2022 IEEE International Performance, Computing, and Communications Conference (IPCCC) | 978-1-6654-8018-5/22/$31.00 ©2022 IEEE | DOI: 10.1109/IPCCC55026.2022.9894306

Optimal Incentive Mechanisms for Fair and Equitable Rewards in PoS Blockchains

Hadi Sahin[1], Kemal Akkaya[1], and Sukumar Ganapati[2]
[1]Advanced Wireless and Security Lab, [2]Dept. of Public Policy and Administration
Florida International University, Miami, Florida 33199, USA
Emails: {asahi004, kakkaya, ganapati}@fiu.edu

***Abstract*—Blockchain technology that came with the introduction of Bitcoin offers many powerful use-cases while promising the establishment of distributed autonomous organizations (DAOs) that may transform our current understanding of client-server interactions on the cyberspace. They employ distributed consensus mechanisms that were subject to a lot of research in recent years. While most of such research focused on security and performance of consensus protocols, less attention was given to their incentive mechanisms which relate to a critical feature of blockchains. Unfortunately, while blockchains are advocating decentralized operations, they are not egalitarian due to existing incentive mechanisms. Many current consensus protocols inadvertently incentivize centralization of mining power and inequitable participation. This paper explores and evaluates alternative incentive mechanisms for a more decentralized and equitable participation. We first evaluate inequality in existing Proof of Stake (PoS) based incentive mechanisms, then we examine three alternatives in which rewards scheme is more partial to low-stakeholders. Through simulation, we show that two of our alternative mechanisms can reduce inequality and offer an attractive solution for sustainability of blockchain-based applications and DAOs.**

***Index Terms*—Blockchain, Proof of Stake, consensus, incentives, inequality, reward distribution**

I. Introduction

With the emergence of Bitcoin, blockchain has emerged as a powerful tool that can offer distributed trust through its immutability, transparency and underlying security. It not only transformed the way cryptocurrencies are utilized, but also enabled many new applications that depend on its distributed ledger for data storage and transactions. While there has been many variants of blockchains, the idea is mainly based on the approval of transactions through consensus mechanisms which can be done collaboratively by the stakeholders. The rules of consensus defines how decentralized nodes could achieve agreement on a transaction or on a given state of the blockchain network, including who verify transactions, who arrange them in a new block and append it into a chain of blocks. Today, there are many domains such as finance, health, supply chain, automotive and forensics that heavily depend on the capabilities of blockchains [1].

While blockchain technology has allowed us to create secure and stable applications in various domains without trusted third parties, the aspiration to run blockchain-network and blockchain-based platforms, such as DAOs, through a distributed consensus mechanism without the need of a central authority and hierarchical structure has not been fully achieved [2]. For instance, at the governance level, several blockchain platforms are still backed by strong centralized foundations that have ultimate power over major decisions. In less centralized ones such as Ethereum, core developers and early backers have unparalleled influence over the blockchain networks [3], [4].

The problem is more acute at the consensus level, where we still observe centralization tendencies on the two widely used consensus mechanisms: (i) Proof of Work (PoW); and (ii) Proof of Stake (PoS). Recall that PoW, which is well-known due to its employment on Bitcoin, relies on computation of a hash puzzle (i.e., proof of work) to decide who creates the next block. In theory, this provides equal opportunity to all users to enter into competition; namely to mine and receive block rewards. However, in practice due to reliance on high computational power, an individual alone can rarely achieve that. Therefore, a dozen of mining pools dominate the mining activities [5]. As an example, currently, a single pool could control up to 23% of hashrate share[1].

In PoS, the probability of a node to validate a block is proportional to her stakes [6]. Once a new block is created, the validator receives block reward and associated transaction fees. Such consensus protocols of selection and rewards set up an incentive structure where there is potential for (i) centralization by creating power disparities among users/miners and (ii) inequitable outcomes where the rich (e.g., high-stakeholders) get richer and low-stakeholders are unable to participate. This incentive structure has the danger of running contrary to blockchain's very core philosophy of enabling decentralized autonomous organizations and disenfranchising low-stakeholders who would be eventually edged out [7]. Studying the fairness and equity of the incentive structure of the consensus protocols is thus fundamental to the preservation of the cardinal principles of blockchains.

Consequently, in our paper, we examine incentive structures of blockchain consensus protocols that would provide fairness and equity in rewards across all stakeholders. Some earlier works as well as current applications tried to tackle this problem by focusing on distributing the reward money to larger group of people, either by allowing for stake pools or by giving benefits to committee members that are involved in

[1]https://btc.com/stats/pool, accessed on June 25, 2022

the consensus process [7], [8]. Others focused on the nature of the reward mechanism. For instance, [9] proposed a geometric reward schedule instead of a constant one practiced by Bitcoin. Nevertheless, none of these studies/solution offer an ideal solution to achieve optimal fairness and equity. Therefore, in this paper, by focusing on the reward function of PoS blockchains, we propose an optimal solution that provide preferential treatment to low-stakeholders to compensate their disadvantage at the selection process.

The studies on optimal taxation examine efficiency and redistribution issues, and thus provide us with insights on alternative incentive mechanisms (See [10]–[12]). Borrowing from these theories, we propose new PoS incentive mechanisms including (i) a marginal reward rate which decreases with participant's owned stakes; (ii) a flat rate reward mechanism with lump-sum transfers to nodes whose stakes are lower than certain threshold; and (iii) a flat rate reward mechanism with uniform lump-sum transfers to all participants or all online nodes.

We implemented the proposed incentive structures in PoS consensus protocols within a PoS simulator in Python [13], [14] that replicates consensus behavior and allows us to manipulate and trace users' stakes. The existing incentives of PoS protocols are also examined as a baseline to determine the extent of centralization under current PoS protocols. The simulation results show that our proposed incentives which offer uniform transfers to all or low-stakeholders reduce inequality irrespective of initial distribution. On the other hand, uniform transfers can incentivize users to create multiple nodes to receive more benefits. Therefore, we also propose adding a reputation mechanism that records one's honest and continued interaction in the network.

This paper is organized as follows: The next section provides background information on consensus protocols and taxation. Section III discusses earlier studies on fairness and equality. Section IV presents our proposed incentive mechanisms. Section V includes experimental setup and results. Section VI concludes the paper.

II. Related Work

Centralization in blockchains at the governance level has been discussed extensively in non-technical papers (See [15], [16]). There are a relatively fewer works that examine equality and centralization at the consensus level. We can categorize these papers into three groups: 1) Fairness; 2) Distribution of Rewards; and 3) Equality in Pooled PoS:

A. Fairness

The first group examine fairness by looking at the relationship between one's initial investment and expected earnings. As long as they are proportional, the incentive mechanisms are considered as fair.

As an example, [17] examine fairness in various PoS-based blockchains. In particular, the authors study multi-lottery PoS (ML-PoS) for Qtum and Blackcoin, single-lottery PoS (SL-PoS) for NXT and compound PoS for Ethereum (C-PoS). They define two kinds of fairness; expectational and robust fairness. Expectational fairness means that a miner will get rewarded proportional to her investment level. Robust fairness measures whether expected rewards for investment concentrate around a constant number with high probability. They found that except SL-PoS, all consensus protocols satisfy expectational fairness. PoW always provide robust fairness; also it is relatively easier to achieve robust fairness in C-PoS. However, SL-PoS and ML-PoS protocols do not comply with robust fairness.

Similarly, [18] argue that an investors' share in PoS protocol shows martingale condition which means that an investor's expected earnings in the future will be the same as the current earnings. The "rich" are more likely to gain from consensus, but comparatively they lose more as their investment is diluted when someone else wins. Thus, overall in the long-run the expectational gain for "rich" and "poor" investors stay relatively stable. They also examine whether investors have incentive to buy more shares to increase their gains. They found that the gain from new investment will dilute the rewards an investor can earn, therefore at some point the investors become indifferent in making further investment.

These studies implicitly state that initial inequalities in stake distribution will propagate through time. Instead, we try to examine how given inequalities can be reduced by manipulating incentive mechanisms.

B. Distribution of Rewards

The second group of papers focus on the distribution of reward earnings among consensus participants. For instance, [9] note that the "rich" are more likely to get selected for block creation and therefore they are more likely to receive block rewards. In return, the newly earned rewards will increase their weight in the network and their chances for re-selection. This effect compounds each time they are selected. Rather then changing the reward mechanism, the authors focus on reward schedule. They propose a geometric reward function where at initial rounds of a period the reward money is close to zero and increases geometrically with each block creation. This reward mechanism does not offer a solution to inequality, but it postpones the inequality to the end of the reward schedule [19].

C. Equality in Pooled PoS

The last group of studies focus on equality in pooled PoS. Stake pools significantly reduces inequality as low-stakeholders can increase their chances to participate in the consensus process [9]. On the other hand, these cartel-like structures can lead to low degree of decentralization which is not desirable for blockchain networks. [20] study centralization tendencies in PoS due to staking pools. They suggest a mechanism where each round a stake pool is randomly dissolved and the members are invited to either re-form the pool or join another pool. Using game theoretic tools, they showed that there is an equilibrium where dissolving of a pool may lead to creation of new pools. This reduces long-term oligopolistic formations.

Sincere rewards are distributed to the pool members based on their stakes, this reward mechanism will, expectationally, continue to keep initial distribution levels. It could provide equality if only the initial distribution is and stake pools are relatively balanced.

III. Background

A. Consensus in Blockchain

Consensus process is the backbone of the blockchain. This is where transactions are broadcast, verified, included in a block and appended to a blockchain. Consensus protocols define who could propose a new block, who could verify and vote on the validity of transactions, how conflicts are solved, and how nodes are incentivized to stay online and contribute to the consensus process. There are many types of consensus mechanisms. Here, we provide background on the three widely deployed ones and how they address centralization issues:

a) Proof of Work (PoS): PoW is the first consensus mechanism in blockchain, developed by the first blockchain network, Bitcoin. In this protocol, nodes which want to participate in the block creation process, called *miners*, compete to solve a mathematical puzzle using brute-force. The first miner solving the puzzle gains the right to create a new block from verified transactions. She then receives block reward and associated transaction fees. This process is computationally prohibitive, thus, it dissuades miners from engaging dishonest behavior such as running parallel chains on the side. On the other hand, computational requirements make it difficult for solo miners to compute for block reward. Instead, we see mining pools dominating the consensus process.

b) Proof of Stake (PoS): Unlike PoW, PoS does not rely on computation to select block proposers; they are selected randomly from all nodes with weights proportional to the fraction of stakes. This selection mechanism can lead to unequal distribution of stakes. It could allow the richer to get richer as they are more likely to be selected for block creation and receive block rewards [9]. Solana and Ouroboros are some example blockchains that employ a PoS protocol [8], [21]. Ethereum is also transitioning to PoS from PoW [22].

There are many variants of PoS. Some of them allow users to delegate their stakes to a pool. If a staking pool is selected to create a block, the reward is distributed to all members of the pool based on their stakes. This approach is called *pooled PoS* and provides a more egalitarian reward distribution as low-stakeholders could increase their likelihood of receiving rewards by joining to a pool. However, this also leads to concentration of power as stake pools could behave cartel-like structures. Some blockchains addresses this issue by introducing saturation parameters to increase the number of pools and limit their sizes.[2]

c) Practical Byzantine Fault Tolerance (PBFT): This protocol aims to solve the Byzantine Fault Tolerance (BFT) problem which considers situations where decisions should be made given some of the actors are malicious. In its blockchain applications, nodes have to communicate with each other and come up with the right decision even when some of the nodes are dishonest. In this scheme, a leader is selected to order transactions and propose them in a new block. The rest of the nodes are called back-ups and they vote on the proposed block, the decisions are made by majority [1]. We analyze Algorand incentives as an example for PBFT consensus protocols.

B. Taxation and Equity in Economics Literature

Collecting tax revenues while maintaining a balance between efficiency and inequality is an important topic in public economics literature. On one hand, for general welfare we want a society as equitable as possible, therefore we redistribute some of the government revenues back to low-income people to reduce inequality in opportunities. On the other hand, we seek efficiency and encourage productivity, thus we do not want redistributive policies to discourage high-earners from pursuing productive activities.

In his seminal work, Mirrlees [11] explores the trade-off between efficiency and income distribution and creates a framework for future studies. His work does not provide a definitive direction for an optimum taxation schedule, but given some conditions it comes close to a scenario where marginal tax rates are low for the bottom and top income levels. The average tax rate, however, increases with income, thus optimum tax schedule resembles closely to a linear tax rate. [10] visited the same topic and found that marginal tax rate shows a U-shaped pattern. It decreases below the modal skill level and increases for the above. The author argues that marginal tax rates continue to rise for the high-earners as long as we assume bounded distribution of skill levels.

The shape of any taxation schedule for the top earners depend on our assumptions about utility of assumption and distribution of skill levels [23]. But overall the research supports relatively redistributive tax schedule for optimum efficiency and equality, and the practice in the developed world is more or less inline with the theory. Evaluating the lessons from taxation theory, [12] note that a flat tax with a universal lump-sum transfer is the closest to optimum levels. They also state that the trend in OECD countries is towards flatter tax rates.

Determining optimum taxation is a complex issue as it requires information about distribution of skills and consumption. However, the trade-off between efficiency and equality have some resemblance in economics of consensus in blockchains. Especially in PoS blockchains, the participation of high-stakeholders in the consensus process is desirable. PoS assumes that high-stakeholders behave more responsibly and honestly as their utility is highly correlated with the success of the network. On the other hand, blockchains overall benefit from higher number of participants. Higher number of participants decreases the likelihood of dishonest nodes from overpowering the honest ones. Thus, a good incentive mechanism, similar to taxation, should strike a balance between incentivizing low-stake holders and encouraging new users while also continuing to motivate high-stake holders.

[2]https://cardano.org/stake-pool-operation/

IV. Proposed Incentive Mechanisms

The main goals of our proposed incentive mechanism are: (i) to compensate any benefit loses for the low-stakeholders from random but weighted selection process; (ii) to alleviate any inequalities in the initial distribution of stakes. In blockchain networks, the initial distribution can be close to Pareto Distribution where 80% of wealth is controlled by 20% [24]; and (iii) to prevent any wealth compounding effect. The end goal is to strengthen blockchain networks with larger number of users whose stakes are attached to the success of the network.

The overarching rationale for our proposed models is that any incentive mechanism that rewards consensus participants based on their stakes will perpetuate existing distribution, which is more likely to be unequal than equal. In order to have incentives that correct the existing inequalities, the reward mechanism must be preferential to low-stakeholders. Below, we present the proposed incentive mechanisms:

A. Flat Reward Rate with Uniform Universal Transfers

In this scheme, a block proposer is awarded with a portion of block reward, the rest is distributed to all nodes uniformly. The effect of the transfers on high-stakeholders' shares is negligible as the transfer amount could be quite low in proportion to the owned stakes. For median income nodes, the transfers can compensate possible losses from dilution of shares due to addition of the reward money to the money supply. For low-stakeholders the transfers increase their relative shares. Therefore, this incentive mechanism acts as a corrective tax and decreases inequality.

B. Flat Reward Rate with Transfers to Low-stakeholders

This incentive mechanism grants a portion of the participation reward to the block proposer. The rest is distributed to nodes whose share is below certain threshold. As transfers are distributed only to the population with the lowest shares, the transfer per node will be higher in this scheme compared to the previous one. Thus, Low-stakeholders will experience faster increase in their relative stakes. Moreover, for nodes whose shares are above the threshold, increased money supply will dilute their shares if they are not selected as a block proposer. Although incremental, their stakes will decrease relative to the low-stakeholders. Therefore this scheme will progressively increase equality.

C. Decreasing Rewards

In this incentive mechanism, participation rewards decrease with share of stakes. The reward is distributed based on the following function where r is total reward that could be distributed in that round, c is a constant and α is the fraction of stakes a block proposer owns.

$$re^{-c\alpha} \tag{1}$$

This scheme also follows the logic that achieving equality requires some transfers to the low-stakeholders. It provides this by rewarding low-stakeholder block-proposers favorably. On the other hand, rewards are conditioned on being selected as a block proposer. Thus, although this incentive mechanism will reduce inequality, it can do it relatively slower than the previous two mechanisms.

V. Evaluation

This section includes our experimental setup, metrics, benchmarks and discussion of results.

A. Experiment Setup

We run simulations to test how different incentive mechanisms affect distribution of wealth in a PoS based blockchain networks. We developed our Python-based simulation based on [13], [14].[3] In its original form the simulation replicates all Algorand phases and steps: information on cryptographic sortition, gossip events, the two phases of committee voting and their steps can be retrieved from the simulation. However, the authors did not include reward mechanism and stake wallets into the simulator. We extended their implementation to tailor the simulator for our research needs.

We run the simulator with 1000 nodes for 1000 rounds. We tested the incentive mechanisms with initial stakes of normal distribution. The distribution has mean of 25 and standard deviation of 20. Values below 0 are replaced with 1.0. Figure 1 shows the histogram of stake distribution at round one for pure PoS. Although initial stakes for each incentive mechanism is normally distributed, each a have different distribution.

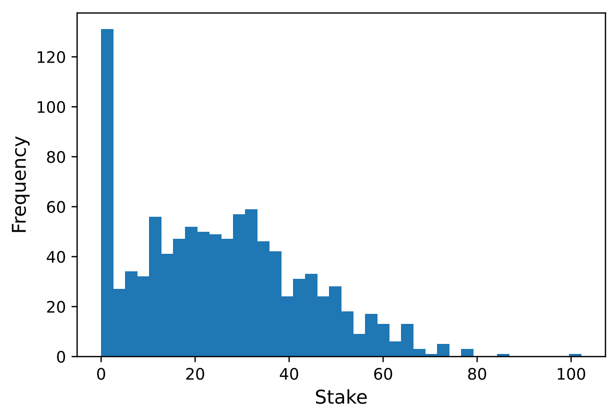

Figure 1. Distribution of stakes in round 1 for Pure PoS

In [14], the authors proposed an incentive mechanism for Algorand which rewards block proposers and committee members only. They calculated the minimum reward for each round as 5.2 *Algos*. We followed their practice and kept the reward at 5.2 *Algos* for all incentive mechanisms. We also do not allow financial transactions among nodes in order to observe the effect of incentives on stake distribution.

B. Benchmarking Mechanisms

We considered and implemented the following consensus mechanisms to compare with our approaches:

[3]https://github.com/ddeka0/Algorand-DES

a) Algorand incentives: We tested Algorand's incentive reward scheme before May 14^{th}. Algorand rewards all users based on their stakes, whether the network agreed on a final or tentative consensus [25].

b) Pure PoS: The block proposer receives the reward after successful creation of a block.

c) Pooled PoS: We assigned nodes randomly to 10 pools. Each pool has equal number of nodes. The winning pool distributes the reward to all members based on their stakes.

d) Geometric Rewards: We implemented incentive mechanism proposed by [9] as described in Equation 2.

$$r(n) := (1+R)^{\frac{n}{T}} - (1+R)^{\frac{n-1}{T}} \tag{2}$$

Where n is the total number of the blocks created including period T_i. [9] assume that in each period 210,000 blocks are created where a certain reward, R, is distributed. This number is halved every 210,000 block creation period. We assume that in each reward period T, 1000 blocks are created.

For our proposed incentives we use the following parameters: for *Flat Reward Rate with Uniform Universal Transfers*, in each round, 20% of the participation money is distributed to all nodes, 80% is awarded to block proposer; for *Flat Reward Rate with Transfers to Low-stakeholders* 10% percent of the reward is distributed to nodes with stakes below 10% threshold while block proposer receives 90% of the block reward; lastly for *Decreasing Rate* we assume the constant c is 20. Our approaches are represented in the Figures as Flat Rate, Transfer to $< 10\%$ and Decreasing Rate.

C. Performance Metrics

We used two metrics to assess the success of our approaches:

- The evolution of the stake distribution is measured by *Gini coefficient* which is frequently used in Economics and Political Economy to analyze inequality in wealth distribution [26], [27]. We applied the following formula to calculate the Gini coefficient. n, s_i, and $\overline{x}$ denote number of nodes, stake owned by node *i*, and average stake.

$$\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}|s_i - s_j|}{2n^2\overline{s}} \tag{3}$$

- Following [9] we also measured inequality with *variance*. The formula is:

$$\frac{\sum_{i=1}^{n}(s_i - s_j)^2}{n-1} \tag{4}$$

We normalized s_i, to be able to compare variance across rounds. Thus, $\sum s_i = 1$.

D. Performance Results

The simulation results are presented in Figure 2 and 3. Figure 2 displays evolution of Gini coefficient for each incentive mechanism across all rounds. Gini coefficient ranges from 0 to 1, 0 expressing perfect equality. As discussed we use normal distribution for initial allocation of stakes, therefore, the starting inequality scores for our models are around 0.4.

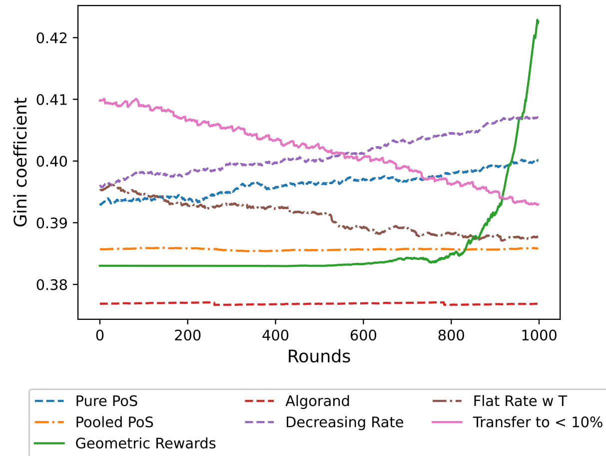

Figure 2. Evolution of inequality, measured by Gini coefficient, under different incentive mechanisms

Figure 2 shows that inequality increases with time in *Pure PoS* protocol. By earning rewards, the "rich" increases their weight and chances for re-election and this effect compounds as time passes. In Figure 5 we graph the change of wealth for top and bottom 10% nodes.[4] At the end of the rounds, the top 10% increases their total wealth from around 6000 by approximately 19%, while total stakes for the bottom 10% stays relatively constant around 103.

The level of inequality for *pooled PoS* remain relatively stable according to Figure 2, indicating that one can earn rewards proportional to her initial investment level. This is a fair outcome as discussed by some literature [17], however it may not be necessarily egalitarian. We can observe an equal outcome only if the initial distribution is relatively equal. If the initial distribution is skewed, this incentive mechanism continues to propagate the initial inequality. Moreover, we assume balanced stake pools; in our simulation nodes are randomly selected to equally sized pools. However, imbalances between stake pools in terms of size and wealth may lead to unfair reward distribution.

Algorand incentives show similar pattern with *pooled PoS*; inequality remains stable throughout the rounds. This is expected as Algorand incentives reward all nodes based on their fraction of stakes. In a way, the whole node population is assumed as one single pool.

Fanti et al's [9] research is the closest to our paper in terms of its focus on distribution of stakes among nodes. However, our simulation results do not show support for their argument that geometric incentives decreases inequality. Figure 2 shows that geometric rewards keep inequality steady for most of the reward period. However, inequality increases substantially when we near to end of the period. This is expected, as geometric reward scheme does not offer preferential treatment towards low-stakeholders neither in terms of rewards nor the selection method. It postpones the reward to the end of the period, but nevertheless it is distributed similar to *pure PoS*. On the other hand, this reward mechanism can provide

[4]There are 101 and 111 nodes, respectively in top and bottom 10%

more egalitarian distribution if applied to initial stages of a blockchain. In their formation years, the pool of participants in blockchains is rather small, thus early participants could gain a disproportional stake in the network. As confirmed by our results the current incentive schemes, at best, perpetuate the initial distribution. Geometric rewards can prevent this to some extent by offering lower rewards in the initial rounds. Then, the magnitude of the reward increase as the blockchain network matures.

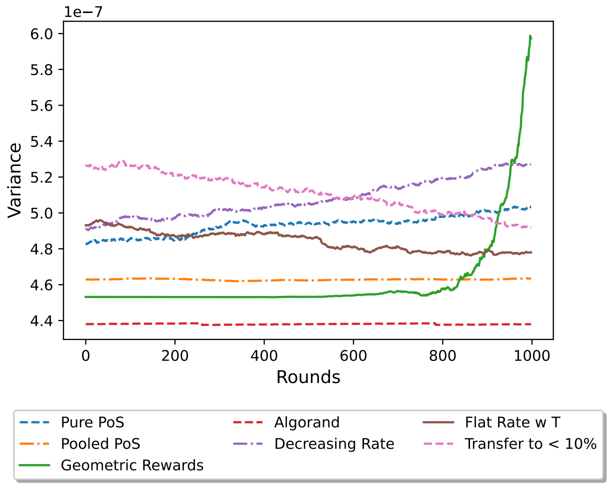

Figure 3. Evolution of inequality, measured by variance, under different incentive mechanism

We also examined how inequality evolves under multi-period *Geometric Reward* mechanism. We assumed 100-round reward schedules, rather than 1000, where participation reward is halved each round. Figure 4 displays the Gini coefficient results. The change in rewards is not as dramatic as that in Figure 2. This is expected, since shorter time period means smaller quantities of rewards for each reward period. The line flattens around 400 rounds and remains relatively stable afterwards. However at this point the reward is one sixteenth of its initial value. Overall, the results for multi period *Geometric Reward* does not support the claim that it reduces inequality.

The *decreasing rate* incentive mechanism imitates Pure PoS in terms of selection of block proposer, but decreases marginal rate of reward by stakes. Thus, "rich" nodes are rewarded less compared to the "poor". Our results show that this does not solve inequality problem. Preferential rewards towards the low-stakeholders does not compensate for the inequality that originates from the selection mechanism.

Flat rate with with universal transfers decreases inequality as shown in Figure 2. Gini coefficient steadily decreases throughout the rounds as expected. Transfers are equally distributed to the 'poor' and the 'rich' while still preventing the erosion of wealth for low-stakeholders against high-stakeholders. Similarly, *Transfer to* $< 10\%$ incentive mechanism decreases inequality as seen in 2 and 3. The slope of the decrease is steeper than *Flat rate* suggesting that transferring rewards to the low-stakeholders solves inequality more quickly than universal transfers. Figure 5 graphs the change of total

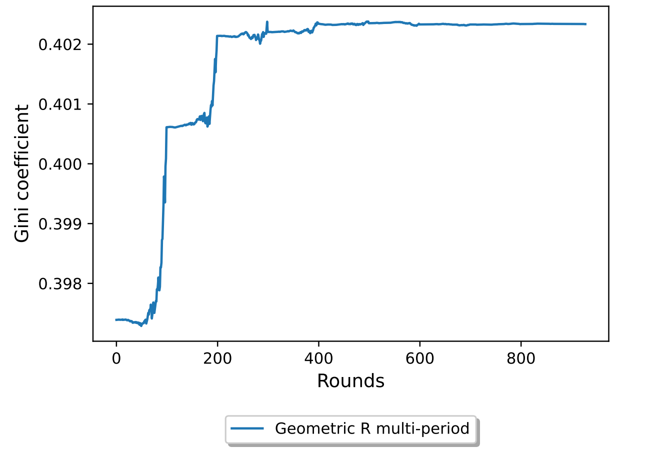

Figure 4. Evolution of inequality, measured by Gini coefficient, under multi-period Geometric Rewards mechanism

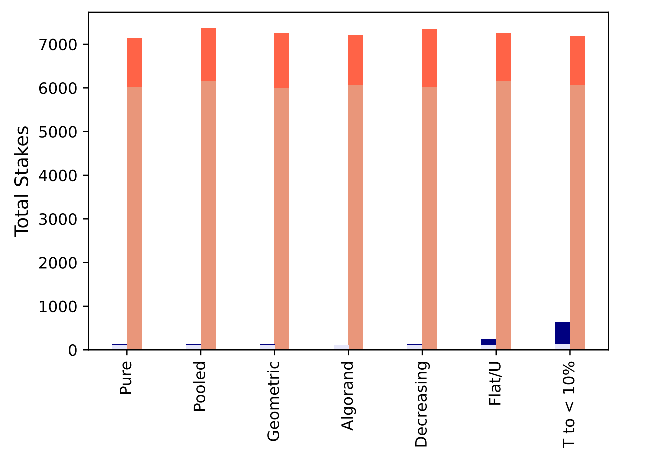

Figure 5. Evolution of inequality under multi-period Geometric Function

stakes for top and bottom 10% of the population. It shows that both flat rate with transfer approaches significantly increase wealth of the nodes at the bottom. Furthermore, Table I displays the share of the stakes for the bottom. Again, both approaches significantly increases total stake shares among low-stake holders.

Finally, [9] use variance to measure inequality. Therefore, we also graph evolution of variance for each incentive mechanism in Figure 3. The results replicate our findings for Gini coefficient in Figure 2.

Table I
CHANGE IN THE FRACTION OF STAKES FOR BOTTOM AND TOP 10 PERCENT

Incentive Mechanisms	$\leq 10\%$		$\geq 90\%$	
Round	1	1000	1	1000
Pure PoS	0.004031	0.004027	0.23400	0.231346
Pooled PoS	0.004139	0.004158	0.23213	0.232358
Geometric	0.004144	0.003882	0.224672	0.227467
Algorand	0.003628	0.003652	0.222544	0.222533
Decreasing Rate	0.004452	0.00423	0.233987	0.238177
Universal Transfers	0.004434	0.008212	0.238374	0.234187
Transfers to $\leq 10\%$	0.005000	0.020804	0.240838	0.236545

These results are promising for equal and fair distribution of rewards, however the implementation could be challenging. The incentive mechanisms that transfers money in some uniform nature could create adverse incentives; individuals can create multiple identities/nodes in order to reap more benefits. Therefore, these reward mechanisms could work best if they are coupled with reputation-like scores to prevent these incentives. The reputation score could be marginally related to stakes, but should rely more on one's interactions and history in the blockchain network.[5]

VI. Conclusion

In this paper, we focused on one of the aspects of centralization and examine fairness and equality in PoS based incentive mechanisms. We find that *pure PoS* and *geometric rewards* increase inequality irrespective of initial distribution of stakes. In *Pooled PoS* the level of inequality remain stable. Thus, it can provide equality if the initial distribution is egalitarian and the stake pools are balanced. However, stake pools themselves could also prevent decentralization if they are allowed to function as cartel-like structures. Our results show that Algorand's incentive mechanism treats all nodes as a single stake pool, therefore similar to the *pooled PoS* keeps inequality levels stable. But Algorand incentives are better than *pooled PoS* in the sense that there is no concern about balancing the stake pools.

We provide three alternative incentive mechanisms that could provide fair and equal distribution of rewards. Decreasing rate mechanism suggest rewarding the "poor" more generously than the "rich", however our results show that this increases inequality and cannot correct the inequality of the selection process. Our simulations provided promising results for the two incentive models; that propose transfers to users, one suggesting a universal transfer, the other transfers to bottom 10%. We find that both significantly can provide a more equal distribution of rewards.

References

[1] A. A. Monrat, O. Schelén, and K. Andersson, "A survey of blockchain from the perspectives of applications, challenges, and opportunities," *IEEE Access*, vol. 7, pp. 117 134–117 151, 2019.

[2] V. Buterin, "Moving beyond coin voting governance," Aug. 16, 2021 [Online]. [Online]. Available: https://vitalik.ca/general/2021/08/16/voting3.html

[3] A. Carvalho, J. W. Merhout, Y. Kadiyala, and J. Bentley II, "When good blocks go bad: Managing unwanted blockchain data," *International Journal of Information Management*, vol. 57, p. 102263, 2021.

[4] M. Zachariadis, G. Hileman, and S. V. Scott, "Governance and control in distributed ledgers: Understanding the challenges facing blockchain technology in financial services," *Information and Organization*, vol. 29, no. 2, pp. 105–117, 2019.

[5] N. Leonardos, S. Leonardos, and G. Piliouras, "Oceanic games: Centralization risks and incentives in blockchain mining," in *Mathematical research for blockchain economy*. Springer, 2020, pp. 183–199.

[6] H. Huang, W. Kong, S. Zhou, Z. Zheng, and S. Guo, "A survey of state-of-the-art on blockchains: Theories, modelings, and tools," *ACM Computing Surveys (CSUR)*, vol. 54, no. 2, pp. 1–42, 2021.

[7] L. Brünjes, A. Kiayias, E. Koutsoupias, and A.-P. Stouka, "Reward sharing schemes for stake pools," in *2020 IEEE European Symposium on Security and Privacy (EuroS&P)*. IEEE, 2020, pp. 256–275.

[5]See [28], [29] for successful implementation of reputation/trust scores.

[8] A. Kiayias, A. Russell, B. David, and R. Oliynykov, "Ouroboros: A provably secure proof-of-stake blockchain protocol," in *Annual international cryptology conference*. Springer, 2017, pp. 357–388.

[9] G. Fanti, L. Kogan, S. Oh, K. Ruan, P. Viswanath, and G. Wang, "Compounding of wealth in proof-of-stake cryptocurrencies," in *International conference on financial cryptography and data security*. Springer, 2019, pp. 42–61.

[10] P. A. Diamond, "Optimal income taxation: an example with a u-shaped pattern of optimal marginal tax rates," *American Economic Review*, pp. 83–95, 1998.

[11] J. A. Mirrlees, "An exploration in the theory of optimum income taxation," *The review of economic studies*, vol. 38, no. 2, pp. 175–208, 1971.

[12] N. G. Mankiw, M. Weinzierl, and D. Yagan, "Optimal taxation in theory and practice," *Journal of Economic Perspectives*, vol. 23, no. 4, pp. 147–74, 2009.

[13] P. J. Debashish Deka, Abhisekh Singh, "Algorand discrete event simulator," https://github.com/ddeka0/Algorand-DES/tree/master/\protect\protect\unhbox\voidb@x\hbox{Algorand$_$python}, 2019.

[14] M. Fooladgar, M. H. Manshaei, M. Jadliwala, and M. A. Rahman, "On incentive compatible role-based reward distribution in algorand," in *2020 50th Annual IEEE/IFIP International Conference on Dependable Systems and Networks (DSN)*. IEEE, 2020, pp. 452–463.

[15] A. Walch, *In code (rs) we trust: Software developers as fiduciaries in public blockchains*. Oxford University Press, 2019, ch. Regulating Blockchain. Techno-Social and Legal Challenges.

[16] A. Ekblaw, C. Barabas, J. Harvey-Buschel, and A. Lippman, "Bitcoin and the myth of decentralization: Socio-technical proposals for restoring network integrity," in *2016 IEEE 1st international workshops on foundations and applications of self* systems (FAS* W)*. IEEE, 2016, pp. 18–23.

[17] Y. Huang, J. Tang, Q. Cong, A. Lim, and J. Xu, "Do the rich get richer? fairness analysis for blockchain incentives," in *Proceedings of the 2021 International Conference on Management of Data*, 2021, pp. 790–803.

[18] I. Roşu and F. Saleh, "Evolution of shares in a proof-of-stake cryptocurrency," *Management Science*, vol. 67, no. 2, pp. 661–672, 2021.

[19] W. Tang, "Stability of shares in the proof of stake protocol–concentration and phase transitions," *arXiv preprint arXiv:2206.02227*, 2022.

[20] A. Kiayias, E. Koutsoupias, and A.-P. Stouka, "Incentives against power grabs or how to engineer the revolution in a pooled proof of stake system," in *2021 IEEE International Conference on Decentralized Applications and Infrastructures (DAPPS)*. IEEE, 2021, pp. 1–10.

[21] A. Yakovenko, "Solana: A new architecture for a high performance blockchain v0. 8.13," *Whitepaper*, 2018.

[22] W. Duggan and F. Powell, "What is ethereum 2.0? understanding the merge," Forbes, Jun. 9, 2022 [Online]. [Online]. Available: https://www.forbes.com/uk/advisor/investing/cryptocurrency/what-is-ethereum-2/

[23] M. Dahan and M. Strawczynski, "Optimal income taxation: An example with a u-shaped pattern of optimal marginal tax rates: Comment," *American Economic Review*, vol. 90, no. 3, pp. 681–686, 2000.

[24] Y. Wang, G. Yang, A. Bracciali, H.-f. Leung, H. Tian, L. Ke, and X. Yu, "Incentive compatible and anti-compounding of wealth in proof-of-stake," *Information Sciences*, vol. 530, pp. 85–94, 2020.

[25] M. Abbasi, M. H. Manshaei, M. Rahman, K. Akkaya, and M. Jadliwala, "Transaction fee: Challenges and mechanism design," in *the IEEE International Conference on Communications (ICC)*. IEEE, 2022.

[26] J. W. Patty and E. M. Penn, "Measuring fairness, inequality, and big data: Social choice since arrow," *Annual Review of Political Science*, vol. 22, pp. 435–460, 2019.

[27] C. Gini, "Measurement of inequality of incomes," *The economic journal*, vol. 31, no. 121, pp. 124–126, 1921.

[28] G. F. Camilo, G. A. F. Rebello, L. A. C. de Souza, and O. C. M. Duarte, "A secure personal-data trading system based on blockchain, trust, and reputation," in *2020 IEEE International conference on blockchain (blockchain)*. IEEE, 2020, pp. 379–384.

[29] M. Król, A. Sonnino, M. Al-Bassam, A. G. Tasiopoulos, E. Rivière, and I. Psaras, "Proof-of-prestige: A useful work reward system for unverifiable tasks," *ACM Transactions on Internet Technology (TOIT)*, vol. 21, no. 2, pp. 1–27, 2021.