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Coin concentration of Proof-of-Stake blockchains

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ABSTRACT

This paper studies the concentration of block production in selected Proof-of-Stake (PoS) blockchains and finds evidence consistent with participants entering and leaving the consensus process, thereby changing the concentration level, but not with disproportionate compounding of wealth for large stakes.

1. Introduction

Nakamoto (2008) introduced the *Bitcoin* blockchain, which employs a Proof-of-Work (PoW) consensus protocol as part of its economic design. PoW mechanisms have been criticized to encourage block producers (miners) to engage in computational arms races with extensive and expensive energy consumption. The most prominent contestant of PoW is Proof-of-Stake (PoS) (cf. Irresberger et al. (2020)), in which the next block producer is chosen based on the amount of wealth (in the form of the native cryptocurrency) it puts at stake. The chosen block producer is then rewarded via transaction fees paid by users and newly "minted" coins. Both PoW and PoS protocols have been accused of leading to a centralization of validation power. In PoW, miners benefit from pooling their hash power to validate blocks and share the reward — at lower risk. While there is economic incentive to pool mining resources for risk-sharing purposes, Cong et al. (2021) show that there is a natural limit to centralization. Compared to PoW consensus, PoS validators are able to follow a 'buy-and-hold' strategy and have their wealth compound over time. The probability of a node being chosen as the next block producer is proportional to the size of its coins at stake. Block producers with higher stake will be chosen more often to append blocks and thus, get rewarded more often. Intuitively, this should lead to a scenario where "the rich get richer" and thus, a concentration of coins among a few block producers. However, Rosu and Saleh (2021) challenge that intuition with a theoretical result on the evolution of block producer shares and show that in expectation, we do not observe a disproportionate increase or decrease in block producer shares in PoS protocols over time.

In this paper, we empirically evaluate whether such wealth (power) accumulation takes place in practice. We collect block producer information on millions of blocks for selected (delegated) PoS blockchains and compute concentration measures (Gini Coefficients, HHI) to observe whether block production becomes more concentrated over time. Our evidence suggests that increases in concentration metrics are not due to unfair advantages large stakes may have in PoS protocols, but rather due to other block producers entering or leaving the consensus process. However, we do find different degrees in concentration across blockchains, with the delegated PoS blockchain *EOS.IO* exhibiting less concentrated block production than some of the selected pure PoS blockchains (*NxT*, *WAVES*), despite having fewer unique block producers overall. Our empirical findings are in line with theory and highlight that decentralization in PoS consensus is not undermined by wealth accumulation dynamics of large stake-holders, but rather stems from differences in incentive designs that result in (D)PoS block production being more or less concentrated.

2. Data and methodology

We collect data on millions of blocks from three major public PoS blockchains, *NxT*, *WAVES*, and *QTUM* and one Delegated PoS (DPoS) blockchain *EOS.IO*. Historical blockchain records can

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be retrieved by using APIs[1] or web scraping of block explorer websites,[2] or accessing existing full nodes.[3] For *EOS.IO*, we obtain data on the first 90 million blocks provided by Zheng et al. (2021). While we cannot directly observe block producers' coins at stake, we can infer the share of the overall wealth (power) by counting the number of blocks produced by an entity over a given time window. The number of unique producers and the distribution of shares are then used to compute indicators of the networks' degree of decentralization or concentration in the consensus process.

For each blockchain, we count the number of unique addresses that append blocks and estimate their share of blocks produced (e.g., over 10,000 blocks). We compute a Herfindahl–Hirschman Index (HHI) as the sum of squared shares (%) of blocks created by each address. We also estimate Gini Coefficients (GC) by sorting N block producers' shares $\{S_i\}_{i=1,\ldots,N}$ in ascending order and calculating actual (observed) and ideal (equal) cumulative shares as $\sum_{i=1}^{n} S_i$ and n/N for each $n \leq N$, respectively, to then generate cumulative distribution functions (CDF). GCs are then calculated as ratios of areas under an ideal versus actual (observed) CDFs and range from zero to one. Higher GC values indicate that the distribution of block production shares deviates more from a perfect equality among block producers and thus, indicate higher (coin) concentration within the set of block producers. Both measures are sensitive to changes in the distribution of block production shares, i.e., they will increase (decrease) when block producers leave (enter) the competition for blocks or if the distribution of shares becomes more (less) concentrated over time.

3. Empirical evidence

3.1. Proof-of-Stake (PoS)

Fig. 1 shows the time evolution of HHI, GC, and the number of unique block producers for the three PoS blockchains based on 10,000 block windows. On the *NxT* blockchain (left panels), we observe an increase in both concentration measures over time, coinciding with a downward trend in the number of block producers. At block height 1,000,000, there are over 300 block producers and just under 200 producers at block height 2,000,000. In that period, HHI values increase by almost four times to 2000 and the GC is above 0.9, indicating high levels of inequality in block production. For *WAVES* (mid panels), we see decreases in HHI and GC overall but concentration remains relatively stable towards the end of the sample period. *WAVES* has fewer block producers than the other two blockchains, but is slightly less concentrated than *NxT* with HHI and GC around 1000 and 0.85, respectively. Evidence on *QTUM* (right panels) reveals that after an initial starting period, coin concentration varies closely around HHIs of 200 and GCs between 0.7 and 0.8, which translates to a higher number of block producers with relatively smaller shares.

A striking insight from Fig. 1 is that the data are not consistent with an accumulation of wealth over time by block producers with large shares (given a relatively constant number of block producers). That is, the intuition that the "rich" get (disproportionally) richer by staking for a long time does not hold true. Instead, we observe jumps in coin concentration measures when producers leave or enter the network (i.e., the number of block producers changes rapidly). For example, in the *NxT* network, HHI and GC rise sharply around block height 1,500,000 where the number of producers drops significantly. Similarly, when more producers enter the consensus process in *WAVES* before block height 2,000,000, concentration measures decrease instantly.

3.2. Large stake behavior

Two of the three blockchains above exhibit high concentration in block production due to a low number of entities with larger stakes getting selected to append blocks in PoS consensus protocols. To illustrate this, Fig. 2 shows the share of blocks produced by "large stakes" (those with a share above 5% over at least one 10,000 block window) over time. At block height 1,000,000, *NxT* only has four large block producers that create less than 40% of blocks. Later, more block producers enter the network such that large nodes produce approximately 80% of blocks. Most importantly, we do not observe that large stakes continuously dominate and increase their overall shares. Even the producer with the initially highest share (dark gray bars) appears to have a similar share in *NxT* block production towards the end of the sample. Increases in the overall share of blocks captured by large stakes are more likely to come from block producers entering or leaving the competition. Such jumps are more consistent with investment-related events, i.e., block producers buying or selling coins to alter their stake levels. For example, the shares represented by the black bars (*NxT*) experience a jump after block height 1,600,000 and subsequently have a higher share in the validation process. Looking at large stake behavior on the *WAVES* blockchain, we see that not only do some block producers decrease shares over time, but also new producers enter the competition for blocks. *QTUM* has the least concentrated stake distribution, but exhibits similar dynamics for large stakes, i.e., jumps rather than continuous increases in block production shares.

The main takeaway from above observations is that block producer share dynamics are in line with the theoretical considerations in Rosu and Saleh (2021). Major changes in coin concentration occur when participants enter or leave the competition by buying or selling their coins, but not through continuous staking and having disproportionate advantages of starting out with a higher stake.

3.3. Delegated Proof-of-Stake

In contrast to PoS protocols, DPoS block producers are voted upon by other stake-holders to append blocks for a fixed block window ("round") until there is another vote. The number of delegates for each round is typically fixed (e.g., 21 on *EOS.IO* for a 126 s round) and blocks are equally distributed to the chosen delegates within a round. The composition of delegates only changes when stake-holders vote to replace some of the block producers after a round has ended. This means that concentration measures such as HHI or GC will only vary when there is sufficient turnover of block producers and (stake-weighted) votes by other users are less concentrated.

To observe block producers' turnover and associated changes in concentration measures, we choose different block windows (10,000; 100,000; 1,000,000) in which we count the number of unique delegates and compute the share of blocks they have produced in that window. Fig. 3 shows block producer counts, HHI and GC of block production shares for the first 90,000,000 blocks of the EOS blockchain (excluding the first million blocks for ease of illustration). Compared to PoS blockchains, the *EOS* blockchain has much lower concentration in block production than *NxT* or *WAVES*, despite having less than 30 unique block producers over any given calculation window. That is, although *EOS* as a DPoS blockchains has only 21 delegates producing blocks each round,

1 https://nxtportal.org/nxt.
2 https://qtum.info/block
3 http://node.wavesbi.com:6869/api-docs/index.html

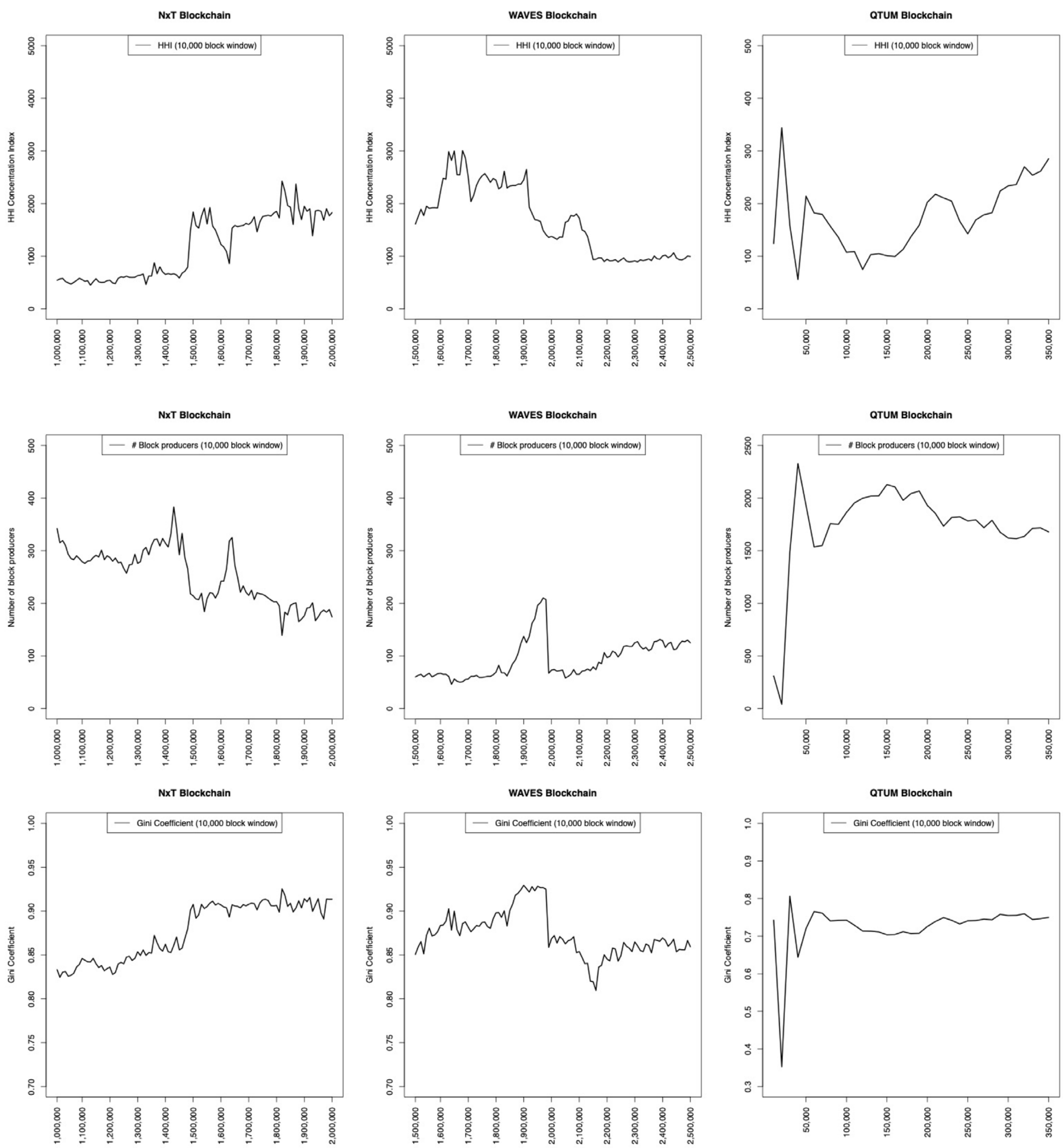

Fig. 1. Evolution of concentration in PoS block production.
This figure shows HHI (top) and Gini Coefficient (bottom) concentration measures and the number of unique block producers (mid) calculated over 10,000 block windows for the PoS blockchains *NxT*, *WAVES*, and *QTUM*.

it is less concentrated than its PoS counterparts where a few large stakes dominate block production (cf. Fig. 2), resulting in lower HHIs and GCs for the DPoS blockchain. HHI values revolve around 450 and GCs are lower than for PoS protocols, varying mostly between 0.05 to 0.2, indicating a lower degree of inequality among block producers. Most strikingly, we do not observe jumps in concentration levels as in PoS due to the low number of unique block producers that compete for votes by stake-holders, relative to the available delegate slots to fill in the consensus process. Except for *EOS*'s starting period, we regularly observe between 21 and 26 unique block producers in each window, showing that there is no reduction in unique block producers over time. That is, evidence on the DPoS blockchain *EOS.IO* is not consistent with an accumulation of votes by stake-holders that would give selected block producers more concentrated validation power over time.

Data availability

Data will be made available on request.

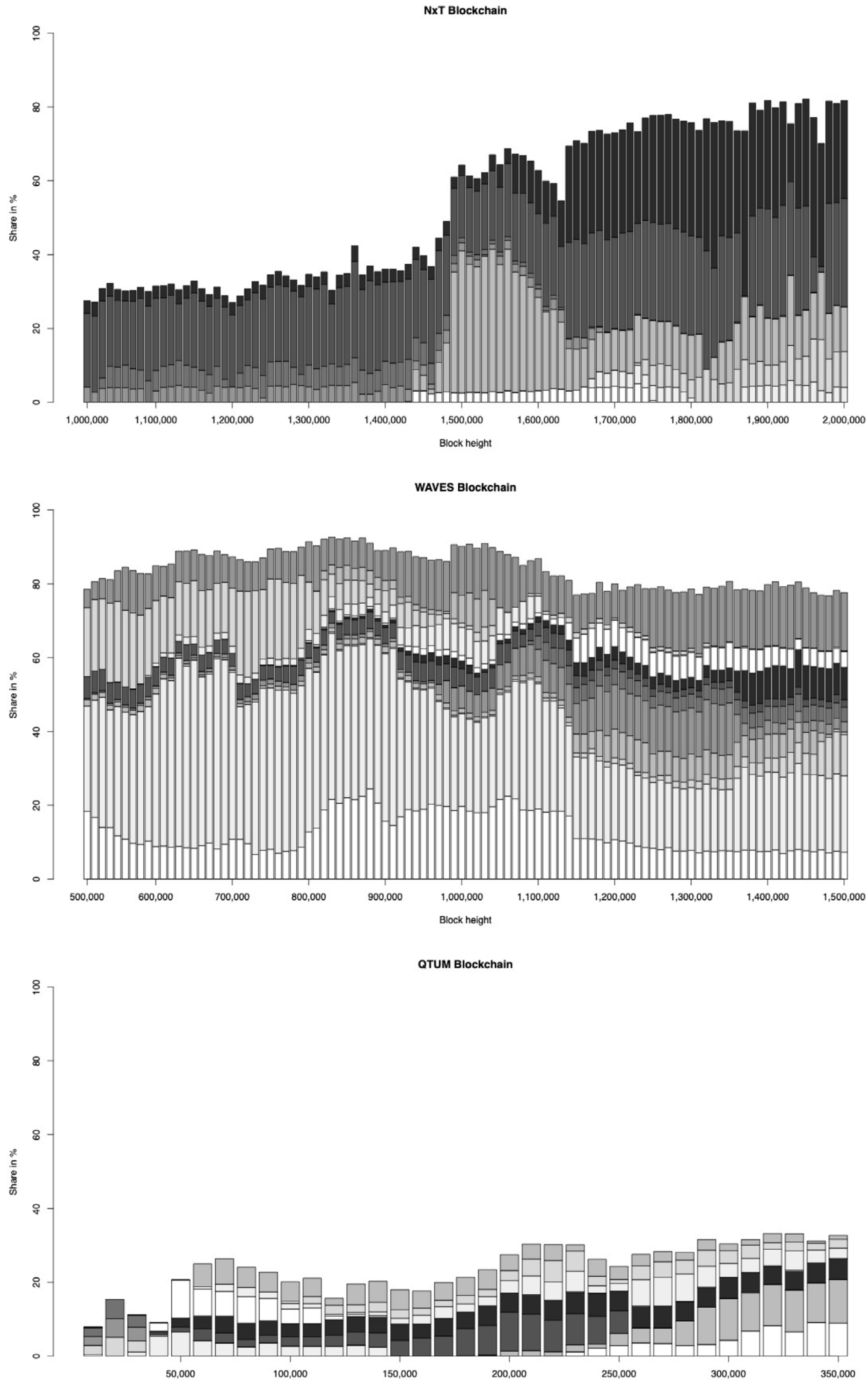

Fig. 2. Evolution of large PoS block producer shares.
Large stakes are defined as block producers that solve over 5% of blocks over at least one 10,000 block window.

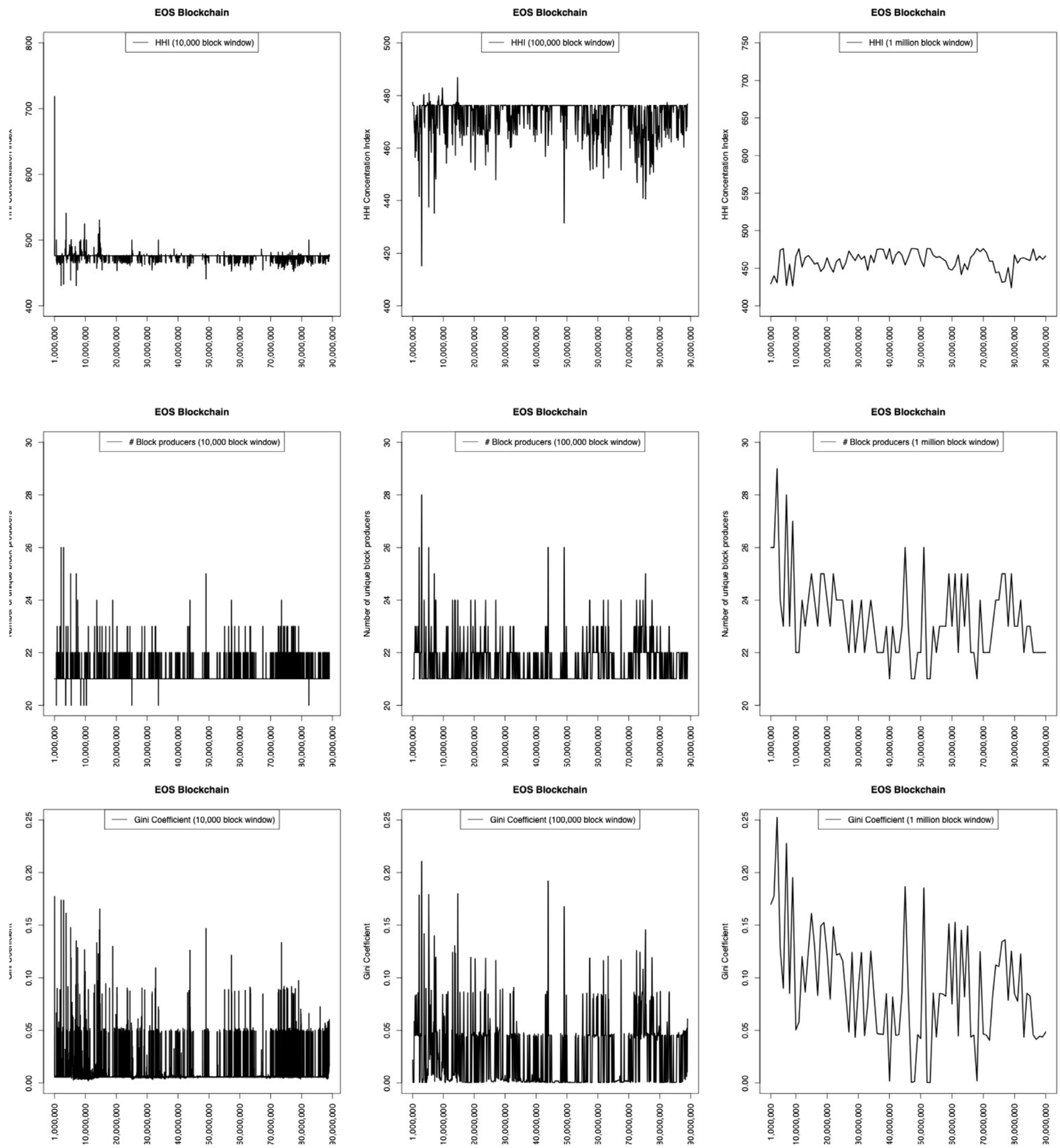

Fig. 3. Evolution of concentration in DPoS block production (EOS.IO).

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