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Developing Dimensions and Indicators to Measure Decentralization in Decentralized Autonomous Organizations

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Abstract: Decentralization holds a significant role in the context of decentralized autonomous organizations (DAOs), with its nature being not a fixed value but a comparative spectrum. Prior research investigating the measurement of decentralization in nations' governance system provides a foundation for our current study. This research aims to integrate these insights to define dimensions and indicators, tailored explicitly for assessing decentralization levels within DAOs. Then, the article undertakes an examination of the suitability of traditional decentralization measurement approaches within the unique DAO context, employing confirmatory factor analysis (CFA) as our analytical tool based on a total of 44 DAOs. Hence, the results suggest that DAOs have three dimensions for measuring decentralization, 'political decentralization as a participatory engagement', 'economic decentralization as a resource distribution', and 'administrative decentralization as the self-governing execution of decisions'. By substantiating the applicability of established decentralization measurement frameworks within the unique context of DAOs, the findings not only enhance the understanding of this emergent governance paradigm but also provide DAO practitioners, policymakers, and researchers with invaluable insights.

Keywords: decentralization; decentralized autonomous organization; confirmatory factor analysis; innovative organization; decentralized technologies

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1. Introduction

Prior to the emergence of blockchain-based decentralized autonomous organizations (DAOs) in 2016, the concept of decentralization had been extensively examined and actively discussed. Primarily, decentralization found its application within the governance of nation-states and political science, administrative structures, fiscal realms (Blackorby and Brett 2000; Ahmad 2006; Bahl 1999; Blöchliger and King 2006), and more. Notably, the exploration of decentralization within governmental systems has captivated scholarly interest, leading to inquiries into its definition, measurement, and the identification and validation of key factors influencing decentralization (Rondinelli et al. 1983; Manor 1999; Bird and Vaillancourt 1998; Schneider 2003).

Conversely, research on decentralization within the realm of DAOs remains in its nascent stages. Prior research concerning DAOs has primarily concentrated on historical perspectives (Dhillon et al. 2017; Monrat et al. 2019; Mehar et al. 2019; Singh and Kim 2019; El Faqir et al. 2020), potential benefits and challenges of DAOs, as well as their legal and technical limitations (Hutchcroft 2001), isolated case studies, societal implications, and their integration into existing governmental, social, and corporate frameworks, often sidelining the core aspect of decentralization (Beck et al. 2018; Diallo et al. 2018; Santos and Kostakis 2018; Morrison et al. 2020; Singh and Kim 2019; Far and Bamakan 2022). In parallel, some investigations have delved into the underlying technology that empowers DAOs or conducted analyses of voluminous DAO-related data to identify prevailing trends (Kaal 2020; Chughtia et al. 2022; Saurabh et al. 2023).

Pioneers such as Vitalik Buterin, a prominent figure in the space of DAOs, have suggested multidimensional perspectives on decentralization. In later works (London 1975), Buterin delineated decentralization across architectural, political, and logical dimensions: (1) An architectural dimension, as in how many computers the system is made up of; (2) A political dimension, as in how many controls those computers; (3) A logical dimension, as in how the interface and data structures add up. Recent contributions, exemplified by Henrik's work, have proposed definitions of "sufficient decentralization" and furnished overarching frameworks for assessing decentralization (Axelsen et al. 2023). Henrik's framework delineates five dimensions for decentralization assessment, denoted as token-weighted voting, infrastructure, governance, escalation, and reputation (TIGER). Conversely, some research identifies the crux of blockchain decentralization as "permissionless" and conducts decentralization studies through the prism of peer-to-peer trust relationships. This approach places a particular emphasis on examining the consensus algorithms employed by various blockchains, including Proof-of-Work (POW) and Proof-of-Stake (POS). Moreover, it extends its analysis to encompass quorum-based blockchains such as Ripple and Stellar (Wang et al. 2022).

The findings from previous research underscore the existence of decentralization within DAOs, dispelling the notion that it is merely a myth. However, a crucial aspect remains unexplored: the comprehensive evaluation of the actual extent of decentralization within DAOs. Consequently, a consensus has yet to emerge regarding the precise definition of decentralization, the factors that influence or shape it, and the methodologies for its measurement. For example, despite the significance of these conceptualizations and the derived dimensions in comprehending decentralization within DAOs, a conspicuous gap remains regarding the quantitative and empirical measurement of decentralization degrees in DAOs.

To address this ambiguity and bridge the existing void, this study introduces a framework of factors that outline the concept of decentralization. Moreover, it empirically demonstrates the influence of these factors on decentralization by utilizing quantifiable variables. In this pursuit, our research seeks to apply the knowledge gained from the examination of decentralization within conventional governmental structures to the domain of DAOs. The primary objectives are to confirm the applicability of established decentralization research within the novel context of DAOs and initiate the inaugural efforts in quantitatively assessing the decentralization of DAOs.

The primary research questions that guide our study are as follows:

1. What is the precise definition of decentralization within the context of DAOs and what factors influence or shape it?
2. How can decentralization within DAOs be quantitatively measured and what are the methodologies best suited for this purpose?
3. To what extent can established decentralization research within conventional governmental structures be applied to the novel context of DAOs?
4. What are the efforts required to quantitatively assess the decentralization of DAOs and validate the applicability of existing decentralization theories in this context?

2. Dimensions and Indicators of Decentralization

Many established methodologies for assessing decentralization encompass three primary dimensions: political decentralization, administrative decentralization, and economic or financial decentralization (Schneider 2003; Morozov 2016). Many related studies delve into these three dimensions as significant analytical criteria, including research on the effectiveness and utility of national policies (Nunes Silva 2017), the essence and scope of decentralization within countries (Haydanka 2020), assessments of the impact and effectiveness of decentralization policies and practices (Panda and Thakur 2016), and the understanding of the impact and effectiveness of decentralization in specific systems like health (Goldberg and Schär 2023). According to Fox and Aranda, decentralized political systems are characterized by the prominence of political actors and issues at the local level, which are at least partially independent of those at the national level (Fox and Aranda 1996). Within this framework, numerous studies concentrate on the processes of mobilization, organization, articulation, participation, contestation, and aggregation of interests (Treisman 1999, 2007; Gallego 2010; Fan et al. 2009).

Administrative decentralization, on the other hand, explores the degree to which subordinate organizations enjoy autonomy from a central entity and the extent to which this autonomy relies on the capacities of the subordinate organization. Kaufmann, Kraay, and Mastruzzi define such capacities through indicators like "Government Efficiency (GE)," "Rule of Law (RW)," and "Control of Corruption (CC)." These indicators encompass aspects such as the quality of public service provision, the efficacy of the bureaucracy, the civil service's ability to withstand political pressures, and the government's commitment to policies (Kaufmann et al. 2000, 2003; Kaufmann and Kraay 2008). Terms like deconcentration, delegation, and devolution are often employed to describe this spectrum (Rondinelli et al. 1983; Rondinelli 1990).

Theories on economic and fiscal decentralization had focused on maximizing social welfare, which is portrayed as a combination of economic stability, allocative efficiency, and distributive equity (Musgrave and Peacock 1958; Oates 1993, 1997). Recently, the dimension of economic or fiscal decentralization focuses on expenditures and revenues. In this context, a higher percentage share of expenditures and revenues held by a substructure indicates a higher degree of decentralization within the organization (Schneider 2003).

Drawing from established decentralization research, this study divides the dimensions for assessing DAO decentralization equally into political, economic, and administrative decentralization. It employs six key indicators to measure these dimensions: "voting participation, proposal participation", "token distribution, voting power index", "percentage of quorum condition selections", and "pass rate of proposal with quorum condition".

The examination of decentralization invariably revolves around the dynamics of power and resource allocation between central and decentralized entities (Schneider 2003; Park et al. 2023). In the context of DAOs, the central entity is defined as the operating organization responsible for the DAO's inception, token issuance, and initial policy establishment because it has all the power and receives the resources first. In contrast, the subordinate entities refer to the individual accounts (users) that autonomously participate within the DAO. Within the scope of this study, the political decentralization of a DAO is intricately linked to "participation," which assesses the extent to which accounts engage in the available proposals and votes. We postulate that political decentralization can be measured through two key indicators:

1. Voting Participation: This indicator quantifies the number of accounts actively participating in voting relative to the total potential voting accounts eligible to engage in the voting process. Voting participation serves as an indicator of the level of engagement in voting activities within the DAO and is derived from both voter and holder information. Specifically, voting data is sourced from Snapshot and entails the tally of accounts that have cast votes, counting each unique account only once even if multiple votes have been recorded. The holder information aligns with the token distribution data, utilizing the cumulative count of accounts that have held tokens at some point. Essentially, this metric aims to assess the extent to which accounts actively participated in voting in comparison to the total number of potentially eligible voting accounts.
2. Proposal Participation: This indicator measures the number of accounts actively participating in proposing changes compared to the total potential accounts capable of submitting proposals. Proposal participation is figured out in a way similar to how we calculate voting participation. But, instead of counting the number of voters, we look at how many different accounts have made proposals. This metric quantifies the percentage of individuals who have actively submitted proposals relative to the total number of individuals with the capacity to do so.

The assessment of economic decentralization within a decentralized autonomous organization is focused on evaluating the degree of decentralization in the DAO's financial operations. In this study, our examination is specifically centered on DAOs that incorporate project tokens into their structure. Consequently, the metrics we aim to assess here are inherently tied to these tokens. Project tokens play a pivotal role in granting individuals certain rights and capabilities within the DAO, notably in activities like voting and proposal initiation. This evaluation encompasses two primary indicators:

1. Token Distribution: This metric provides insights into the extent of token dispersion within the DAO. A more even distribution of tokens suggests a higher level of economic decentralization, where ownership is not concentrated in the hands of a few. To work this out, we use the overall token supply and the count of accounts that have possessed the tokens at some point. We figure out the number of accounts that have ever held the project's token by analyzing all the times tokens were transferred in the project's token contract. By using the total supply stated in the smart contract and the number of different accounts who have held the project's token, we determine the token distribution.
2. Voting Power Index: Voting power refers to the degree of influence or control an individual account or entity possesses within a voting system in DAO. This indicator quantifies the level of voting power required for a proposal to pass, elucidating the number of participants needed to contribute their voting power for a successful vote outcome. It serves as a proxy for economic decentralization, with a higher voting power index implying a more inclusive and decentralized decision-making process. Voting power is occasionally associated with token-weighted voting systems, allowing participants to allocate a greater number of tokens to proposals they consider significant. It can be inferred that as proposals necessitate a higher level of voting power for approval, and as more participants are incentivized to contribute their tokens, the DAO's level of economic decentralization tends to increase.

In contrast, administrative decentralization within a DAO is assessed by examining the extent to which individual accounts within the DAO derive genuine benefits and possess autonomy. A significant element in this evaluation is the utilization of quorum requirements, a critical administrative mechanism within DAOs. Snapshot, a platform often used by DAOs, enables proposers to set a minimum quorum for a proposal to achieve passage (Ooi et al. 2021). This administrative feature ensures that the proposal decision-making process operates autonomously without artificial interference and permission (Bracciali et al. 2021). Consequently, this quorum condition serves as a crucial benchmark for evaluating the DAO's capacity for autonomous, decentralized, and permissionless decision making, free from central intervention. To measure administrative decentralization effectively, two key indicators are considered:

1. Percentage of Quorum Condition Selections: This metric quantifies the extent to which quorum criteria are employed to facilitate autonomous voting, without external intervention. A higher percentage signifies a greater reliance on predefined quorum conditions for decentralized decision making.
2. Pass Rate of Proposal with Quorum Condition: This indicator reveals the degree to which proposals subject to such quorum requirements autonomously result in successful votes. It demonstrates the effectiveness of these conditions in enabling autonomous and decentralized decision outcomes.

These indicators collectively provide a robust framework for evaluating the administrative decentralization of DAOs, with a particular emphasis on the autonomy and self-sufficiency of their decision-making processes. Based on this framework, our research hypotheses are as follows:

Hypothesis 1. *Greater voting participation and proposal participation within DAOs positively correlate with higher levels of political decentralization.*

Hypothesis 2. *A more equitable distribution of tokens among DAO participants is associated with increased economic decentralization.*

Hypothesis 3. An increase in the voting power index corresponds to enhanced economic decentralization within DAOs.

Hypothesis 4. *Higher percentages of autonomously determined quorum condition selections within DAOs reflect greater administrative decentralization.*

Hypothesis 5. *A higher pass rate of proposals with quorum conditions signifies improved administrative decentralization within DAOs.*

In addition to the six primary indicators, we indeed desired to incorporate a broader range of variables such as Distribution of Funds, Token Ownership Concentration, Participation Diversity, Delegation Rate, Inclusivity Index, Decision-making Autonomy, Role Distribution, Governance Structure, and Autonomous Execution. However, due to practical limitations such as constraints in obtaining comprehensive on-chain data, the sheer scale and diversity of data, and resource constraints, we were regrettably unable to include these additional indicators in this study (see Table 1). Therefore, it is imperative that future research endeavors include a more extensive set of indicators, including those mentioned.

Table 1. Decentralization dimensions and indicators.

Political Dimension	Economic Dimension	Administrative Dimension
Voting Participation	Token Distribution	Percentage of Quorum Condition Selection
Proposal Participation	Voting Power Index	Pass Rate of Proposal with Quorum Condition

3. Research Design and Method

3.1. Data Collection

To select DAO cases and collect the data from them for this research, we initially extracted DAOs ranking up to the 100th position according to the Snapshot Ranking (2023). Subsequently, we exclusively considered DAOs that operate within the "Ethereum" ecosystem and possess their distinct project tokens. Consequently, a total of 44 DAOs met these stringent criteria and were included in this study. It is important to note that each blockchain operates with its unique consensus algorithm, resulting in variations in decentralization levels. To minimize the complexities introduced by these differences and focus on our core hypotheses and variables, we chose to work exclusively with the Ethereum blockchain. This decision was made to streamline our research and maintain a consistent and controlled environment for our analysis.

Our choice to focus on the top 100 DAOs in our analysis was deliberate, driven by the hypothesis that DAOs' level of activation experiences a sharp decline as their rankings decrease. We deemed it more appropriate to assess decentralization within the context of active DAOs. To underscore this point, consider the 2022 study, which marked the inaugural empirical investigation of DAOs using Snapshot data. This study encompassed 581 DAOs and scrutinized 16,246 proposals (Wang et al. 2022). In our study, the cumulative number of proposals across the top 100 DAOs amounted to 15,907, spanning from the inception of Snapshot in August 2020 up to August 2023 (the time of composing this paper). Remarkably, this figure does not substantially deviate from the number of proposals examined in a previous study encompassing all 581 DAOs, even when considering a one-year gap. Consequently, in assessing the level of activity among DAOs using proposal counts as a metric, our analysis focused on the top 100 DAOs. In our analysis, we narrowed our focus to the final 44 DAOs and it is noteworthy that the total number of proposals we examined amounted to 8640.

It is crucial to acknowledge that the degree of decentralization within a blockchain's mainnet is contingent on the consensus algorithm and policies governing that mainnet. These policies, in turn, are influenced by the choice of mainnet adopted by a specific DAO. Therefore, in the context of this study, we exclusively examined DAOs that operate on the same mainnet. Ethereum was chosen as the primary focus due to its widespread adoption, hosting the largest number and variety of DAOs. Furthermore, DAOs require their independent project tokens to function autonomously within the mainnet. Hence, our analysis centered on DAOs within the Ethereum ecosystem that possessed their own project tokens (see Table 2).

Table 2. The list of selected DAOs.

No	Name	No	Name	No	Name	No	Name
1	Aave	12	Lido	23	JuiceboxDAO	34	Alchemix
2	Uniswap	13	Starknet	24	Frax	35	Yearn (old)
3	Gitcoin	14	OlympusDAO	25	Decentral Games	36	PoolTogether
4	Galxe	15	Bankless DAO	26	The Graph	37	MoonDAO
5	ENS	16	Gearbox	27	Doodles	38	SharkDAO
6	Decentraland	17	Curve Finance	28	Yam	39	mStable
7	BitDAO	18	Hop	29	SafeDAO	40	PieDAO
8	ApeCoin DAO	19	dYdX	30	Synapse Protocol	41	Euler
9	Balancer	20	AirSwap	31	Developer DAO	42	Ribbon
10	Sushi	21	Bancor	32	Fei	43	LinksDAO
11	Proof of Humanity	22	ShapeShift	33	Aura Finance	44	Krause House

Snapshot serves as an invaluable open-source tool, particularly for decentralized organizations, by enhancing the quality of their voting and proposal processes and covering 95% in the wild DAO projects for data collection and analysis (Wang et al. 2022). It is essential to note that votes are conducted off the blockchain while their verification occurs on-chain. Snapshot accommodates a range of voting mechanisms, including quadratic and approval voting systems. Given the widespread adoption of Snapshot by major DAOs, our study also incorporated data derived from Snapshot rankings. For the foundational DAO information presented in this paper, we gathered data pertaining to space, proposals, and voting activities from the Snapshot platform. Each DAO space was subsequently linked with an entity within Deep DAO, and we augmented this data using information concerning the DAO's project token and governance token contracts (see Figure 1).

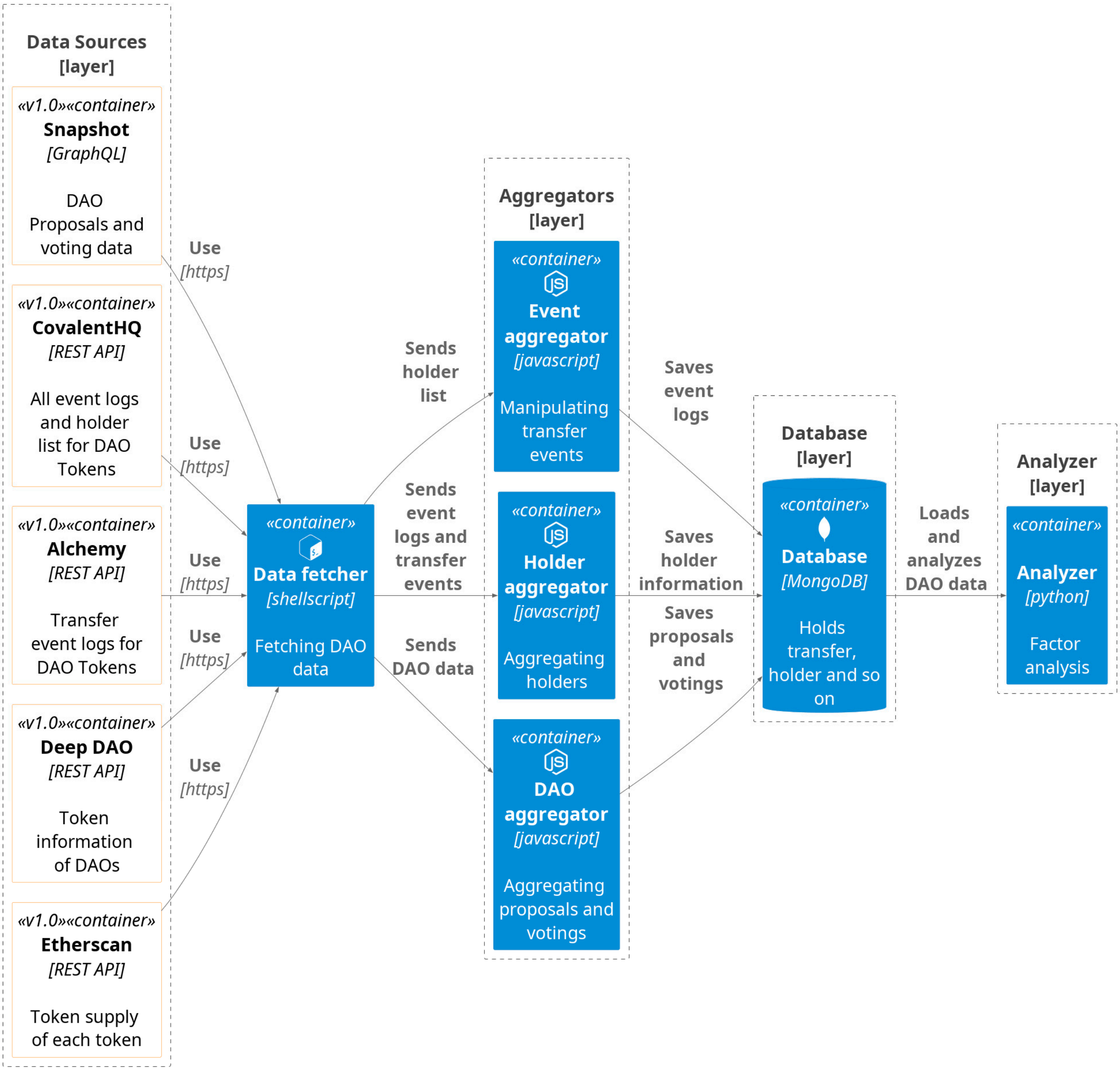

Figure 1. The process of data collection and analyzation.

3.2. *Confirmatory Factor Analysis*

Confirmatory factor analysis (CFA) was employed to assess the hypothesis that three underlying dimensions of decentralization can be measured through a set of observable indicators. These six indicators encompassed voting participation, proposal participation, token distribution, voting power index, percentage of quorum condition selections, and pass rate of proposal with quorum condition. The hypothesis posited that the first two indicators primarily measure political decentralization, the next two assess economic decentralization, and the final two measure administrative decentralization.

CFA serves as a valuable statistical technique with the principal objective of evaluating the suitability of a pre-established factor model for explaining an observed dataset. Common applications of CFA encompass: (1) Establishing the validity of a factor model; (2) Assessing the significance of specific factor loadings; (3) Examining relationships among multiple factor loadings; (4) Evaluating whether a set of factors exhibits correlations or remains uncorrelated (Bollen 1990). The strength of CFA lies in its capacity to assess the goodness of fit between the model and the data, especially in cases where significant correlations among variables may exist.

Given the intricate and interconnected nature of decentralization dimensions, CFA represents an appropriate and valid methodology for our research. Consequently, CFA emerges as one of the most robust methodological tools for the development of a DAO decentralization index in our study.

4. Results

Cumulative variance is a measure that helps evaluate how much of the total variance in the observed variables is accounted for by the factors included in the model. In CFA, researchers aim to capture as much variance as possible with the fewest factors. Cumulative variance is typically reported as a percentage. Higher percentages indicate that a greater proportion of the variance in the observed variables is explained by the included factors. Most researchers often set a threshold for cumulative variance (e.g., capturing 70% or 80% of the variance) to determine how many factors to retain in the model. Higher cumulative variance values suggest that the chosen factors are effective in explaining the observed data.

Eigenvalues are numerical values obtained as part of the factor analysis process. They represent the amount of variance explained by each factor. In CFA, eigenvalues are particularly useful for determining the number of factors to retain in the model. Researchers typically consider eigenvalues greater than 1 as indicative of factors that explain more variance than individual observed variables.

In this study, principal factor analysis of the dataset confirmed that three dimensions provided the most suitable organizational structure for the data. The determination of three factors was reached through a cumulative variance analysis, which indicated that the cumulative variance values continued to increase as an additional factor was introduced. However, it is worth noting that when considering the eigenvalues, the addition of a fourth factor resulted in a significant drop, falling below the threshold of 1, with a value of approximately 0.48.

Another valuable test for identifying the underlying factors or dimensions in our analysis is the examination of the scree plot of eigenvalues. A scree plot is a graphical representation used in factor analysis and principal component analysis to help determine the number of factors or components that should be retained from a dataset. It is a line plot that displays the eigenvalues (variance explained) for each factor or component in descending order. Researchers often use the scree plot to decide how many factors or components to retain. They look for the point on the plot where the eigenvalues start to level off, indicating that additional factors or components do not explain much more variance. This test also aligns with the conclusions drawn from Table 3 and Figure 2, providing additional support for our findings.

Subsequently, the examination of inter-variable correlations was employed to assess the relationships between variables and their underlying dimensions. The outcomes of this analysis are presented in Table 4, which provides factor coefficients and loadings for each indicator within each factor. As expected, the variables "proposal participation" and "voting participation" exhibited a notably high correlation with each other, aligning closely with the dimension labeled "political decentralization." The factor coefficient for "proposal participation" was calculated at 0.996, while that for "voting participation" mirrored this figure at 0.996.

Table 3. Eigenvalues and cumulative variance.

Factor	Initial Eigenvalue	Cumulative Variance
1	2.1155	0.3324
2	1.7773	0.5971
3	1.3679	0.7736
4	0.4809	0.7869
5	0.2576	0.7997
6	0.0008	1.0000

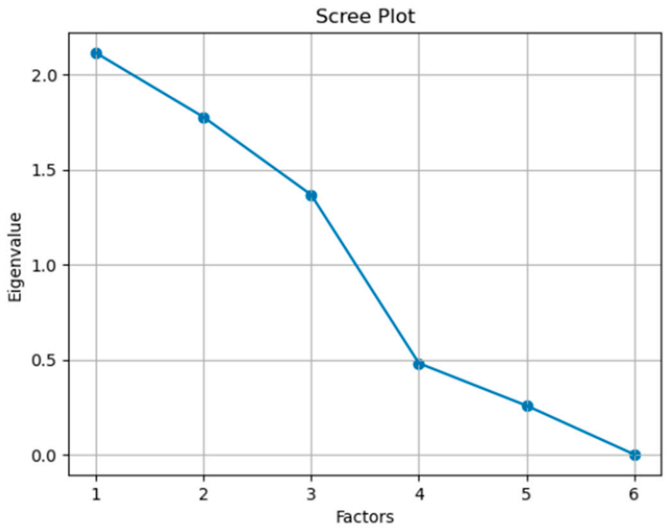

Figure 2. Scree plot.

Table 4. Factor coefficient results of decentralization dimensions and indicators.

	Political Decentralization	Economic Decentralization	Administrative Decentralization
Proposal Participation	**0.9965**	−0.0166	−0.0601
Voting Participation	**0.9969**	−0.0164	−0.0552
Token Distribution	−0.0217	**0.8636**	−0.0322
Voting Power Index	−0.0108	**0.8945**	0.1334
Percentage of Quorum Selections	−0.0245	−0.0704	**0.6986**
Quorum Proposal Pass Rate	−0.0794	0.1917	**0.7385**

Bold type indicates the factor on which the indicator loads most heavily.

Also, as anticipated, “token distribution” and the “voting power index” displayed the strongest correlation with each other, closely affiliated with the dimension denoted as “economic decentralization.” Specifically, the factor coefficient for “token distribution” registered at 0.863, while the “voting power index” yielded a coefficient of 0.894.

Lastly, the variables “percentage of quorum condition selections” and “pass rate of proposals with quorum conditions” demonstrated a notable association with each other, as well as an alignment with the third identified dimension, labeled “administrative decentralization.” The factor coefficient for “percentage of quorum condition selections” was determined to be 0.698, while the coefficient for “quorum proposal pass rate” stood at 0.738.

Factor analysis also facilitates an exploration of the inter-relationships among the identified dimensions. Given the inherent nature of decentralization, wherein one form of decentralization may exert an influence on others, it was anticipated that correlations among the dimensions would manifest. However, the results of the factor analysis revealed that the correlations between these dimensions were relatively modest and did not attain statistical significance.

To visually represent the nature and magnitude of these relationships between dimensions and variables, Figure 3 presents a graphical model. Here, the three latent dimensions are depicted as oval elements on the right, while the six observed variables are positioned on the left. The intensity of the relationship between each variable and dimension is denoted by the factor coefficient, denoted as “b.” The first subscript indicates the observed variable and the second subscript indicates the factor. For instance, “b11” signifies the relationship between the first variable (proposal participation) and the first dimension (political decentralization). In total, eighteen coefficients are utilized to quantify the strength of the relationship between each of the six observed variables and each of the three abstract dimensions. This diagram, thus, serves as a comprehensive measurement model of the decentralization concept, wherein three abstract dimensions are assessed employing six observable variables.

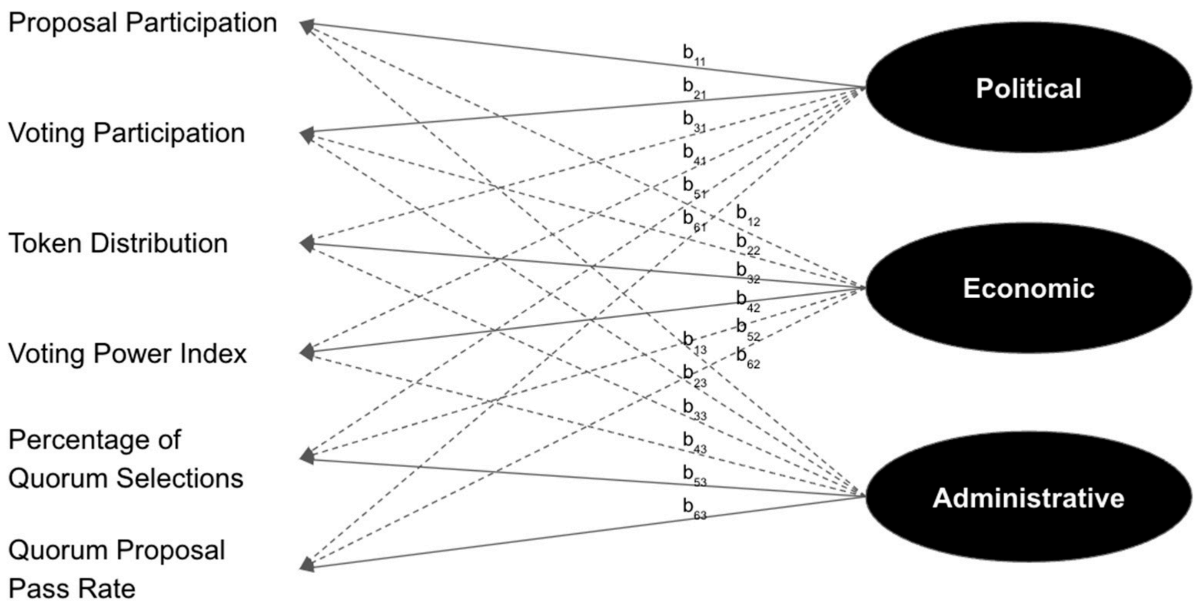

Figure 3. Diagram for measurement model of DAO's decentralization.

The final step in our methodological approach involves evaluating the quality of our model through confirmatory factor analysis. CFA models involve various theories and perspectives regarding the number and combination of reported indices and statistics. Some of these statistical measures may be influenced by factors such as sample size or the indicator-to-factor ratio, potentially limiting their ability to fully represent model fit (Koufteros 1999).

For instance, the Chi-Square statistic is theoretically expected to yield non-significant results ($p > 0.05$) for a well-fitting model. However, empirical studies have demonstrated that the Chi-Square statistic is highly sensitive to sample size. When dealing with the large sample sizes typically required for CFA and Structural Equation Models (SEM), the Chi-Square statistic and its associated p-value tend to be significant ($p < 0.05$). Consequently, researchers have recommended the use of the Chi-Square/df measure, which should fall within the range of 1 to 3 for an acceptable fit. Similarly, the Goodness-of-Fit Index (GFI), a measure of absolute fit, is significantly influenced by sample size.

Different fit indices may perform better in specific scenarios, necessitating the use of multiple fit indices to provide a comprehensive assessment of goodness of fit. This approach addresses concerns related to sample size and model complexity (Schermelleh-Engel et al. 2003; Vandenberg 2006; Gatignon 2003). Given the diversity of recommendations on the selection of appropriate indices, researchers have proposed a set of key indices that should be reported in research findings (Hu and Bentler 1999; Schreiber et al. 2006; Kline 2023). Table 5 outlines the essential set of fit indices for assessing model fit, along with their descriptions and cutoff criteria (Kline and Santor 1999; Sureshchandar 2023).

To assess the goodness of fit of the model developed in this study, we conducted an analysis using R. In this study, we scrutinized three prominent fit indices: CFI, which assesses model error with minimal susceptibility to the influence of x^2 and sample size; RMSEA, which takes into account both model parsimony and explanatory power; and SRMR (Hong 2000). The fit indices for the model are as follows: SRMR = 0.036, RMSEA = 0, and CFI = 1. These values indicate that the fit of the model in this study is excellent.

Table 5. Cutoff criteria for selecting indices to determine model fit in CFA.

Purpose	Measure	Description	Acceptable Values
Absolute fit	Chi-Square/df	The Chi-Square test examines whether the covariance matrix of the sample matches that of the population.	1 to 3
	Standardized root mean square residual (SRMR)	The standardized square root of the difference between the sample covariance matrix and the implied covariance matrix according to the proposed model.	<0.08: Excellent 0.08 to 0.10: Good
	Root means square error of approximation (RMSEA)	It quantifies the error associated with using the proposed model to predict the sample data. Additionally, it considers the impact of model complexity in relation to SRMR.	<0.06: Excellent 0.06 to 0.08: Good
Incremental fit	Comparative fit index (CFI)	It assesses the superiority of the proposed model (default model) compared to a baseline null model, determining whether the proposed model offers a better fit.	>0.95: Excellent 0.9 to 0.95: Good

5. Discussions

This study has yielded several noteworthy findings. Firstly, it has introduced a measurement model for assessing the decentralization of individual DAOs, drawing inspiration from previously established models used in the examination of decentralization within government organizations. This model was rigorously tested and validated through the analysis of data collected from 44 DAOs, thus providing a valuable tool for quantifying decentralization in the context of DAOs. Unlike prior studies such as those by Buterin (2014), which primarily theorized about the concept of decentralization, this research provides a structured approach for its empirical evaluation. The introduction of three distinct dimensions (political, economic, and administrative decentralization) and the set of six associated indicators significantly advances the field. These indicators bridge the gap between theoretical discussions and practical measurements, offering a systematic framework for quantitatively assessing DAO decentralization.

Despite the widespread adoption of decentralized autonomous organizations (DAOs) and extensive discourse surrounding their decentralization, the concept still grapples with conceptual ambiguities. As Wang et al. (2022) indicated, these theoretical ambiguities can significantly hinder the development of effective decentralization systems within organizations. Given the considerable academic and industry debates about DAO decentralization, this study is poised to serve as a foundational work in the realm of DAO measurement.

A pivotal contribution of this study lies in the delineation of three core factors for gauging DAO decentralization: political, economic, and administrative decentralization. Political decentralization, anchored in participation indicators, illuminates whether a DAO operates in a decentralized manner. Economic decentralization assesses the equitable distribution and utilization of resources, particularly tokens, essential for DAO participation. Administrative decentralization delves into the presence and effective utilization of mechanisms that enable a DAO to operate autonomously. This study aligns with previous research on government decentralization while introducing indicators tailored to the unique characteristics of DAOs. Notably, it underscores the autonomous operational mechanisms, named as administrative decentralization in this study, as an independent and vital measure of decentralization, alongside participation levels and token distribution. This revelation is expected to stimulate further research, especially concerning the role of devices like quorum in DAO decentralization, as evidenced in our primary data source, Snapshot.

Certain indicators were considered but excluded during the initial data collection phase. For instance, the delegation rate, which indicates the percentage of members actively delegating their voting power, was omitted due to its limited utilization in DAOs. As Santos and Kostakis (2018) mentioned, governance structures like multi-signature setups and council configurations were also excluded because they are more appropriately assessed through qualitative analyses or by examining DAO policies separately rather than via Snapshot data. In the case of the delegation rate, as the quorum system was found to have a significant effect on decentralization in the study, it would be meaningful to conduct a follow-up study to find the significance of the variable, by selecting DAOs that utilize this feature. Additionally, qualitative studies scrutinizing detailed policy documents of DAOs or quantitative analyses focusing solely on policy quantification offer promising avenues for further investigation.

6. Conclusions

6.1. Practical Implications

This study explored a measurement model for decentralization comprising three fundamental dimensions, subsequently assessing the model's compatibility with decentralization-related factors through the analysis of Snapshot data sourced from the top 44 Ethereum-based DAOs. A significant contribution of this study lies in its affirmation that the conventional dimensions of decentralization—namely, political, economic, and administrative, as employed in traditional decentralization research—remain pertinent in evaluating the decentralization of DAOs, emerging decentralized entities built upon blockchain technology.

In particular, beyond political and economic decentralization which facilitates participation and fosters widespread token ownership, the existence of mechanisms enabling 'autonomous' or 'automated' final decision making and execution, along with their degree of utilization, exerts a notable influence on decentralization. In the context of DAOs, the automatic and autonomous realization of outcomes stands as a fundamental attribute, albeit one still reliant on human intervention. Therefore, the quest for minimizing human involvement and maximizing the level of 'autonomy' assumes a pivotal role in enhancing the decentralization and operational efficiency of DAOs (Wright 2021).

Furthermore, this implies that decentralization does not hinge upon a solitary factor or even a duo of factors; rather, it can be assessed through a diverse array of variables. DAOs find applicability across an extensive spectrum, spanning political, social, economic, and other domains, and their degree of decentralization may fluctuate in accordance with the entity operating them and their intended purpose. Consequently, organizational decentralization can be adjusted by skillfully amalgamating and leveraging various variables. For instance, an entity necessitating limitations on participation can offset this constraint by instituting mechanisms that ensure autonomy or by fostering greater economic decentralization. Conversely, organizations requiring the allocation of resources to a select few can enhance decentralization by promoting 'participation' in decisions concerning the allocation of these resources.

From the innovative management perspective, the model represents an innovative step in the field of blockchain and decentralized technologies. It equips researchers and practitioners with a structured approach to evaluate and enhance decentralization. Also, insights from this study help drive innovation by guiding the development of new tools and methodologies to assess the evolving landscape of DAOs. Innovations may include AI-driven governance systems, enhanced tokenomics, and more secure smart contracts, all designed to maximize decentralization.

This research also provides a roadmap for informed decision making. Understanding the three main dimensions of decentralization—political, economic, and administrative—allows for strategic adjustments. For example, DAO leaders can tailor voting mechanisms to align with their specific goals, whether that is encouraging wider participation or fine-tuning the distribution of voting power. And, improved understanding of the administrative decentralization dimension can lead to more transparent and trustworthy DAO operations. This, in turn, enhances members' confidence in the organization and its decision-making processes. Managers can use this knowledge to design governance structures that minimize the need for manual intervention, fostering a higher level of trust among stakeholders.

Finally the practical implications of this research extend to various industries utilizing DAOs, including finance, supply-chain management, gaming, and more. Organizations in these sectors can leverage the research findings to customize their DAO structures for optimal outcomes. For instance, supply chain DAOs may focus on economic decentralization to ensure fair distribution of resources. Also, by understanding the indicators of decentralization, organizations can identify potential weaknesses or bottlenecks in their operations. This enables proactive risk mitigation and the design of resilient DAO systems that can withstand unexpected challenges. This research sparks philosophical discussions within the blockchain ecosystem. It prompts exploration of the core principles of decentralization and their practical manifestations. Such discussions can lead to paradigm shifts in how blockchain and decentralized technologies are conceptualized and implemented. The principles and dimensions of decentralization identified in this research can inspire cross-application learning. For instance, insights from DAOs can inform the design of decentralized finance (DeFi) protocols or decentralized identity systems, expanding the impact of blockchain technology into broader domains.

6.2. Research Limitations and Future Studies

Acknowledging the study's limitations is crucial. Primarily, due to Snapshot's off-chain data nature, the analysis focuses on data occurring off-chain rather than on-chain at the smart contract level. While Snapshot was selected for research design due to its widespread adoption among DAOs, this limits the use of metrics that can be autonomously and automatically assessed at the smart contract level. Therefore, future research should explore DAO decentralization based on on-chain transactions.

Furthermore, the DAOs examined in this research share a commonality in their utilization of the Ethereum chain. Different mainnets exhibit varying degrees of decentralization, stemming from their distinct consensus algorithms and policies. Consequently, different dimensions or indicators may emerge when assessing DAOs operating on mainnets with different characteristics like Solana, Polygon, and BNB. A comparative study across mainnets would be instrumental in elucidating the varying degrees of decentralization across different DAO ecosystems.

Also, it is important to note that the voting system was not a central variable under examination in this study. The reason being that DAOs employ a diverse array of voting systems, and the choice of voting system significantly impacts the outcomes of votes. Moreover, platforms like Snapshot offer a selection of six distinct voting types and, when combined with variations in voting power, this results in over 350 potential voting strategies for users. While we attempted to incorporate voting type as a primary variable in this study, it is worth highlighting that the majority of the proposals scrutinized (86%) favored the simplest single-choice voting method. Consequently, it did not emerge as a statistically significant variable in our analysis. Future research endeavors exploring the influence of voting type on decentralization may benefit from qualitative analyses of individual DAOs or specialized studies that focus on specific voting types.

Lastly, this study did not delve into the architectural and technological aspects of the decentralization areas highlighted. Future research endeavors should take up the mantle of exploring these crucial dimensions, including architectural and technological aspects, to provide a holistic perspective on decentralization within DAOs. This will allow for a more complete understanding of how the architectural design and underlying technology of DAOs influence their decentralization levels.

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