. The normalised version of the measure has an upper boundary, which allows for easier visualisation and interpretation of the results. The NSE takes values in [0,1]. Higher values indicate higher unpredictability. We assume that a globally distributed voting system can potentially exhibit high unpredictability, due to the fact that multiple individuals influence the voting outcomes. The difference between the Gini coefficient and the NSE is described in Appendix A. The NSE is given by

$$\mathrm{NSE} = -\sum_{i=1}^{N}\frac{p_i\log(p_i)}{\log N}, \tag{2}$$

where $0\log(0) \equiv 0$ by convention since $\lim_{p\to 0} p\log(p) = 0$. It is 0 for δ_{i_0} and 1 for the uniform distribution (i.e., the extremes are interchanged when compared to the Gini coefficient).

3.3.3. Normalised Euclidean distance (NED)

The NED is a commonly used distance measure. It compares two distributions and measures the shortest distance between them. The NED allows us to compare each case's distribution of voting rights tokens against a hypothetical, uniform distribution in which every wallet address holds equal voting rights. If there is a small distance between a case's distribution of voting rights tokens and the hypothetical, uniform distribution, we assume that this result would be interpreted by various parties as equitable, egalitarian, democratic, or decentralised. The NED is given by

$$\mathrm{NED} = 2^{-\frac{1}{2}}\left\|\frac{p}{\|p\|_2} - \frac{s}{\|s\|_2}\right\|_2, \tag{3}$$

where $p = (p_1, p_2, \ldots, p_N)$ and $s = (s_1, s_2, \ldots, s_N)$ with $s_i = \frac{1}{N}$ for every $i \in \{1, \ldots, N\}$.

3.3.4. Jensen-Shannon divergence (JSD)

The JSD belongs to the f-divergence family. It measures differences in data distributions [107]. We use the JSD, like the NED, to compare each case's distribution of voting rights tokens against the hypothetical, uniform distribution. If there is a small divergence between a case's distribution of voting rights tokens and the hypothetical, uniform distribution, we assume that this result would be interpreted as decentralised. The JSD is given by

$$\mathrm{JSD}(P\,\|\,S) = \frac{1}{2}(D(P\,\|\,M) + D(S\,\|\,M)), \tag{4}$$

where $D(P\,\|\,M) := \sum_{i=1}^{N} p_i\cdot\log_2\left(\frac{p_i}{m_i}\right)$ and $D(S\,\|\,M) := \sum_{i=1}^{N} s_i\cdot\log_2\left(\frac{s_i}{m_i}\right)$ with $m_i := \frac{1}{2}(p_i + s_i)$.

To analyse our third and fourth data sets and to assess the governance participation rates, we considered voting rounds for each case's major improvement proposals. We calculated the number of wallet addresses that exercised voting rights during each round, then we compared this with the number of wallet addresses that held voting rights tokens at the beginning of each round. We thus compared the potential voting rights with the exercised voting rights over time for each case.

4. Findings

4.1. Documented entitlements of voting rights tokens

The voting rights tokens from our study are case-specific. They have only three properties in common: the tokens are fungible and Ethereum-based (ERC-20), they grant holders the right to vote on community proposals, and they can be traded on both custodial and non-custodial crypto-asset exchanges. There are not many entitlements or powers pre-determined by developers. In a figurative sense, voting rights tokens grant the holder permission to enter the Senate Floor and cast votes on the measures of the day [10].

Table 3 provides a reduced summary of the token-holders' entitlements that are: (a) specified in the project documentation, and (b) common to at least two cases. The entitlements can change at any time, if each project's community votes to implement changes to their token's entitlements. The table does not, therefore, represent every possible or actual entitlement.

Unsurprisingly, all the voting rights tokens entitle holders to cast votes about improvement proposals. Improvement proposals consist of executable code that can either be implemented or rejected, in accordance with the voting results. For all cases except Synthetix, token-holders can directly cast votes. Synthetix's SNX token-holders can only vote indirectly, that is, by nominating a representative from the Synthetix Council. For some cases, the power to vote and/or select what proposals are put up for a vote can be delegated to Ethereum wallet addresses that hold either no voting rights tokens or else an insufficient number of tokens. Only four cases' tokens offer a reward when they are staked: AAVE, SNX, SUSHI, and ZRX. The three lending platforms' tokens – AAVE, MKR, and COMP – entitle holders to manage the collateral types and the associated risk parameters.

There are two entitlements that happen to be unique; hence they are not mentioned in Table 3. UNI entitles token-holders to manage a *community treasury,* and UMA entitles token-holders to cast *dispute resolution* votes. Uniswap's developers created the community treasury and allocated to it 43% of the total token supply (430 million UNI). The developers ceded control of the community treasury to UNI token-holders on 18 October 2020. As of this date, UNI token-holders could "vote to allocate UNI towards grants, strategic partnerships, governance

Table 3
Documented entitlements of voting rights tokens.

Case	Token	Cast votes	Choose proposals	Manage collateral	Staking reward	Delegation
Uniswap	UNI	×	×			×
Aave	AAVE	×	×	×	×	×
Maker	MKR	×	×	×		×
Compound	COMP	×	×	×		×
SushiSwap	SUSHI	×	×		×	
Synthetix	SNX	×			×	×
Yearn	YFI	×	×			
0x	ZRX	×			×	×
UMA	UMA	×				

initiatives, [...] and other programs". The documentation's language is purposefully unspecific, because it is not possible to predict what decisions the community will make over time about the treasury funds. As for UMA token-holders, they can vote to resolve disputes using the Voter dApp. The work required to resolve disputes generates new UMA tokens (as payment for the work). The UMA token supply is thus inflationary. There are two grounds for disputes: incorrect crowd-sourced (off-chain) pricing information, and contracts liquidated for an improper reason. UMA token-holders can assess the disputes and verify the pricing data and liquidation data. UMA employs this system, named the Data Verification Mechanism, instead of an oracle's data feed.

4.2. Comparison between trading volume and delegation volume

Four cases allow token-holders to delegate their voting rights: 0x, AAVE, Compound, and Uniswap. For these cases, we can compare the cumulative delegation volume with the cumulative trading volume. Fig. 3 illustrates that the number of traded tokens is much larger than the number of delegated tokens for each of the four cases. In short, these voting rights tokens are primarily traded; they are secondarily used for delegation purposes.

4.3. Token supply policies and distribution strategies

We collected data about two economic factors that are considered important by *tokenomics* researchers [70,108,109]: the *quasi-monetary policy* that determines the supply of tokens, and the *distribution strategy* or initial allocation of the tokens.

Table 4 provides a high-level overview of our cases' quasi-monetary policies. The emission type is usually inflationary, but in the cases of Aave and Maker, it is deflationary. Aave has a Buy-Back-and-Burn policy; Maker has a Burn-and-Mint policy. These policies are motivated by the assumed link between economic value and resource scarcity, hence they are expected to affect the value of AAVE and MKR tokens over time [70]. There is an important caveat about Maker: although the supply of MKR tokens is deflationary, Maker's DAO once elected to mint and sell additional MKR tokens in order to cover debts [110]. This explains why the fully diluted supply of MKR tokens is larger than the initial supply of MKR tokens.

Distribution strategies are important for our study of voting rights tokens, since they determine how many wallet addresses initially exercise control over a project and how much voting power these wallet addresses possess. The initial allocations of tokens are case-specific (Fig. 4). After an initial allocation is made, the tokens can be traded bi-laterally and on crypto-asset exchanges. These token transactions, recorded on Ethereum's public ledger, change the distributions of voting rights over time.

The initial allocations of MKR tokens and AAVE tokens each warrant an aside. The initial allocation of MKR tokens is not included in our study. Maker's founder, Rune Christensen, admitted that Maker's governing bodies "don't have the precise data" about the initial allocation of MKR tokens [111]. Maker's founders hold an undisclosed number of MKR tokens, and participants in three private funding rounds from 2017 to 2019 received an undisclosed number of MKR tokens. To account for the initial allocation of AAVE tokens, we had to briefly examine an early version of the Aave project from 2017 named ETHLend. ETHLend issued LEND tokens. LEND token-holders later received an opportunity to *migrate* from LEND tokens to Aave's new AAVE tokens (at a ratio of 100 LEND to 1 AAVE). The total supply of AAVE tokens is 16 million. 13 million AAVE tokens could be redeemed by LEND holders. The three million remaining AAVE tokens were allocated to Aave's treasury. We examined ETHLend's initial allocation of LEND tokens; but other details about the LEND tokens are outside the scope of our study.

Tokens are initially distributed to stakeholders from five distinguishable categories: the beachhead, team, early investors, treasury, and incentives. The beachhead is a small, influential community that promotes the project and supports the technology's adoption. The team receives remuneration or commissions for project development or related work. Early investors and venture capitalists receive tokens in response to their provision of project development funds. A project's treasury can act as a fund, overhead, or reserve. Incentives, finally, are distributed to a project's users, contributors, or prospective participants: Uniswap's *airdrop* of UNI tokens, for example, rewarded the exchange's traders and liquidity providers.

Three cases allocated a considerable portion of their tokens to the beachhead, team, and early investors: UMA (63.5%), UNI (55%), and SNX (40%). In two other cases, the team and investors received 49.95% of COMP tokens and 35% of ZRX tokens. Yearn Finance and SushiSwap did not allocate tokens to these same categories. They each branded their distribution strategy a *fair launch*. Yearn Finance initially allocated 100% of the YFI tokens to users and contributors. In the case of SushiSwap, the beachhead and early investors did not receive an initial allocation of SUSHI tokens. Prospective participants initially received 90% of SUSHI tokens. The SushiSwap treasury received the remaining 10%. At the time of this initial allocation, only developers could access the SushiSwap treasury. SushiSwap's and Yearn Finance's *fair launch* policies are thus not the same.

4.4. Decentrality: distributions of voting rights

According to our decentrality measurements, all cases' distributions of voting rights tokens are highly concentrated. The most concentrated distributions are those of COMP, UMA, and UNI. All three distributions started with a high degree of concentration, then they became even more concentrated over a short period of time. For about a year afterwards, the concentration levels remained relatively steady. Notably, throughout the entire period of our analysis, 50% of the active supply of UMA tokens was never held by more than five wallets.

MKR and ZRX tokens are the oldest. Both launched in late 2017, which is years before the launch of our other cases' tokens (aside from the aforementioned LEND tokens). The distributions of MKR and ZRX each began with a very low level of centrality that took some months to

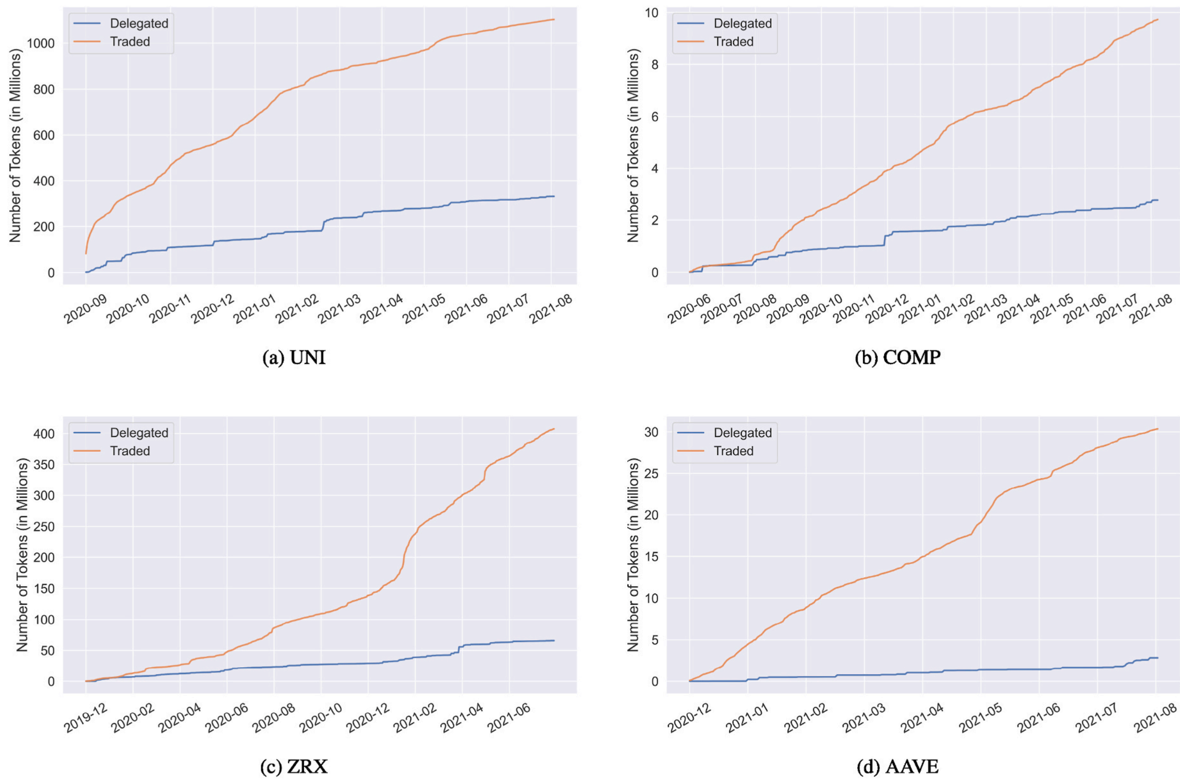


Fig. 3. Number of traded tokens against the number of delegated tokens.

Table 4
The nine cases' quasi-monetary policies.

Case	Token	Emission type	Fully diluted supply	Initial supply
Uniswap	UNI	Inflationary	1,000,000,000	1,000,000,000
Aave	AAVE	Deflationary	16,000,000	16,000,000
Maker	MKR	Deflationary	1,005,577	1,000,000
Compound	COMP	Inflationary	10,000,000	10,000,000
SushiSwap	SUSHI	Inflationary	250,000,000	0
Synthetix	SNX	Inflationary	212,424,133	100,000,000
Yearn Finance	YFI	Inflationary	36,666	30,000
0x	ZRX	Inflationary	1,000,000,000	1,000,000,000
UMA	UMA	Inflationary	101,172,570	100,000,000

increase significantly.[3] As of 15 August 2021, both the MKR and ZRX distributions are highly concentrated.

AAVE is the newest token. Its distribution began with a relatively low level of centrality, but it rapidly reached high values that are comparable with those of YFI and ZRX. For the active supply of AAVE, at any given point in time, no more than 53 addresses control more than 50%. Although this is not as concentrated as the distribution of UMA tokens, it is still highly concentrated.

As noted, SUSHI and YFI tokens were distributed via *fair launches*. The *fair launch* policies did not noticeably affect the decentrality measurements of either SUSHI or YFI. The SNX distribution exhibits the lowest level of centrality, and it did not involve a *fair launch*. As of 15 August 2021, more than 4,400 addresses (approximately 5% of the total number of addresses holding SNX) are required in order to control more than 50% of the SNX voting rights. What distinguishes Synthetix from the other eight cases is its *quadratic voting* mechanism. Whereas other

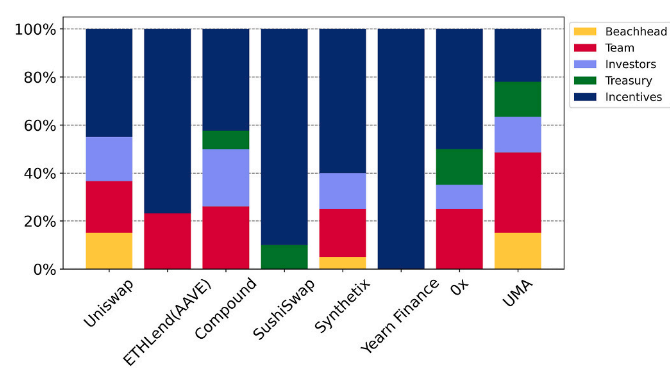


Fig. 4. Initial token allocations (for each case except Maker).

projects adopted a one-to-one connection between tokens and voting power, Synthetix's quadratic voting mechanism calculates an address's voting power as the square root of the number of tokenised voting rights that it holds. The quadratic voting mechanism is designed to limit the voting power of an address with a significant number of SNX tokens, such that an address that holds 10,000 SNX tokens, for example, would possess the power to cast only 100 votes. Furthermore, the voting power's rate of reduction *increases* in relation to the number of SNX tokens that an address holds. There is, however, an important caveat: quadratic voting is not Sybil-resistant [112], which means that individuals can divide their SNX tokens across multiple wallet addresses and obtain greater voting power than they otherwise would have if they held all their SNX tokens in a single wallet address.

Aside from SNX, the examined distributions of voting rights tokens all exhibit a very high level of centrality (Fig. 5), with fewer than 100 addresses controlling more than 50% of the voting power. This is true even when we exclude the tokens held by custodial exchanges and lending services (Fig. 6). The initial token allocation appears to have a

[3] Under the NSE, the initial distribution of MKR tokens appears to be highly concentrated. This is, however, a metric artefact caused by the fact that, up until 13 December 2017, only 11 addresses held any MKR tokens, and just three of these addresses controlled more than 97% of the active supply.

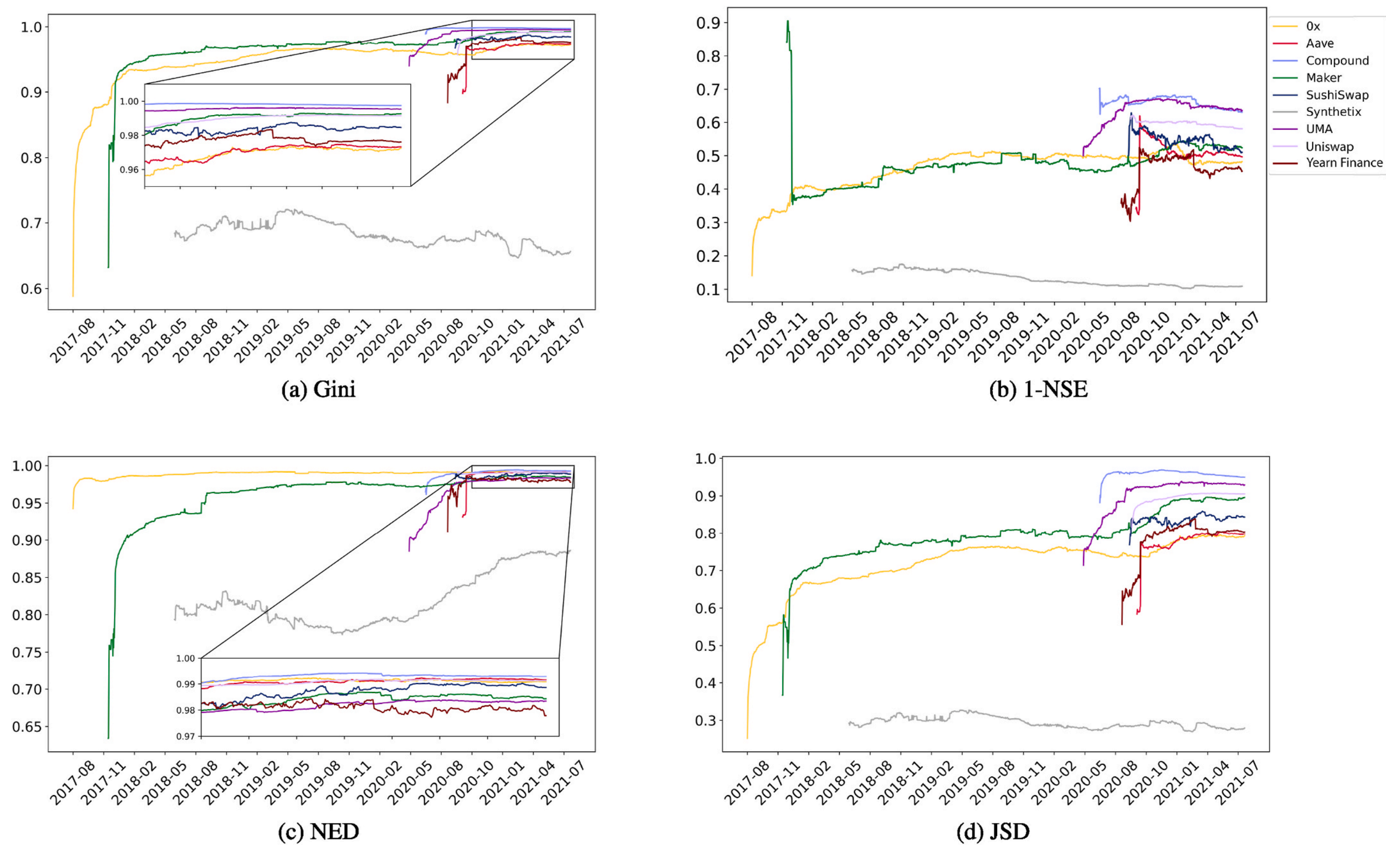


Fig. 5. Levels of decentrality (when custodial exchanges and lending platforms are included). Higher values indicate higher levels of centrality.

short-term effect on a project's decentrality. This means that, even if a case deploys a *fair launch*, the centrality level increases rapidly following the launch date, then later, the centrality seems to stabilise at a high level. Quadratic voting is seemingly the only factor from our cases that affects the decentrality measurements.

Finally, we determined that the number of voting rights tokens held by custodial exchanges and lending platforms only has a negligible impact on most cases' decentrality measurements (see Fig. 7). This is despite the fact that custodial exchanges and lending platforms hold a considerable number of tokens for each project.

4.5. Participation: exercise of voting rights

To assess the voting participation rates for each of our cases, we determined the proportion of wallet addresses that exercised voting rights in relation to the total number of wallet addresses that held eligible voting rights (see Section 3.2). For all our cases, the voting participation rates were very low. In the final months of the analysis period, only three cases witnessed more than 1% of the eligible wallet addresses engaged in voting rounds. Fig. 8 presents the voting participation rates. The active scenario accounts for voting rights that were exercised from non-delegators' wallet addresses and delegates' wallet addresses. For the sake of a comparison, the passive scenario accounts for voting rights that were exercised from non-delegators' wallet addresses and delegates' wallet addresses as well as voting rights that were delegated. In other words, the active scenario only accounts for votes that were actually cast, whereas the passive scenario also counts delegation-transactions as evidence of participation.

According to our analysis, Yearn Finance's governance participation rates are the highest. More than 60% of YFI token-holders voted for/against the first improvement proposal. This can probably be attributed to the fact that, at the time, only a small number of wallet addresses held voting rights tokens that were earned from liquidity mining programs. This rate of participation did not last long. Shortly after crypto-asset exchanges listed YFI tokens, Yearn Finance's governance participation rates diminished drastically. Both Yearn Finance and SushiSwap have higher governance participation rates than the cases that permit delegation.[4] In the majority of recent voting rounds, approximately 1%–2% of Yearn Finance's and SushiSwap's token-holders exercised their voting rights. Yearn Finance's rate reached as high as 7% in one of the recent voting rounds.

Aave, Compound, and Uniswap each permit delegation. In recent voting rounds, these cases' participation rates are lower than 0.1% in the active scenario, and they are consistently lower than 0.5% in the passive scenario. Aave and Compound have the lowest participation rates in the active scenario; and in the passive scenario, Aave's participation rates are the lowest by a substantial margin. As in the case of Yearn Finance and in the case of SushiSwap, Compound's initial participation rates were high, then they soon declined.

UMA's governance participation rates are notable, since they are the third highest and the most consistent. Other cases' rates exhibit significant fluctuations over time. UMA incentivises token-holders to exercise their voting rights by minting and distributing 0.05% of its token supply to wallet addresses that actually cast votes. It also offers *gas* rebates to cover the voting transaction costs. This effectively eliminates a drawback of on-chain voting. In spite of these incentives (and the fact that it ranks third among our cases), UMA's participation rates are not high. They are usually around 0.5%.

We were unable to include the MKR, SNX, and ZRX tokens during this stage of our analysis. In accordance with Maker's Continuous

4 The current version of Yearn Finance allows token-holders to delegate their voting power via Snapshot, not via an Ethereum transaction. This type of delegation is outside the scope of our data collection.

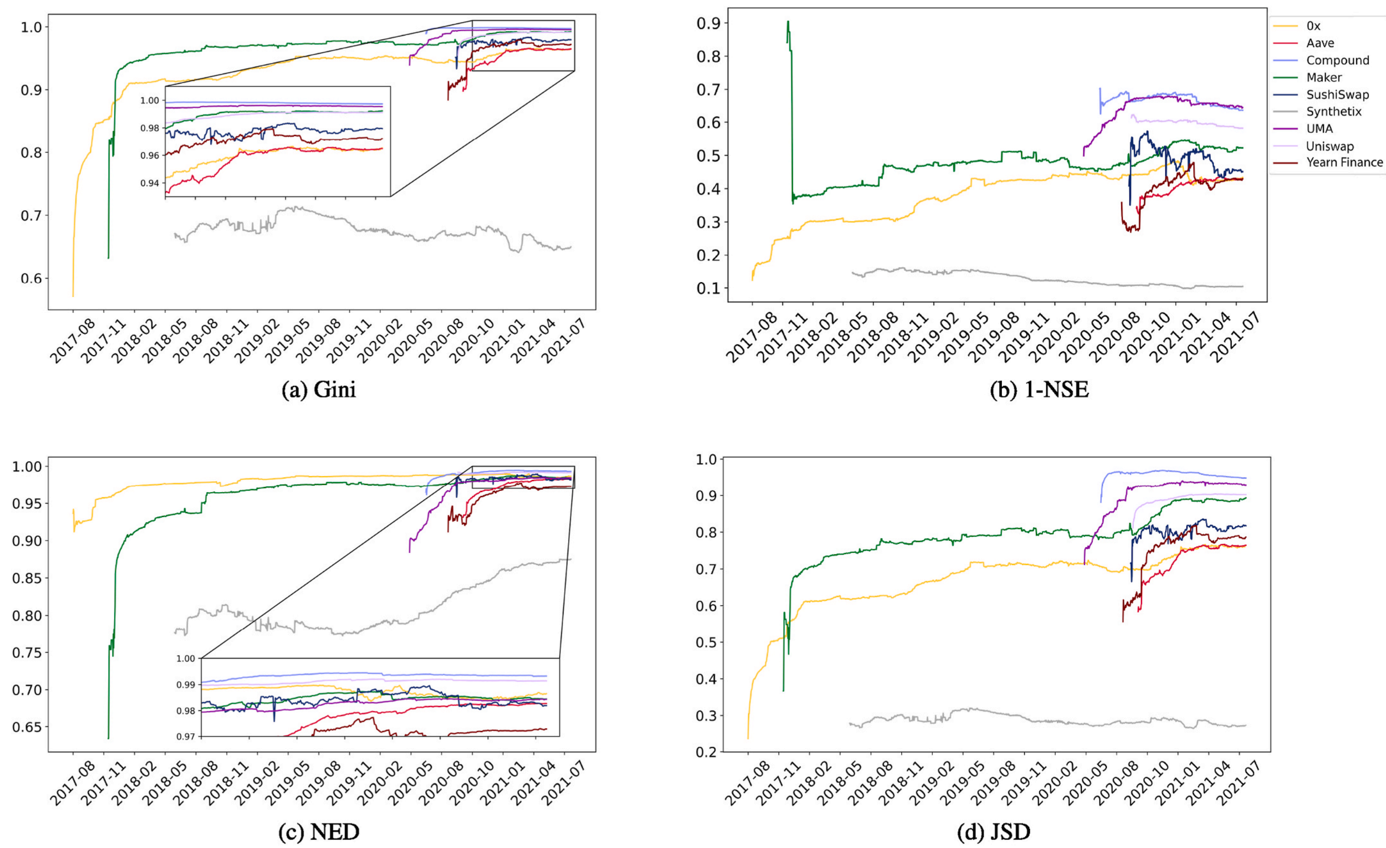


Fig. 6. Levels of decentrality (when custodial exchanges and lending platforms are excluded). Higher values indicate higher levels of centrality.

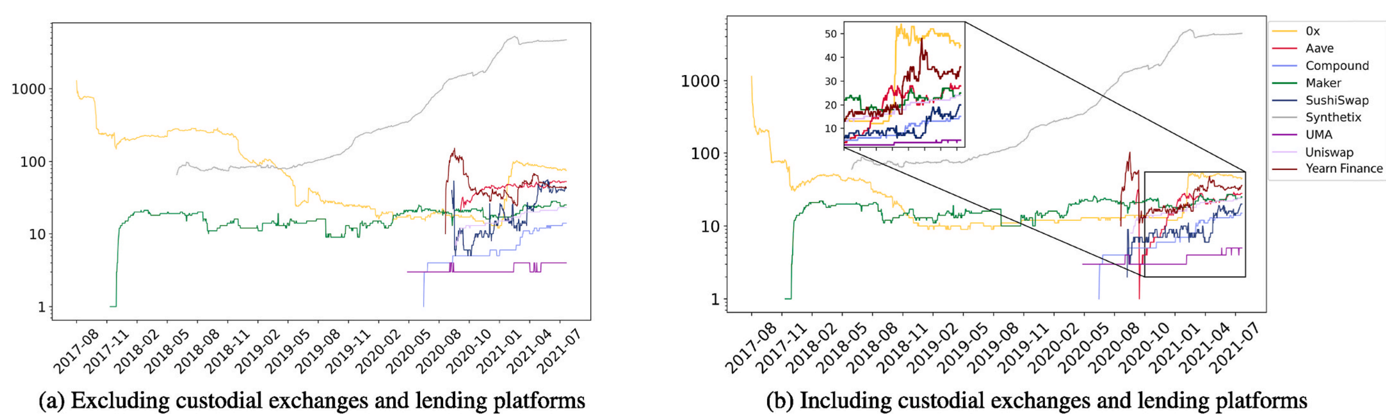


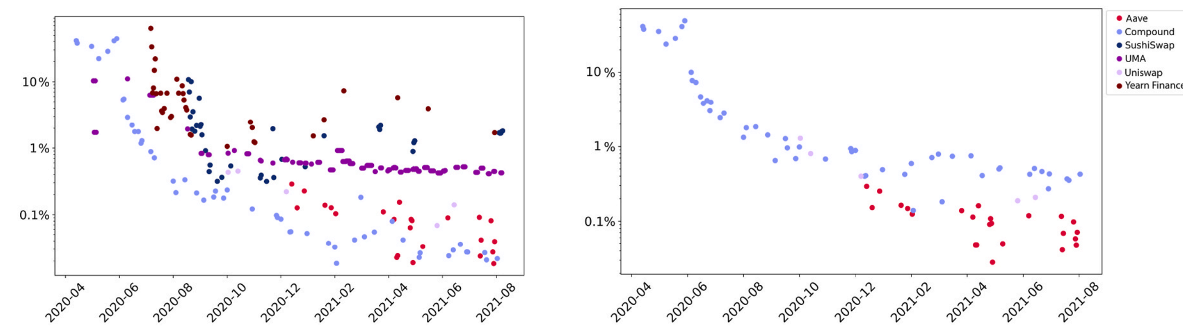
Fig. 7. Minimum number of addresses required to accumulate more than 50% of the active supply.

Approval Voting model, voting rounds for improvement proposals remain open indefinitely. We decided to not compare participation data about Maker's *indefinite* voting rounds with participation data about the other cases' *defined* voting rounds. According to a pre-print by Sun et al. [113], the participation rates in Maker's indefinite voting rounds are low. Most proposals attract votes from fewer than 60 wallet addresses (less than 0.04% of the total eligible wallet addresses). Only four proposals attracted votes from more than 100 wallet addresses. Synthetix's SNX tokens are excluded, because we could not retrieve participation data for all four Spartan Council elections that occurred during the analysis period. We could only collect data about the third and fourth proposals. These proposals attracted votes from no more than 356 wallet addresses (0.22% of the total eligible wallet addresses). As for 0x, we could not include the ZRX tokens, because 0x uses its own off-chain mechanism for voting rounds, from which we could not access data. According to 0x's "Governance Update #1" [139], just 600 wallet addresses (0.17% of the total eligible wallet addresses) cast votes across a sum of 10 improvement proposals.

5. Discussion

Some findings are consistent across all nine cases; hence we can formulate a general definition of DeFi's voting rights tokens. Established texts about concentrated governance power, *bearer shares*, and unregulated markets account for portions of our findings; but the existing literature does not precisely account for the *type* of minority rule that is evidenced by our cases.

Repeated points from blockchain literature about DeFi's democratic



(a) Active scenario   (b) Passive scenario

Fig. 8. Governance participation rates. Each point corresponds to an improvement proposal's voting round.

and inclusive governance are especially at odds with our findings. Hence we discuss DeFi's token-holder governance as *timocratic*, not democratic. The discussion's sceptical style is justified by a "rich data-driven inquiry" [114; pp. 271–273]. It satisfies recent calls from critical Information Systems researchers for philosophical interventions [40,41].

5.1. Definition of voting rights tokens

For all our cases, voting rights tokens are not backed by anything physical; therefore they are "digital assets" [70]. The tokens are not legal contracts, and the token-holders' legal identities are not mandatorily registered. The tokens do not entitle the holders to a share of a registered company's profits, and none of our cases' DAOs are registered as limited liability companies [27].

For the four cases that permit delegation (for actual voting purposes), the cumulative number of trading events is much greater than the number of delegation events. We thus classify voting rights tokens as *primarily* tradable. We classify voting rights tokens *secondarily* as "usage-based" [70; p. 10], since only a small minority of token-holders actually use the tokens for something other than trading. For most cases in the final months of our analysis period, this minority is less than 1%. We classify voting rights tokens *thirdly* as "distributed", in a weak sense, for even though token-holders are scattered across the globe, the token distributions exhibit low decentrality. The token distributions are in fact highly concentrated. In sum, we propose a three-part definition of voting rights tokens. Voting rights tokens are:

1. Tradable crypto-assets without registered holders.
2. "Usage-based" (but used only by a small minority).
3. "Distributed" (but far from equi-distributed).

Our first classification is corrective with respect to the intuitive assumption that voting rights tokens are primarily used for voting purposes. Our second classification is qualified: voting rights tokens are potentially utilised (for something other than trading), but only a small minority of voting rights tokens are actually utilised. Our third classification is determinedly sceptical: voting rights tokens are indeed distributed, but their distributions are highly concentrated. These classifications are crucial to our anti-platitudinous theory of DeFi's governance as a type of minority rule.

5.2. Governance discussions from legal and political texts

Since DeFi's DAOs are non-liable and holders of tokenised voting rights are unregistered, analogies with corporate governance norms and registered shareholders' voting rights are often distant [5,6]. A close analogy can be made, however, between unregistered token-holders' voting rights and *bearer shares* that happen to attribute voting rights [115–118]. This is because they both attribute voting rights to whoever is the bearer – to whoever holds them – without requiring the disclosure of legal identity information. A proof of legal identity is not required when DeFi's tokens are used to cast votes, just as it is not required when the tokens are sold on non-custodial exchanges like Uniswap and SushiSwap. If it were possible for global, unincorporated associations to issue bearer share certificates in a digital form, these certificates would closely resemble DeFi's tokenised voting rights.

Beyond bearer shares, corporate governance literature offers three distant analogies. First, the concentration of DeFi's voting rights among developers and venture capitalists is roughly akin to "the decline of shareholder democracy and the normalisation of founder primacy", exemplified by Snap, Inc. [119], or alternatively "the curious turn toward board primacy" [120; p. 2071]. Second, the recognition that token-tradable voting rights are not democratically distributed is loosely relevant to governance theories that propose democratic alternatives to tradable voting shares [121]. Third, DeFi's non-democratic governance can be placed in a context that includes *controlled companies*, which are governed by just one individual or legal entity. There are over 100 controlled companies listed in the Standard & Poor's Composite 1500 index [122].

Seminal works by Vilfredo Pareto [123,124] and Alexis de Tocqueville [125] help situate DeFi's governance in a modern political context. Pareto's work [123,124] accounts for the emergence of innovative elites following a crisis that affects established elites. To borrow Pareto's animal imagery, DeFi's innovative elites are foxes. They promote decentralisation in a cunning and devious manner, in order to accumulate power and wealth without public displays of force. The traditional financial system's elites are lions. They govern centralised institutions, they aim to conserve power, and they exercise force in public [126]. Pareto [124] held that minority rule is inevitable, since one class of elites follows another class of elites. Pareto's notion of recycled elites complements a maxim by Tocqueville [125]: after power is dissolved and decentralised, it is reassembled and re-centralised. As Tocqueville stated, "all authorities by nature lean towards unity"; hence, if power is decentralised, "it automatically hurtles towards centralisation". These seminal texts prompted us to specify DeFi's type of minority rule.

5.3. Philosophical intervention: DeFi's minority rule is timocratic

All nine DeFi cases exhibited concentrated voting power, which became more concentrated over time rather than less concentrated; and for most cases in the final months of our analysis period, fewer than 1% of eligible token-holders participated in governance proceedings. We deduce that minority rule is the probable consequence of tradable voting rights, ineffectual *fair launch* distribution strategies, and no applicable anti-monopoly or anti-concentration laws. A sceptical-empirical discussion of DeFi's minority rule is therefore appropriate; and, following platitudes about the democratic, inclusive, or empowering nature of DeFi and DAOs (see Refs. [7–9,46,127]), it is desirable as well.

On 7 December 2021, the founder of Yearn Finance, Andre Cronje, wrote, "Time to retire 'decentralised finance'. We aren't decentralised".

This is due to an "old guard" of DeFi insiders [128]. A few days prior, the crypto-asset researcher Ryan Selkis [129; p. 153] named "benevolent dictators", "coin voting" (voting rights tokens), "voter apathy", and oligarchic "collusion" as likely problems for DAOs in the year 2022. On 7 October 2021, the founder of Synthetix, Kain Warwick, identified "plutocracy" as a risk to DeFi. In Warwick's opinion, DeFi's current governance options are "not very generalisable" and "pretty terrible" [130]. This includes ineffectual *fair launches*. Brekke et al. [4], likewise, acknowledged claims that tokenised voting rights lead to "plutocracy" and "governing by the wealthy". *Plutocratic* is a plausible term for DeFi's governance; but in response to our findings, we instead claim that DeFi's governance is timocratic. This reflects the fact that DeFi's elites are not simply wealthy; they are sometimes "shadowy" and unidentified as well.

Timocracy is a type of stakeholder governance that dates back to the Solonian Constitution from the sixth century BC. It involves both producers (developers) and property owners (token-holders) that pursue a mixture of particular interests and common interests. Timocracy's main risk is effectively the same as the risk identified by Warwick [131,132]: if a timocracy degenerates, then it becomes an oligarchy (or a plutocracy).

As discussed in Plato's *Republic* [42; 545a–550c], a timocracy is a conflicted mix of community-oriented virtues and private wealth accumulation. Timocracy's emblematic rulers hide their wealth in "treasuries and strongrooms", which implies that timocratic power is *crypto-* ('concealed or secret'). "Victory and honour", in a timocratic regime, are obtained via calculated risks and courageous conquests, not via harmonious rationality or dialectical reason. Timocratic rulers accumulate wealth in subtle ways that are odds with the commons, and they "run away from the law like children running away from their father" [42]. Socrates' contemporary Sparta is an example of a timocratic regime, and it enjoys an eponymous relationship with Synthetix's Spartan Council. Incidentally, Lycurgus of Sparta first implemented a separated powers model, which Synthetix and Yearn Finance later adopted [133].

A timocracy degenerates into an oligarchy when its constitution is rewritten to explicitly reserve power for the wealthy, and when contracts are created to purposefully exacerbate the division between a wealthy class and a poor class [42]. Although our nine DeFi cases are tacitly governed by wealthy, above-average token-holders (whales), average and below-average token-holders (minnows) are allowed to participate in the governance procedures. The minnows' participation is not as effective as the whales' participation; but it is not strictly precluded. Furthermore, developments like Synthetix's quadratic voting are intended to stop the inequality gap from widening.

To reiterate, DeFi's governance is timocratic. DeFi's timocratic rulers – the unregistered, above-average token-holders – accumulate more power over time by purchasing even more tokens. The concentration of power is gradual, subtle, and putatively neutral, because crypto-asset marketplaces are open to all [52]. DeFi's timocratic governance could degenerate and become oligarchic if above-average token-holders vote for so-called improvement proposals that significantly diminish the power of average and below-average token-holders, or if they vote for changes that make it more difficult for newcomers to acquire and exercise voting rights [42; 550d–551b]. Such actions would further strengthen the "old guard".

6. Summary and outlook

The governance of DeFi projects by DAOs is putatively democratic and inclusive (see Refs. [7–9,127]). DAOs are global, unincorporated associations – euphemistically referred to as online communities – with unregistered token-holders. When we examined both the distribution and exercise of tokenised voting rights, issued by nine DeFi projects, we discovered the following:

1. DeFi's tokenised voting rights are highly concentrated.
2. A very small portion of DeFi's token-holders exercise their voting rights.
3. DeFi's voting rights tokens let holders decide whether or not to implement a contingent array of improvement proposals.

These points directly answer our three research questions.

6.1. Theoretical contribution

A philosophical intervention is required to dispel spurious, platitudinous notions of "democracy" and to precisely account for DeFi's *type* of minority rule. We drew on Plato's *Republic* [42; 545a–550c] and argued that DeFi's minority rule is timocratic. We also played on the association between Synthetix's Spartan Council and the timocratic governance model implemented by Lycurgus of Sparta.

6.2. Limitations and future research topics

Our study bears two notable limitations. First, the selected cases can change by the day. This is especially true for the projects' documentation [129]; hence the validity of our qualitative data is limited to the period of extraction. Our findings are potentially undermined by any community-formulated improvement proposals that were implemented after this article's initial submission date. Synthetix's governance structures in 2023, for example, differ substantially from the governance structures that we examined in 2020 and 2021. Simply put, our findings are context-specific. Second, the metrics we used to assess decentrality are imperfect, and different metrics can yield different outcomes. Hence we employed a variety of metrics from different categories. We are reasonably confident that our measured outcomes reflect reality.

DeFi's governance is a "shadowy" and fascinating research topic that is likely to become more complicated in future. Already, DAOs can optionally register as unincorporated non-profit associations [134], limited liability companies in States like Wyoming [27], or non-grantor purpose trusts in the jurisdiction of Guernsey [135]. From 2024 onwards, a DAO can be recognised by the State of Utah as a *juridical person* that is distinct from a limited liability company [136] – a "LLD" for short, not a "LLC". There are also options to "wrap" less exotic legal forms around the operations of DAOs [137]. We believe that DeFi offers multiple avenues for future research and theory development.

6.3. Coda

DeFi is both decentralised and centralised. It is *de*-centralised, in a stereotypical sense, if its governing bodies are *non*-liable, the holders of its voting rights are *un*-registered, its distributed ledgers are *non*-localisable and *un*-incorporated, its assets are *not* custodied, and its exchanges are *un*-regulated. At the same time, DeFi is politically centralised, because its governance is timocratic.

Credit author statement

Tom Barbereau: Conceptualisation, Method, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Reilly Smethurst**: Conceptualisation, Method, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Orestis Papageorgiou**: Conceptualisation, Method, Software, Data curation, Formal analysis, Visualisation, Writing – original draft, Writing – review & editing. **Johannes Sedlmeir**: Conceptualisation, Method, Data curation, Supervision, Validation, Writing – review & editing, Funding acquisition. **Gilbert Fridgen**: Supervision, Writing – review & editing, Funding acquisition.

Data availability

The data that has been used is confidential.

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Appendices.

Appendix A. Gini coefficient compared to the NSE

Even though the Gini coefficient and the NSE can be used to evaluate the same attribute, there are important differences between the two measures. Unlike the NSE, the Gini coefficient takes into consideration the ranks of the data points in a distribution. This can be seen in Figure A.9: according to the Gini, distribution (2) has lower inequality than distributions (1) and (3); whereas according to the NSE, the three distributions are effectively the same. The Gini produces a different result, because the three data points on distribution (2) have the same rank. It is important to highlight that this is not indicative of the Gini coefficient's poor performance, as both interpretations of inequality can be valid depending on the situation.

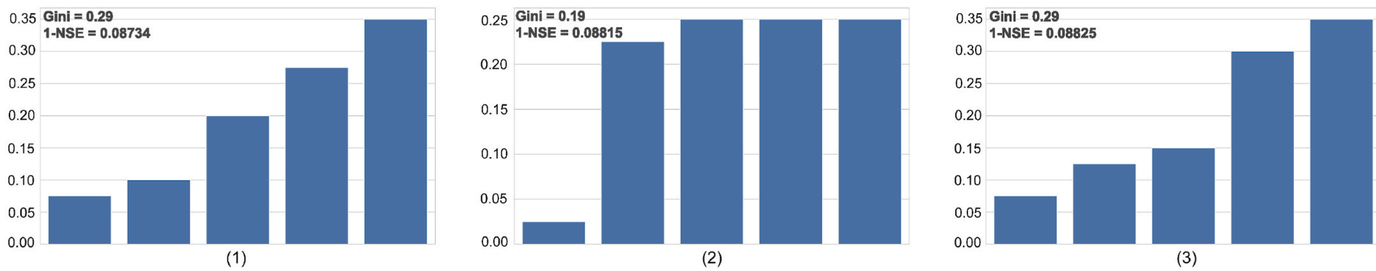

Fig. A.9. The values of the Gini coefficient and NSE for three different distributions.

Appendix B. Gini coefficient's behaviour with many little-funded addresses

For $X \equiv X^{\bar{\epsilon}^{(0)}} = (x_1, x_2, \ldots, x_N)$ representing a distribution of holdings where $0 \le x_1 \le x_2 \le \ldots \le x_N \le 1$ and $\sum_{i=1}^{N} x_i = 1$, the Gini coefficient $G \equiv G^{\epsilon^{(0)}} \equiv G(X^{\bar{\epsilon}^{(0)}})$ can by expressed by [138].

$$G = \frac{2\sum_{i=1}^{N} i x_i}{N} - \frac{N+1}{N} \quad \Rightarrow \quad 2\sum_{i=1}^{N} i x_i = NG + N + 1. \tag{B.1}$$

Let us define a modified distribution by adding a single address that holds tokens corresponding to an $\epsilon^{(1)}$ share of the new total supply (old supply + tokens of the new address), which is not greater than the shares held by any of the previously existing addresses after redistribution:

$$X_i^{\bar{\epsilon}^{(1)}} := \begin{cases} \epsilon^{(1)}, & i = 1 \\ x_{i-1} - \bar{\epsilon}_{i-1}^{(1)} = X_{i-1}^{\bar{\epsilon}^{(0)}} - \bar{\epsilon}_{i-1}^{(1)}, & 2 \le i \le N+1, \end{cases}$$

where $\sum_{i=1}^{N} \bar{\epsilon}_i^{(1)} = \epsilon^{(1)}$, $\epsilon^{(1)} \le x_1 - \bar{\epsilon}_1^{(1)}$, and $x_{i-1} - \bar{\epsilon}_{i-1}^{(1)} \le x_i - \bar{\epsilon}_i^{(1)}$ for all $i \in \{2, \ldots, N\}$. Then $X^{\bar{\epsilon}^{(1)}}$ also satisfies the conditions required for (B.1) to hold, and

$$2\sum_{i=1}^{N+1} i X_i^{\bar{\epsilon}^{(1)}} = 2\sum_{i=1}^{N} (i+1)(x_i - \bar{\epsilon}_i^{(1)}) + 2\epsilon^{(1)} = 2\sum_{i=1}^{N} i X_i + 2 - 2\sum_{i=1}^{N} i\bar{\epsilon}_i^{(1)} = NG + N + 3 - 2\sum_{i=1}^{N} i\bar{\epsilon}_i^{(1)}.$$

Let

$$D_1 := G^{\epsilon^{(1)}} - G^{\epsilon^{(0)}} = G^{\epsilon^{(1)}} - G = \frac{2\sum_{i=1}^{N+1} i X_i^{\epsilon^{(1)}}}{N+1} - \frac{N+2}{N+1} - G = \frac{2\sum_{i=1}^{N+1} i X_i^{\epsilon^{(1)}} - N - 2 - NG - G}{N+1} = \frac{1 - 2\sum_{i=1}^{N} i\bar{\epsilon}_i^{(1)} - G}{N+1}$$

and define inductively $X^{\bar{\epsilon}^{(k)}}$ by adding an address with holdings $\epsilon^{(k)}$ to the distribution described by $X^{\bar{\epsilon}^{(k)}}$ and $D_k := G^{\epsilon^{(k)}} - G = G(X^{\bar{\epsilon}^{(k)}}) - G$. It follows that

$$D_k = G^{\epsilon^{(k)}} - G = \sum_{j=1}^{k} \frac{1 - 2\sum_{i=1}^{N+j-1} i\bar{\epsilon}_i^{(j)} - G^{\epsilon^{(j-1)}}}{N+j}, \qquad G^{\epsilon^{(j)}} = \frac{1 - 2\sum_{i=1}^{N+j-1} i\bar{\epsilon}_i^{(j)} + (N+j-1)G^{\epsilon^{(j-1)}}}{N+j}.$$

We also have

$$X_i^{\bar{\epsilon}^{(j)}} = \begin{cases} \epsilon^{(j-i+1)} - \sum_{m=1}^{i-1} \bar{\epsilon}_{i-m}^{(j-m+1)}, & i \leq j \\ x_{i-j} - \sum_{m=1}^{j} \bar{\epsilon}_{i-m}^{(j-m+1)}, & i \geq j+1. \end{cases}$$

For our multiple-case study, we exclude the addresses that hold token balances valued at less than \$1, and we subtract the balances of these excluded addresses from the total supply. Consequently, in our special case, $\bar{\epsilon}_i^{(1)} = x_i \bar{\epsilon}^{(1)}$ and

$$0 \leq \bar{\epsilon}_i^{(j)} = X_i^{\bar{\epsilon}^{(j-1)}} \epsilon^{(j)} = \begin{cases} \left(\epsilon^{(j-i)} - \sum_{m=1}^{i-1} \bar{\epsilon}_{i-m}^{(j-m)}\right)\epsilon^{(j)}, & i \leq j-1 \\ \left(x_{i-j+1} - \sum_{m=1}^{j-1} \bar{\epsilon}_{i-m}^{(j-m)}\right)\epsilon^{(j)}, & i \geq j \end{cases} \leq \begin{cases} \epsilon^{(j-1)}\epsilon^{(j)}, & i \leq j-1 \\ x_{i-j+1}\epsilon^{(j)}, & i \geq j. \end{cases}$$

We want to prove that $G^{\epsilon^{(j)}} \geq G^{\epsilon^{(0)}}$ for all j, which is equivalent to $D_j \geq 0$ for all these j. Indeed,

$$2\sum_{i=1}^{N+j-1} i\bar{\epsilon}_i^{(j)} \leq 2\sum_{i=1}^{j-1} i\epsilon^{(j-1)}\epsilon^{(j)} + 2\sum_{i=1}^{N}(i+j-1)X_i\epsilon^{(j)} \leq \epsilon^{(j-1)}\epsilon^{(j)}(j-1)j + \epsilon^{(j)}(NG+N+2j-1)$$

and

$$G^{\epsilon^{(j)}} = \frac{1 - 2\sum_{i=1}^{N+j-1} i\bar{\epsilon}_i^{(j)} + (N+j-1)G^{\epsilon^{(j-1)}}}{N+j} \leq \frac{NG+j}{N+j}.$$

Finally

$$D_k = \sum_{j=1}^{k} \frac{1 - \epsilon^{(j-1)}\epsilon^{(j)}(j-1)j - \epsilon^{(j)}(NG+N+2j-1) - G^{\epsilon^{(j-1)}}}{N+j} \geq \frac{k - \epsilon^{(1)}\epsilon^{(2)}\frac{(k-1)k(k+1)}{3} - k\epsilon^{(1)}(NG+N+k) - \sum_{j=1}^{k} G^{\epsilon^{(j-1)}}}{N+k}.$$

Since $D_k \geq 0$,

$$k - k\epsilon^{(1)}\left(\epsilon^{(2)}\frac{(k^2-1)}{3} + NG+N+k\right) - \sum_{j=1}^{k}\frac{NG+j-1}{N+j-1} \geq 0 \quad \Rightarrow \quad \frac{k - \sum_{j=1}^{k}\frac{NG+j-1}{N+j-1}}{k\left(\epsilon^{(2)}\frac{(k^2-1)}{3} + NG+N+k\right)} \geq \epsilon^{(1)}.$$

The case of Uniswap on 15 August 2021 presents the *worst case* scenario for this boundary, with N = 227,946, k = 34,934, G = 0.99184 and $\epsilon^{(2)} = 6.42 \cdot 10^{-11}$. This results in an upper bound for $\epsilon^{(1)}$ of $1.55 \cdot 10^{-8}$, which is greater than the largest $\epsilon^{(1)}$. The largest $\epsilon^{(1)}$ is of scale 10^{-9}. It was recorded for SushiSwap. After excluding all the addresses that hold less than \$1 worth of tokens, the Gini coefficient decreases in every case. This justifies our claim from Section 3.2, in which we argued that our analysis yields an upper boundary with respect to decentrality. Furthermore,

$$\frac{D_k}{G} = \frac{G^{\epsilon^{(k)}} - G}{G} \leq \frac{\frac{NG+k}{N+k} - G}{G} = \frac{k(1-G)}{G(N+k)} = 0.09305$$

for G = 0.58816, which is the lowest value recorded for the ZRX distribution. Consequently, the Gini coefficient would increase by at most 9.305% if we included these addresses in our analysis.

With similar arguments, one can prove that 1 − NSE increases when addresses with low-value holdings are added. This is also apparent from a continuity argument. When adding an address with 0 holdings, NSE is divided through $\frac{\log(N+1)}{\log(N)} > 1$ (for NSE = 0, δ_{i_0} the case is even simpler) and hence 1 − NSE increases; so by continuity of 1 − NSE, there is a threshold such that for adding holdings smaller than the threshold, 1 − NSE will increase.

References

[1] M. Atzori, Blockchain Technology and Decentralized Governance: Is the State still Necessary? J. Govern. Regul. 6 (2017) 45–62, https://doi.org/10.22495/jgr_v6_i1_p5.

[2] L. Shin, The Cryptopians: Idealism, Greed, Lies, and the Making of the First Big Cryptocurrency Craze, PublicAffairs, 2022.

[3] D. Tapscott, A. Tapscott, Blockchain Revolution: How the Technology behind Bitcoin and other Cryptocurrencies is Changing the World. Penguin, 2018.

[4] J.K. Brekke, K. Beecroft, F. Pick, The Dissensus Protocol: Governing Differences in Online Peer Communities, Front. Hum. Dynam. 3 (2021), https://doi.org/10.3389/fhumd.2021.641731.

[5] J.G. Allen, Bodies without Organs: Law, Economics, and Decentralised Governance, Stanford Journal of Blockchain Law and Policy, 2021. https://stanford-jblp.pubpub.org/pub/law-econ-decentralised-governance.

[6] D.A. Zetzsche, D.W. Arner, R.P. Buckley, Decentralized Finance, J. Financ. Regul. 6 (2020) 172–203, https://doi.org/10.1093/jfr/fjaa010.

[7] M. Brennecke, T. Guggenberger, B. Schellinger, N. Urbach, The De-Central Bank in Decentralized Finance: A Case Study of MakerDAO, in: Proceedings of the 55th Hawaii International Conference on System Sciences, AIS, 2022, pp. 6073–6082, https://doi.org/10.24251/HICSS.2022.737.

[8] R. Ozcan, Decentralized Finance, in: Financial Ecosystem and Strategy in the Digital Era: Global Approaches and New Opportunities, Springer, 2021, pp. 57–75, https://doi.org/10.1007/978-3-030-72624-9_4.

[9] K. Pandian, D. Pfeiffer, S. Qian, Decentralized Finance, in: The Emerald Handbook on Cryptoassets: Investment Opportunities and Challenges, Emerald, 2023, pp. 141–156, https://doi.org/10.1108/978-1-80455-320-620221010.

[10] T. Barbereau, R. Smethurst, O. Papageorgiou, A. Rieger, G. Fridgen, DeFi, not so Decentralized: The Measured Distribution of Voting Rights, in: Proceedings of the 55th Hawaii International Conference on System Sciences, AIS, 2022, pp. 6043–6052, https://doi.org/10.24251/HICSS.2022.734.

[11] X. Sun, C. Stasinakis, Decentralization Illusion in DeFi: Evidence from MakerDAO. https://arxiv.org/abs/2203.16612, 2022.

[12] H. Amler, L. Eckey, S. Faust, M. Kaiser, P. Sandner, B. Schlosser, DeFi-ning DeFi: Challenges & Pathway, 2021. http://arxiv.org/abs/2101.05589.

[13] T. Katona, Decentralized Finance: The Possibilities of a Blockchain “Money Lego” System, Financ. Econ. Rev. 20 (2021) 74–102, https://doi.org/10.33893/FER.20.1.74102.
[14] M. Nadler, F. Schär, Decentralized Finance, Centralized Ownership? An Iterative Mapping Process to Measure Protocol Token Distribution, 2020. https://arxiv.org/abs/2012.09306,arXiv:2012.09306.
[15] K. Qin, L. Zhou, Y. Afonin, L. Lazzaretti, A. Gervais, CeFi vs. DeFi — Comparing Centralized to Decentralized Finance, 2021. https://arxiv.org/abs/2106.08157.
[16] S. Hassan, P. De Filippi, Decentralized Autonomous Organization, Internet Policy Re. 10 (2021), https://doi.org/10.14763/2021.2.1556.
[17] E. Warren, Warren Releases Response from SEC Chair Gensler Affirming Need to Regulate Cryptocurrency Exchanges and Protect Investors and Our Financial System, 2021. https://www.warren.senate.gov/newsroom/press-releases/warren-releases-response-from-sec-chair-gensler-affirming-need-to-regulate-cryptocurrency-exchanges-and-protect-investors-and-our-financial-system.
[18] M. DeCambre, Crypto Is Reshaping the World Economy, 50 Years after Nixon Ended the Dollar’s Peg to Gold. Here’s How Some Are Playing it, 2021. https://www.marketwatch.com/story/nixon-reshaped-the-world-economy-50-years-ago-is-crypto-on-the-brink-of-doing-the-same-now-11628893012.
[19] Financial Action Task Force, Virtual Assets: Update of FATF Guidance for a Risk-Based Approach to Virtual Assets and VASPs – Sixth Draft – Public Consultation, 2021.
[20] G. Gensler, Remarks before the Aspen Security Forum, 2021. https://www.sec.gov/news/public-statement/gensler-aspen-security-forum-2021-08-03.
[21] G. Gensler, Testimony before the United States Senate Committee on Banking, Housing, and Urban Affairs, 2021. https://www.sec.gov/news/testimony/gensler-2021-09-14.
[22] S. Brown, P.J. Toomey, A. Walch, J. Brito, M. Belcher, Cryptocurrencies: What are they Good for?, 2021. https://www.banking.senate.gov/hearings/cryptocurrencies-what-are-they-good-for.
[23] E. Warren, Warren Urges FSOC to Use Authority to Address Cryptocurrency Market, Protect Consumers, and Mitigate Financial Stability Risks, 2021. https://www.warren.senate.gov/download/fsoc-crypto-letter-07262021.
[24] T. Emmer, Opening Address: Exploring the Risks of Central Bank Digital Currencies, 2023. https://www.cato.org/events/central-bank-digital-currency.
[25] J.R. Jensen, V. von Wachter, O. Ross, How Decentralized is the Governance of Blockchain-Based Finance? Empirical Evidence from Four Governance Token Distributions, 2021. https://arxiv.org/abs/2102.10096,arXiv:2102.10096.
[26] L. Anker-Sørensen, D.A. Zetzsche, From Centralized to Decentralized Finance: The Issue of ‘Fake-DeFi’, 2021. https://ebi-europa.eu/publications/working-paper-series/.
[27] S. Aramonte, W. Huang, A. Schrimpf, DeFi Risks and the Decentralisation Illusion, 2021. https://www.bis.org/publ/qtrpdf/r_qt2112b.pdf.
[28] P. De Filippi, B. Loveluck, The Invisible Politics of Bitcoin: Governance Crisis of a Decentralised Infrastructure, Internet Policy Re. 5 (2016), https://doi.org/10.14763/2016.3.427.
[29] P. De Filippi, M. Mannan, W. Reijers, Blockchain as a Confidence Machine: The Problem of Trust & Challenges of Governance, Technol. Soc. 62 (2020), 101284, https://doi.org/10.1016/j.techsoc.2020.101284.
[30] Q. DuPont, Experiments in Algorithmic Governance — A History and Ethnography of “The DAO,” a Failed Decentralized Autonomous Organization, in: Bitcoin and Beyond: Cryptocurrencies, Blockchains and Global Governance, Routledge, 2017, pp. 157–177, https://doi.org/10.4324/9781315211909-8.
[31] W. Reijers, I. Wuisman, M. Mannan, P. De Filippi, C. Wray, V. Rae-Looi, A. Cubillos Vélez, L. Orgad, Now the Code Runs Itself: On-Chain and Off-Chain Governance of Blockchain Technologies, Topoi 40 (2018) 821–831, https://doi.org/10.1007/s11245-018-9626-5.
[32] K.M. Eisenhardt, Building Theories from Case Study Research, Acad. Manag. Rev. 14 (1989) 20, https://doi.org/10.5465/amr.1989.4308385.
[33] K.M. Eisenhardt, M.E. Graebner, Theory Building from Cases: Opportunities and Challenges, Acad. Manag. J. 50 (2007) 25–32, https://doi.org/10.5465/amj.2007.24160888.
[34] R.K. Yin, Case Study Research and Applications: Design and Methods, sixth ed., Sage, 2018.
[35] C. Brooke, Critical Research in Information Systems: Issue 1, J. Inf. Technol. 17 (2002) 45–47, https://doi.org/10.1080/02683960210154139.
[36] D. Howcroft, E.M. Trauth, Choosing Critical IS Research, in: D. Howcroft, E. M. Trauth (Eds.), Handbook of Critical Information Systems Research: Theory and Application, Edward Elgar, 2005, pp. 1–15, https://doi.org/10.4337/9781845426743.00007.
[37] B.C. Stahl, Information Systems: Critical Perspectives, Routledge, 2008.
[38] K. Becker, Blockchain Matters – Lex Cryptographia and the Displacement of Legal Symbolics and Imaginaries. Law and Critique, 2022, https://doi.org/10.1007/s10978-021-09317-8.
[39] B. Bodó, J.K. Brekke, J.H. Hoepman, Decentralisation: A Multidisciplinary Perspective, Internet Policy Re. 10 (2021) 1–21, https://doi.org/10.14763/2021.2.1563.
[40] N.R. Hassan, J. Mingers, B. Stahl, Philosophy and Information Systems: Where are We and Where should we Go? Eur. J. Inf. Syst. 27 (2018) 263–277, https://doi.org/10.1080/0960085X.2018.1470776.
[41] F. Rowe, Being Critical is Good, but Better with Philosophy! From Digital Transformation and Values to the Future of IS Research, Eur. J. Inf. Syst. 27 (2018) 380–393, https://doi.org/10.1080/0960085X.2018.1471789.
[42] G.R.F. Ferrari (Ed.), Plato: The Republic, Cambridge University Press, 2000.
[43] R. Morrison, N.C.H.L. Mazey, S.C. Wingreen, The DAO Controversy: The Case for a New Species of Corporate Governance? Front. Blockchain 3 (2020) https://doi.org/10.3389/fbloc.2020.00025.
[44] S. Davidson, P. De Filippi, J. Potts, Blockchains and the Economic Institutions of Capitalism, J. Inst. Econ. 14 (2018) 639–658, https://doi.org/10.1017/S1744137417000200.
[45] D. Rozas, A. Tenorio-Fornés, S. Díaz-Molina, S. Hassan, When Ostrom Meets Blockchain: Exploring the Potentials of Blockchain for Commons Governance, Sage Open 11 (2021), https://doi.org/10.1177/2158244021100252.
[46] C. Santana, L. Albareda, Blockchain and the Emergence of Decentralized Autonomous Organizations (DAOs): An Integrative Model and Research Agenda, Technol. Forecast. Soc. Change 182 (2022), https://doi.org/10.1016/j.techfore.2022.121806.
[47] J.P. Vergne, Decentralized vs. Distributed Organization: Blockchain, Machine Learning and the Future of the Digital Platform, Organ. Theor. 1 (2020), https://doi.org/10.1177/2631787720977052.
[48] P. Dylan-Ennis, D. Kavanagh, L. Araujo, The Dynamic Imaginaries of the Ethereum Project, Econ. Soc. 52 (2023) 87–109, https://doi.org/10.1080/03085147.2022.2131280.
[49] V. Buterin, The Meaning of Decentralization, 2017. https://medium.com/@VitalikButerin/the-meaning-of-decentralization-a0c92b76a274.
[50] N. Schneider, Decentralization: An Incomplete Ambition, J. Cult. Econ. 12 (2019) 265–285, https://doi.org/10.1080/17530350.2019.1589553.
[51] S.P. Gochhayat, S. Shetty, R. Mukkamala, P. Foytik, G.A. Kamhoua, L. Njilla, Measuring Decentrality in Blockchain Based Systems, IEEE Access 8 (2020) 178372–178390, https://doi.org/10.1109/ACCESS.2020.3026577.
[52] V. Kostakis, C. Giotitsas, The (a)political economy of Bitcoin, tripleC 12 (2014), https://doi.org/10.31269/triplec.v12i2.606.
[53] S. Nagarajan, Bitcoin hit the $1 trillion market cap milestone twice as fast as Amazon and three times faster than Apple, data shows. https://www.businessinsider.in/stock-market/news/bitcoin-hit-the-1-trillion-market-cap-milestone-twice-as-fast-as-amazon-and-three-times-faster-than-apple-data-shows/articleshow/82064390.cms, 2021.
[54] S. Nakamoto, Bitcoin: A Peer-To-Peer Electronic Cash System, 2008. https://bitcoin.org/bitcoin.pdf.
[55] D. Drummer, D. Neumann, Is Code Law? Current Legal and Technical Adoption Issues and Remedies for Blockchain-Enabled Smart Contracts, J. Inf. Technol. 35 (2020) 337–360, https://doi.org/10.1177/0268396220924669.
[56] H. Nabilou, How to Regulate Bitcoin? Decentralized Regulation for a Decentralized Cryptocurrency, Int. J. Law Info Technol. 27 (2019) 31, https://doi.org/10.1093/ijlit/eaz008.
[57] H. Nabilou, Bitcoin Governance as a Decentralized Financial Market Infrastructure, Stanford J. Blockchain Law Policy (2021). https://stanford-jblp.pubpub.org/pub/bitcoin-governance.
[58] M. Gupta, P. Gupta, Gini Coefficient based Wealth Distribution in the Bitcoin Network: A Case Study, in: R. Sharma, A. Mantri, S. Dua (Eds.), Computing, Analytics and Networks, vol. 805, Springer, 2018, pp. 192–202, https://doi.org/10.1007/978-981-13-0755-3_15.
[59] I. Makarov, A. Schoar, Blockchain Analysis of the Bitcoin Market, 2021. http://www.nber.org/papers/w29396.
[60] J. Parkin, The Senatorial Governance of Bitcoin: Making (de)centralized Money, Econ. Soc. 48 (2019) 463–487, https://doi.org/10.1080/03085147.2019.1678262.
[61] L. Ante, Smart Contracts on the Blockchain — A Bibliometric Analysis and Review, Telematics Inf. 57 (2021), 101519, https://doi.org/10.1016/j.tele.2020.1015190.
[62] A. Groce, J. Feist, G. Grieco, M. Colburn, What are the Actual Flaws in Important Smart Contracts (and how can we Find Them)? in: J. Bonneau, N. Heninger (Eds.), Financial Cryptography and Data Security Springer, 2020, pp. 634–653, https://doi.org/10.1007/978-3-030-51280-4_34.
[63] G.A. Oliva, A.E. Hassan, Z.M. Jiang, An Exploratory Study of Smart Contracts in the Ethereum Blockchain Platform, Empir. Software Eng. 25 (2020) 1864–1904, https://doi.org/10.1007/s10664-019-09796-5.
[64] A. Pazaitis, P. De Filippi, V. Kostakis, Blockchain and Value Systems in the Sharing Economy: The Illustrative Case of Backfeed, Technol. Forecast. Soc. Change 125 (2017) 105–115, https://doi.org/10.1016/j.techfore.2017.05.025.
[65] M. Casey, P. Vigna, In Blockchain We Trust, vol. 18, MIT Technology Review, 2018. https://www.technologyreview.com/2018/04/09/3066/in-blockchain-we-trust/.
[66] G. Gensler, Response from SEC Chair Gensler Affirming Need to Regulate Cryptocurrency Exchanges and Protect Investors and Our Financial System, 2021. https://www.warren.senate.gov/imo/media/doc/gensler_response_to_warren_-_cryptocurrency_exchanges.pdf.
[67] E. Warren, Warren Asks SEC Chair Gensler about Risks Posed by Cryptocurrency Exchanges, 2021. https://www.warren.senate.gov/oversight/letters/warren-asks-sec-chair-gensler-about-risks-posed-by-cryptocurrency-exchanges.
[68] FinTech Innovation Hub, FinTech Innovation Hub Report, second ed., 2021. Technical Report 2. Financial Services Agency, https://www.fsa.go.jp/policy/bgin/FIH_Report_2nd_ja.pdf.
[69] D.M. Berkovitz, Climate Change and Decentralized Finance: New Challenges for the CFTC, 2021. https://www.cftc.gov/PressRoom/SpeechesTestimony/opaberkovitz7.
[70] L. Oliveira, L. Zavolokina, I. Bauer, G. Schwabe, To Token or not to Token: Tools for Understanding Blockchain Tokens, in: Proceedings of the 39th International Conference of Information Systems, 2018, pp. 1–17.

[71] W.M. Klimon, Beyond the Board: Alternatives in Nonprofit Corporate Governance, Harvard Bus. Law Rev. 9 (2018).
[72] N. Arnosti, S.M. Weinberg, Bitcoin: A Natural Oligopoly, Manag. Sci. (2022), https://doi.org/10.1287/mnsc.2021.4095.
[73] Q. Lin, C. Li, X. Zhao, X. Chen, Measuring Decentralization in Bitcoin and Ethereum using Multiple Metrics and Granularities, in: 37th International Conference on Data Engineering Workshops, IEEE, 2021, pp. 80–87, https://doi.org/10.1109/ICDEW53142.2021.00022.
[74] B. Kaplan, D. Duchon, Combining Qualitative and Quantitative Methods in Information Systems Research: A Case Study, MIS Q. 12 (1988) 571, https://doi.org/10.2307/249133.
[75] M.D. Myers, M. Newman, The Qualitative Interview in IS Research: Examining the Craft, Inf. Organ. 17 (2007) 2–26, https://doi.org/10.1016/j.infoandorg.2006.11.001.
[76] N.B. Schirrmacher, J.R. Jensen, M. Avital, Token-Centric Work Practices in Fluid Organizations: The Cases of Yearn and MakerDAO, in: Proceedings of the 42nd International Conference on Information Systems, 2021, pp. 1–17.
[77] G.G. Gable, Integrating Case Study and Survey Research Methods: An Example in Information Systems, Eur. J. Inf. Syst. 3 (1994) 15, https://doi.org/10.1057/ejis.1994.12.
[78] J.E. de Azevedo Sousa, V. Oliveira, J. Valadares, G. Dias Goncalves, S. Moraes Villela, H. Soares Bernardino, A. Borges Vieira, An Analysis of the Fees and Pending Time Correlation in Ethereum, Int. J. Netw. Manag. 31 (2021) e2113, https://doi.org/10.1002/nem.2113.
[79] Y. Sovbetov, Factors Influencing Cryptocurrency Prices: Evidence from Bitcoin, Ethereum, Dash, Litecoin, and Monero, J. Econ. Financ. Anal. 2 (2018). https://ojs.tripaledu.com/index.php/jefa/article/view/360.
[80] M. Spain, S. Foley, V. Gramoli, The Impact of Ethereum Throughput and Fees on Transaction Latency during ICOs, in: International Conference on Blockchain Economics, Security and Protocols, 2020, pp. 9:1–9:15, https://doi.org/10.4230/OASIcs.Tokenomics.2019.9.
[81] L. Nuzzi, Bitcoin Miners Are Escaping China, 2021. https://medium.com/coinmetrics/bitcoin-miners-are-escaping-china-d3937e8f018c.
[82] K. Babel, P. Daian, M. Kelkar, A. Juels, Clockwork Finance: Automated Analysis of Economic Security in Smart Contracts, 2021. http://arxiv.org/abs/2109.04347.
[83] W. Chan, A. Olmsted, Ethereum Transaction Graph Analysis, in: 12th International Conference for Internet Technology and Secured Transactions, 2017, pp. 498–500, https://doi.org/10.23919/ICITST.2017.8356459.
[84] X. Xueshuo, W. Jiming, Y. Junyi, F. Yaozheng, L. Ye, L. Tao, W. Guiling, AWAP: Adaptive Weighted Attribute Propagation Enhanced Community Detection Model for Bitcoin De-anonymization, Appl. Soft Comput. 109 (2021), 107507, https://doi.org/10.1016/j.asoc.2021.107507.
[85] P. Daian, S. Goldfeder, T. Kell, Y. Li, X. Zhao, I. Bentov, L. Breidenbach, A. Juels, Flash Boys 2.0: Frontrunning in Decentralized Exchanges, Miner Extractable Value, and Consensus Instability, in: Symposium on Security and Privacy, IEEE, 2020, pp. 910–927, https://doi.org/10.1109/SP40000.2020.00040.
[86] C.F. Torres, R. Camino, R. State, Frontrunner Jones and the Raiders of the Dark Forest: An Empirical Study of Frontrunning on the Ethereum Blockchain, in: 30th USENIX Security Symposium, 2021, pp. 1343–1359.
[87] J. Liang, L. Li, D. Zeng, Evolutionary Dynamics of Cryptocurrency Transaction Networks: An Empirical Study, PLoS One 13 (2018), https://doi.org/10.1371/journal.pone.0202202.
[88] V. Saraph, M. Herlihy, An Empirical Study of Speculative Concurrency in Ethereum Smart Contracts, in: International Conference on Blockchain Economics, Security and Protocols, 2020, https://doi.org/10.4230/OASIcs.Tokenomics.2019.4.
[89] H. Adams, Yesterday Binance Delegated 13M UNI from its Books, 2022. https://twitter.com/haydenzadams/status/1582714218323017729.
[90] V. Buterin, Moving Beyond Coin Voting Governance, 2021. https://vitalik.ca/general/2021/08/16/voting3.html.
[91] M. Miles, A. Huberman, J. Saldaña, Qualitative Data Analysis: An Expanded Sourcebook, second ed., Sage, 1994.
[92] P. Mayring, Qualitative Content Analysis: Theoretical Foundation, Basic Procedures and Software Solution, Klagenfurt, 2014.
[93] H.K. Klein, M.D. Myers, A Set of Principles for Conducting and Evaluating Interpretive Field Studies in Information Systems, MIS Q. 23 (1999) 67–93, https://doi.org/10.2307/249410.
[94] S.H. Cha, Comprehensive Survey on Distance/Similarity Measures between Probability Density, Int. J. Math. Models Methods Appl. Sci. 1 (2007).
[95] J. Chung, P. Kannappan, C. Ng, P. Sahoo, Measures of Distance between Probability Distributions, J. Math. Anal. Appl. 138 (1989) 280–292, https://doi.org/10.1016/0022-247X(89)90335-1.
[96] H. Dalton, The Measurement of the Inequality of Incomes, Econ. J. 30 (1920) 348, https://doi.org/10.2307/2223525.
[97] L. Kostal, P. Lansky, O. Pokora, Measures of Statistical Dispersion based on Shannon and Fisher Information Concepts, Inf. Sci. 235 (2013) 214–223, https://doi.org/10.1016/j.ins.2013.02.023.
[98] L. Kostal, O. Pokora, Nonparametric Estimation of Information-Based Measures of Statistical Dispersion, Entropy 14 (2012) 1221–1233, https://doi.org/10.3390/e14071221.
[99] F. Liese, I. Vajda, On Divergences and Informations in Statistics and Information Theory, IEEE Trans. Inf. Theor. 52 (2006) 4394–4412, https://doi.org/10.1109/TIT.2006.881731.
[100] I. Sason, S. Verdú, f-divergence inequalities, IEEE Trans. Inf. Theor. 62 (2016) 5973–6006, https://doi.org/10.1109/TIT.2016.2603151.
[101] D. Freedman, R. Pisani, R. Purves, Statistics, fourth ed., Norton, 2007.
[102] C. Gini, Variabilità e mutabilità, 1912.
[103] P.P. Graczyk, Gini Coefficient: A New Way to Express Selectivity of Kinase Inhibitors against a Family of Kinases, J. Med. Chem. 50 (2007) 5773–5779, https://doi.org/10.1021/jm070562u.
[104] W. Halffman, L. Leydesdorff, Is Inequality among Universities Increasing? Gini Coefficients and the Elusive Rise of Elite Universities, Minerva 48 (2010) 55–72, https://doi.org/10.1007/s11024-010-9141-3.
[105] V. Buterin, Against Overuse of the Gini Coefficent, 2021. https://vitalik.ca/general/2021/07/29/gini.html.
[106] C.E. Shannon, A Mathematical Theory of Communication, Bell System Technical Journal 27 (1948) 379–423, https://doi.org/10.1002/j.1538-7305.1948.tb01338.x.
[107] J. Lin, Divergence Measures based on the Shannon Entropy, IEEE Trans. Inf. Theor. 37 (1991) 145–151, https://doi.org/10.1109/18.61115.
[108] L.W. Cong, Y. Li, N. Wang, Token-Based Platform Finance, J. Financ. Econ. (2021), https://doi.org/10.1016/j.jfineco.2021.10.002.
[109] R. Wandmacher, Tokenomics, in: Cryptofinance and Mechanisms of Exchange: The Making of Virtual Currency, Springer, 2019, pp. 113–123.
[110] C. Wan, In a first, MakerDAO protocol to auction MKR tokens to cover $4M bad debt, 2020. https://www.theblock.co/post/58606/in-a-first-makerdao-protocol-to-auction-mkr-tokens-to-cover-4m-bad-debt.
[111] adrienbe, What Was MakerDAO's MKR Initial Supply?, 2019. https://www.reddit.com/r/MakerDAO/comments/apuu9e/what_was_makerdaos_mkr_initial_supply/.
[112] E. Buzziol, M. Clarendon, Democracy Decentralised: Voting, Governance and Transparency, dGen, 2020.
[113] X. Sun, X. Chen, C. Stasinakis, G. Sermpinis, Voter Coalitions and Democracy in Decentralized Finance: Evidence from MakerDAO, arXiv, 2023, https://doi.org/10.48550/ARXIV.2210.11203.
[114] V. Grover, K. Lyytinen, New State of Play in Information Systems Research, MIS Q. 39 (2015) 271–296, https://doi.org/10.25300/MISQ/2015/39.2.01.
[115] OECD, Ownership and Control of Ships, OECD Directorate for Science, Technology, and Industry, 2003. Technical Report, https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=DSTI/DOT/MTC(2003)61/REV1&docLanguage=En.
[116] C. Pacini, N.F. Stowell, Panama Papers and the Abuse of Shell Entities, in: H. K. Baker, L. Purda-Heeler, S. Saadi (Eds.), Corporate Fraud Exposed, Emerald, 2020, pp. 361–382, https://doi.org/10.1108/978-1-78973-417-120201023.
[117] K. Stastna, Anonymous Paper Shares Helped the Wealthy Hide Billions, Panama Papers Show, 2016. https://www.cbc.ca/news/business/panama-papers-bearer-shares-1.3525434.
[118] E.v.d. Does de Willebois, J. Sharman, R. Harrison, J.W. Park, E. Halter, The Puppet Masters: How the Corrupt Use Legal Structures to Hide Stolen Assets and what to Do about it, World Bank Publications, 2011. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/784961468152973030/The-puppet-masters-how-the-corrupt-use-legal-structures-to-hide-stolen-assets-and-what-to-do-about-it.
[119] K. Wiehe, Oh, Snap! Do Multi-Class Offerings Signal the Decline of Shareholder Democracy and the Normalization of Founder Primacy? Va Law Bus. Rev. 12 (2017).
[120] G. Hayden, M.T. Bodie, Shareholder Democracy and the Curious Turn toward Board Primacy, William Mary Law Rev. 51 (2009) 2071–2121.
[121] G.M. Hayden, M.T. Bodie, The Corporation Reborn: From Shareholder Primacy to Shared Governance, Boston Coll. Law Rev. 61 (2020) 2419–2485.
[122] E. Kamonjoh, Controlled Companies in the Standard & Poor's 1500: A Follow-Up Review of Performance and Risk, 2016. https://bpb-us-w2.wpmucdn.com/sites.udel.edu/dist/8/12944/files/2022/08/Controlled-Companies-IRRCI-2015-FINAL-3-16-16.pdf.
[123] V. Pareto, A Treatise on General Sociology vols. 3–4, Dover, 1963 [1916].
[124] V. Pareto, The Rise and Fall of Elites: An Application of Theoretical Sociology, Routledge, 2017 [1901].
[125] A. Tocqueville, The Ancien Régime and the French Revolution, Penguin, 2008 [1856].
[126] C. Fordahl, Lions and Foxes: Revisiting Pareto's Bestiary for the Age of Late Pluto-Democracy, Distinktion: J. Soc. Theor. 21 (2020) 316–333, https://doi.org/10.1080/1600910X.2020.1752274.
[127] A. Wieandt, L. Heppding, Centralized and Decentralized Finance: Coexistence or Convergence? in: T. Walker, E. Nikbakht, M. Kooli (Eds.), The Fintech Disruption: How Financial Innovation is Transforming the Banking Industry Springer, 2023, pp. 11–51, https://doi.org/10.1007/978-3-031-23069-1_2.
[128] A. Cronje, Time to Retire "Decentralized Finance", 2021. https://twitter.com/AndreCronjeTech/status/1468273605502980106.
[129] R. Selkis, Crypto Theses for 2022, 2021. https://messari.io/pdf/messari-report-crypto-theses-for-2022.pdf.
[130] K. Warwick, S. Kulechov, T. Chitra, W. Villanueva, DeFi: The Future of Finance, 2021. https://www.youtube.com/watch?v=0GoACn1RPGU.
[131] Rekt, Curve Wars, 2021. https://rekt.news/curve-wars/.
[132] Rekt, SushiSwap Scandal, 2021. https://rekt.news/sushiswap-scandal.
[133] B. McGing (Ed.), Polybius: The Histories, Oxford University Press, 2010.
[134] D. Kerr, M. Jennings, A Legal Framework for Decentralized Autonomous Organizations, 2021. https://a16z.com/wp-content/uploads/2021/10/DAO-Legal-Framework-Jennings-Kerr10.19.21-Final.pdf.
[135] M. Boiron, Legal Framework: Non-U.S. Trusts in Decentralized Autonomous Organizations, 2022. https://dydx.foundation/blog/en/legal-framework-non-us-trusts-in-daos.

[136] R.B. Lamb, Utah Passes Innovative DAO Legislation, 2023. The National Law Review 13, https://www.natlawreview.com/article/utah-passes-innovative-dao-legislation.
[137] C. Brummer, R. Seira, Legal Wrappers and DAOs, SSRN, 2022, https://doi.org/10.2139/ssrn.4123737.
[138] S. Inoua, Beware the Gini Index! A New Inequality Measure, 2021. https://arxiv.org/ftp/arxiv/papers/2110/2110.01741.pdf.
[139] 0x, 0x Governance Update #1, 2021. https://blog.0x.org/0x-governance-update-1/.