Impact of Consensus Issuance Yield Curve Changes on Competitive Dynamics in the Ethereum Validator Ecosystem

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Abstract

This study analyzes competitive dynamics, elasticities, and event responses within the Ethereum validator ecosystem. Using historical blockchain data from the Beacon Chain genesis to May 2024, we examine differences in competitive advantages between validator subgroups under current and proposed issuance curves. We find that large validator pools (100+ validators) currently have 12-15% higher mean returns compared to solo validators, with proposed issuance reductions potentially exacerbating this advantage.

Elasticity analysis reveals solo stakers are highly sensitive to relative yield decreases compared to other staking categories, while being less responsive to absolute yield changes or DeFi yield fluctuations. Event studies show significant validator behavior changes in response to major ecosystem developments like withdrawal enabling and Bitcoin ETF launches, but limited impact from new staking protocols or macroeconomic events.

Our findings highlight the importance of addressing execution reward imbalances and maintaining relative yield competitiveness across validator segments to preserve a decentralized validator set. We conclude that a balanced approach combining MEV-Burn implementation with gradual issuance adjustments may best maintain a healthy, diverse validator ecosystem. Future research directions are proposed to further explore technological and alternative staking model impacts on validator behavior.

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1. Introduction

1.1. Background and motivation

The current consensus issuance of Ethereum rewards follows the equation $Y_i = cF\sqrt{D}$ with $c \approx 2.6$, F being 64, and D being the deposit size. Under this curve, the consensus reward issuance is proportional to the square root of the deposit site. On top of these rewards, the block proposer is rewarded with execution rewards that depend on how much block builders are paying the proposer to include the block they propose as the next block. The consensus issuance yield under the curve follows the equation $y_i = \frac{Y_i}{D} = \frac{cF}{\sqrt{D}}$.

The Ethereum community has discussed changing the issuance curve in the Electra upgrade happening later this year, e.g. [1, 2, 3, 4]. Some of the most widely discussed curve candidates include a reward curve with gradual reward reduction proposed by Anders following a formula $Y_i = \frac{cF\sqrt{D}}{1+D/k}$ and $k = 2^{26}$, a reward curve with substantial reward reduction proposed by Anders [4] following a formula $Y_i = \frac{cF\sqrt{D}}{1+D/k}$ and $k = 2^{25}$ and a reward curve with an economically capped reward issuance proposed by Vitalik [5] following a formula $y_i = cF(\frac{1}{\sqrt{D}} - \frac{0.5}{\sqrt{2^{25}-D}})$.

We aim to contribute to the discussion by analyzing the current differences in competitive advantages between stakers and what these differences would look like if a different issuance curve was adopted today. We analyze the elasticity of different stakers to identify how likely their stake is to change if issuance and other variables change. In addition, we perform event studies to analyze whether different stakers have changed their stake due to certain events.

1.2. Research problem and questions

While there has been discussion on various aspects of the issuance curve change there is limited understanding of how the competitive advantages among stakers might change if a different issuance curve was adopted. Additionally, the elasticity of stakers' behavior in response to changes in issuance and the impact of specific events on their staking patterns are not well-documented, highlighting a need for a comprehensive analysis of these dynamics.

We aim to answer the following questions

- How would the competitive advantages of stakers change if a different issuance curve were adopted today?
- How elastic are different stakers with respect to changes in issuance rates?
- What factors influence the elasticity of stakers' stake adjustments when issuance decreases?
- How have different types of stakers reacted to major events in terms of changing their stakes?

1.3. Limitations

The study has a limitation in the comparison of data points that may inherently have a time-lagged relationship. When comparing two data points, the effect of a change in one variable might influence the other variable with a certain delay. However, for this study, data points are compared only at identical times. This approach does not fully account for the potential delayed impact that one data point might have on another.

The study does not consider the potential influence of unconsidered third variables on the relationship between the two primary variables being compared. In our analysis, we compare two variables directly, assuming a direct correlation or causation between them. However, it is possible that a third variable, not included in our study, may affect both primary variables, thereby confounding our results. This omission can lead to inaccurate conclusions regarding the nature and strength of the relationship between the two variables under investigation.
The yield analysis assumes the number of validators an entity has stays constant over the observation period. If the number of validators in an entity has significantly increased during the observation period the relative yield compared to other participants will be lower than the actual relationship. Similarly, the number of validators in an entity has significantly decreased during the observation period the relative yield compared to other participants will be higher than the actual relationship.

The yield analysis assumes that stakers are not slashed. This assumption does not hold in reality and thus there is minor inaccuracy in the results. In reality, validators get slashed for different reasons, for example, big institutions might get slashed when they are optimizing their setup for maximal execution rewards and small operators might get slashed for poor staking setups.

The elasticity model assumes a direct and linear relationship between influencing factors and validator behavior. Real-world behaviors might be influenced by additional, unmodeled factors leading to non-linear responses. Also, the normalization of validator exits and rewards to a daily level, while necessary for comparison, may obscure short-term fluctuations and finer-grained behaviors.

The event study utilizes an estimation window before and after an event to determine whether an event has changed the willingness to stake for certain groups. This methodology might not be accurate in estimating the effect of an event in certain cases. For example, an announcement of an event happening in the future might already affect willingness to stake before the actual event as stakers gain new information about the future that they can leverage when making their decision on staking. As a result, in such a scenario our event study might underestimate the effect an event has on stakers.

1.4. Structure of the study

The rest of the study is organized as follows. Section 2 describes the data and methodology including the used data sources and data processing as well as the methodology used for analyzing the current situation, different curve candidates, elasticity, and event studies. Section 3 presents the results and analysis. Section 4 summarizes the results and discusses the findings. Finally, Section 5 concludes the study.

2. Data and methodology

This section describes the data we have used, how we have processed it, and the different methodologies we use. The first subsection describes the data collection and data processing. The second subsection describes the methodology used for analyzing the current competitive landscape and different curve candidates. The third subsection presents the methodology used for analyzing elasticity. The fourth subsection presents the methodology used in event studies.

2.1. Data and data processing

2.1.1. Data collection

To comprehensively analyze the historical beacon chain data and validator behavior in the Ethereum ecosystem, we collect three distinct types of data: historical beacon chain data, validator metadata, DeFi data, and Ethereum price. Our dataset spans from the genesis of the beacon chain to slot 8,984,512 on May-02-2024 at 08:22:47 AM UTC. This dataset enables a thorough examination of validators' activities, staking dynamics, and their interactions with yields on DeFi protocols.

Historical Beacon Chain Data

We acquire historical beacon chain data from Rated Network, encompassing deposits, withdrawals, validator activations, validator exits, and rewards. The rewards are further categorized into attestation, consensus, and execution rewards, providing a granular view of validator incentives. This dataset allows us to track validator performance metrics, staking ratios, and distribution patterns over time.

Validator Metadata

To accurately identify validators and label entities within the beacon chain, we collect data from Rated Network, Dune, and Etherscan. These sources provide the following:

- Rated Network: Metadata for validators, including validator private keys, validator indices, entity labels, activation and exit epochs, and deposit and withdrawal addresses. This enables precise identification of individual validators.
- Dune: Entity labels that enhance our understanding of validator affiliations and behaviors. Identification logic like deposit address factory contracts for a more complete labeling. These are used to supplement the Rated Network metadata.
- Etherscan: Supplementary entity labels to ensure comprehensive coverage and accuracy in our dataset.

By integrating these sources, we achieve a robust labeling system that facilitates the analysis of validator groupings and their respective characteristics.

DeFi Data

We obtain DeFi data to analyze validator behavior under various economic conditions from Dune and TradingStrategy.ai. This data includes the following:

- Dune: Data on Curve's ETH-stETH liquidity APR, offering a view of DeFi yield influence on staking decisions.
- TradingStrategy.ai: Historical liquidity returns for Aave v3 on WETH and wstETH, providing insights into lending market dynamics and their impact on validator behavior.

Ethereum Price

We obtain historical Ethereum market price data from CoinGecko as it offers an aggregate price from a variety of sources. This data enables the study of price movements and their effects on validator behavior.

2.1.2. Data processing

This subsection outlines the methodologies used to process different datasets. These datasets comprise validator metadata, validator activations, and exits, validator yield data, and DeFi yield data. Each dataset is processed to ensure compatibility, coherence, and accuracy.

Validator metadata

Rated's validator metadata dataset serves as the foundation for our validator information. Entity categories are obtained from Dune and further supplemented through online searches. Validators are grouped into entities based on their shared withdrawal addresses; in cases where withdrawal addresses are not available, deposit addresses are utilized as an alternative. This methodology allows for the determination of the count of validators associated with each entity, allowing for an analysis of entity-specific validator distributions.

Validator activations and exits

By leveraging activation and exit epochs from Rated's validator metadata, we compute the historical counts of active validators and validator exits. These values are subsequently grouped according to entity validator count, category, and individual entity, based on the previously processed validator metadata.

For elasticity calculations, validator exits are normalized by dividing by the current active validators within their respective groups. This approach enables relative comparisons across groups with varying validator counts. Furthermore, both historical active validators and exits are normalized to a daily level to ensure alignment with the DeFi data.

Validator yield data

Rated's reward data is processed on a daily level. Slot and epoch data are integrated to ensure compatibility with other datasets. Validator rewards are then categorized by entity size, category, and individual entity.

To compute daily historical validator APYs for elasticity analysis, raw reward values are adjusted for decimal precision, divided by the corresponding validator stake, and subsequently annualized.

DeFi yield data

Aave liquidity APR values are averaged daily for WETH and wstETH pools, maintaining consistency with the daily frequency of most datasets. Additionally, daily percentage changes in the ETH market price are incorporated to enable elasticity analysis. Slots are added to all DeFi yield datasets, including the Curve ETH/stETH liquidity APR data, to ensure compatibility and integration with other datasets.

2.2. Current competitive landscape and comparing curve candidates

2.2.1. Current competitive landscape

The current consensus issuance of Ethereum rewards follows the equation $Y_i = cF\sqrt{D}$ with $c \approx 2.6$, F being 64, and D being the deposit size [1]. Under this curve, the consensus reward issuance is proportional to the square root of the deposit site and the issuance yield under the curve follows the equation $y_i = \frac{Y_i}{D} = \frac{cF}{\sqrt{D}}$. On top of these rewards block proposer is rewarded with execution rewards that, under the current MEV-Boost implementation, depend on how much block builders are paying the proposer to include the block they propose as the next block.

There are differences between the amount of consensus and execution rewards different staking entities achieve. Differences in consensus rewards are caused by how frequently entities are capable of restaking their rewards and how well they perform their validator duties. Differences in execution rewards are caused by differences in how much block builders are willing to pay for a block. Simplifying the block builders' behaviors, their bids depend on present CEX-DEX arbitrage opportunities and other available orderflow. Sophisticated validators can achieve higher expected returns from execution rewards than unsophisticated validators, for example by intentionally delaying the end of block auction to increase the expected value from CEX-DEX arbitrage opportunities resulting in higher expected return.

We analyze the current differences between stakers to determine how big competitive advantage different stakers have due to differences in consensus and execution rewards.

2.2.2. Curve candidates

Anders proposed multiple candidates for a new reward curve [4]. We focus on two curve candidates that are both determined as $Y_i = \frac{cF\sqrt{D}}{1+D/k}$ with $k = 2^{25}$ in the first candidate and $k = 2^{26}$ in the second.

In addition to curve candidates proposed by Anders, we analyze a curve candidate discussed by Vitalik that is economically capped [5]. The curve's issuance is determined as $Y_i = cFD(\frac{1}{\sqrt{D}} - \frac{0.5}{\sqrt{2^{25}-D}})$. In this curve, the consensus yield becomes negative around 26.8 million Ethereum limiting the feasibility of staking Ethereum.

We analyze what the impact of adopting different issuance curve candidates would look like for different validator groups. To do so we analyze the differences in consensus and execution rewards between different validator groups under the current consensus issuance curve over the last million slots of our dataset. Based on the differences we interpret why different validator groups have different historical returns. After determining the root causes of differences between validator groups we extrapolate our results and analyze how changing the issuance curve would reinforce or weaken the differences between different groups.

2.3. Elasticity

This subsection outlines the methodology used for analyzing the elasticity of validators in the Ethereum ecosystem. We analyze how strongly validators react, compared to other validators, to various factors that might influence their behavior including changes in:

- Validator Yield: This is a primary motivator for validator participation and will be significantly affected by the chosen reward structure.
- Yield Difference Between Entities: Stakers might strategically adjust their participation based on discrepancies in yield, seeking to maximize their returns. Analyzing these differences helps us understand competitive dynamics and validator mobility within the network.
- DeFi Yields: DeFi platforms offer alternative investment opportunities for validators. When DeFi yields are high, validators might be incentivized to move their funds to liquid staking solutions or other DeFi products, potentially leading to validator churn.
- Ethereum Dollar Price: The price of Ethereum directly impacts validator profitability as rewards are typically denominated in ETH. Validators also carry the risk of price fluctuations for their staked ETH, potentially influencing decisions to sell their stake and exit the network.

To analyze elasticity, we group validators, validator exits, and rewards based on three criteria:

- Entity Validator Count: This allows us to isolate the behavior of solo and small stakers and compare them against larger, institutional validators. Entities with a higher validator count might exhibit different elasticity patterns due to economies of scale or risk management strategies.
- Entity Category: Grouping validators by category such as exchange, liquid staking, and solo staker can reveal behavioral differences based on the entities' core business and risk tolerance.
- Individual Entity: Analyzing individual entities provides the most granular view and allows for the identification of specific actors who might be particularly sensitive to changes in the factors mentioned above.

By examining validator behavior across these groups, we can gain insights into how the chosen reward structure and overall economic conditions might influence validator participation in the Ethereum ecosystem.

Elasticity in this context is defined as the percentage change in the number of active validators or validator exits as a percentage of active validators in response to a percent change in the influencing factor. The formula used for calculating elasticity (E) is as follows:

$E = \frac{\%\Delta V}{\%\Delta X}$ where $\%\Delta V$ represents the percentage change in the number of validators and $\%\Delta X$ represents the percentage change in the influencing factor (Validator Yield, Yield Difference, DeFi Yields, or Ethereum Dollar Price). The test conducted is a two-sample t-test with a null hypothesis of no elasticity difference compared to the whole dataset.

2.4. Event studies

This subsection outlines the methodology used for event studies to analyze the impact of events on the staking behavior of validators in the Ethereum ecosystem. We examine how strongly different validator groups react to events, compared to other validators.

Event studies measure if an event has affected the behavior of a staker group more or less compared to all other stakers. We determine the timing slot when the event takes place and measure validator deposits and, with a Bitcoin ETF launch, the validator exits hourly for one week (50,400 slots) before and after the event slot. Validators are grouped based on two criteria: Entity Validator Count and Entity Category.

We calculate mean deposits/exits during the event window for each group and conduct a two-sample t-test against the overall population mean. Statistically significant differences indicate the event uniquely influenced that group's staking behavior compared to all validators.

3. Results and analysis

This section presents the results of different analyses. The first subsection discusses the results of analyzing the current competitive landscape and different curve candidates. The second subsection discusses the results of elasticity analysis. The third subsection discusses the results of the event studies.

3.1. Current competitive landscape and comparing curve candidates

3.1.1. Current competitive landscape

As shown in Table A1 there are significant differences in the mean consensus and the mean execution rewards as well as the combination of the two between different groups formed based on pool size, category, and entity. In Panel A the consensus rewards are significantly lower than the sample mean at 1% significance for all groups except pools with 100+ validators which are higher than the sample mean at 1% significance. The consensus rewards increase as the pool size increases. The mean consensus rewards for pools with size of 1 are 3.32%, 3.55% for pools with size of 100+, and 3.54% for the whole data.

For different pool sizes, the mean execution rewards are only significantly different than the mean for pools with 1 validator being lower than the mean of 0.63% at 5% significance. The mean execution rewards for pools with 1 validator are also significantly lower than the mean execution rewards of pools with 100+ validators of 0.87%. The median of execution rewards increases as the pool size increases.

Combining the consensus and execution rewards results in significantly lower than mean rewards for pools with 1 and 6-19 validators. Pools with size 1 have 0.48% percentage points lower total rewards compared to pools with size of 100+ meaning the mean rewards for pools with size of 100+ are 12% higher. Figure 1 illustrates these differences in rewards of differently sized pools at different points of the current issuance curve assuming MEV-burn is not implemented.

In Panel B the sample is split into groups by different categories of stakers. When grouped by category liquid restaking and solo stakers have significantly lower than mean consensus rewards of 3.49% and 3.50%, respectively, while CEX, liquid staking, and staking pools have significantly higher than mean consensus rewards of 3.55%, 3.56%, and 3.55%, respectively. Considering execution rewards no category's execution rewards statistically significantly differ from the sample mean. Combining both consensus and execution rewards, no category has statistically significantly different rewards from the mean.

Panel C observes the 10 biggest individual entities. Out of the entities Lido, Binance, Kraken, and OKX have significantly higher than mean consensus rewards of 3.56%, 3.60%, 3.56%, and 3.59%, respectively, while Coinbase, Rocketpool, Bitcoin Suisse, and Ether.Fi have significantly lower than mean consensus rewards of 3.53%, 3.47%, 3.53%, and 3.47%, respectively. No individual entity has execution rewards statistically significantly different from the mean. Combining consensus and execution rewards Lido has significantly higher than average rewards of 4.44% at 10% significance while Rockerpool has significantly lower than average rewards of 4.30% at 10% significance.

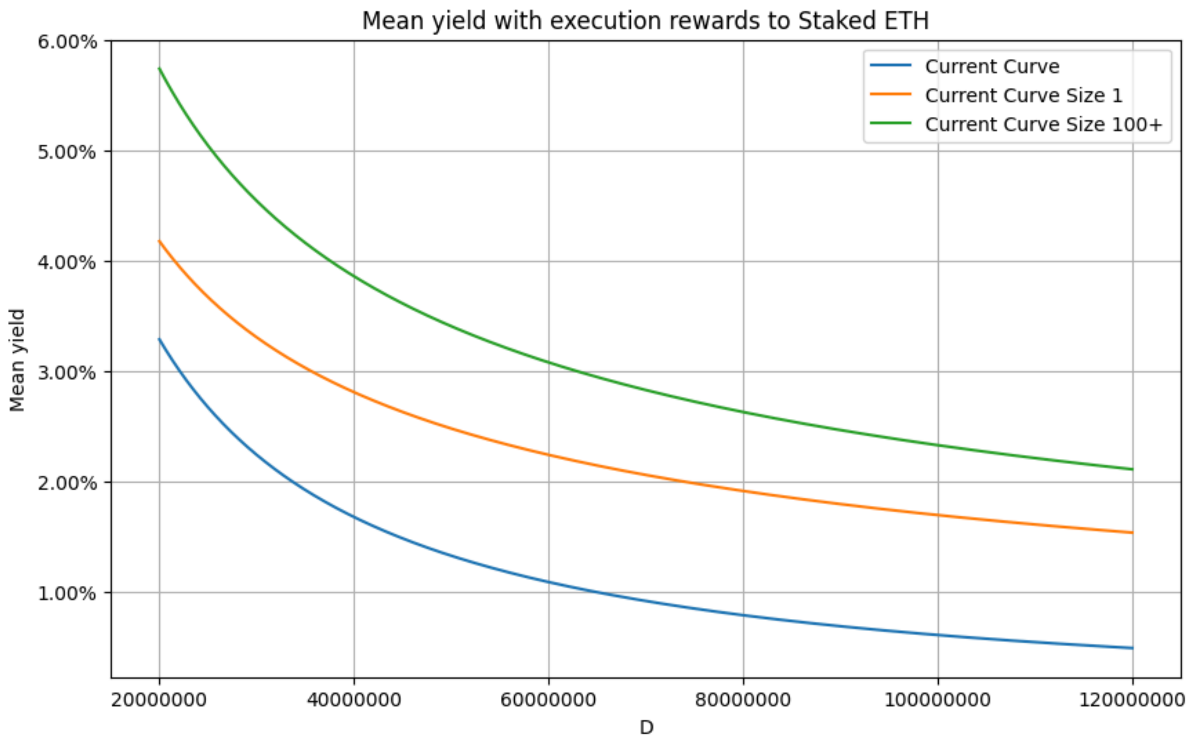

Figure 1: Mean yield of current issuance curve reduction by pool size with execution rewards

3.1.2. Gradual reward curve reduction

Anders proposed a reward curve with gradual reward reduction where the yield of consensus rewards follows a formula $y_i = \frac{cF}{\sqrt{D}(1+D/k)}$ and $k = 2^{26}$. The decrease in the mean rewards with and without execution rewards is visualized in Figures 2 and A1. The decrease in the median rewards with execution rewards is visualized in Figure A2.

Based on the analyzed sample if the issuance curve was to be changed and MEV-burn was not implemented this would result in a situation where staking pools with the size of 1 validator would have a mean APY of 3.13% while the pools with the size of 100+ validators would have a mean APY of 3.55% when considering the execution rewards. This means rewards for pools with a size of 100+ would be 13% higher than that of pools with a size of 1. Figure 3 illustrates these differences in rewards of differently sized pools at different points of the proposed issuance curve assuming MEV-burn is not implemented.

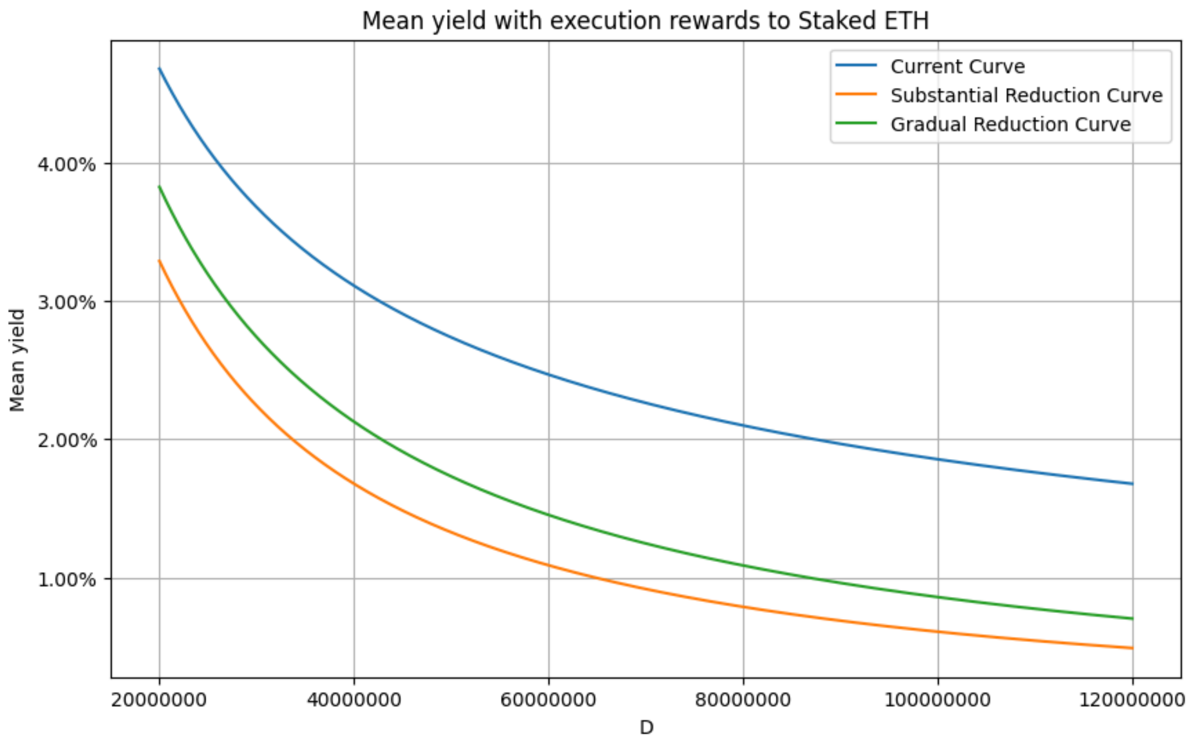

Figure 2: Mean yield of different issuance curves with execution rewards

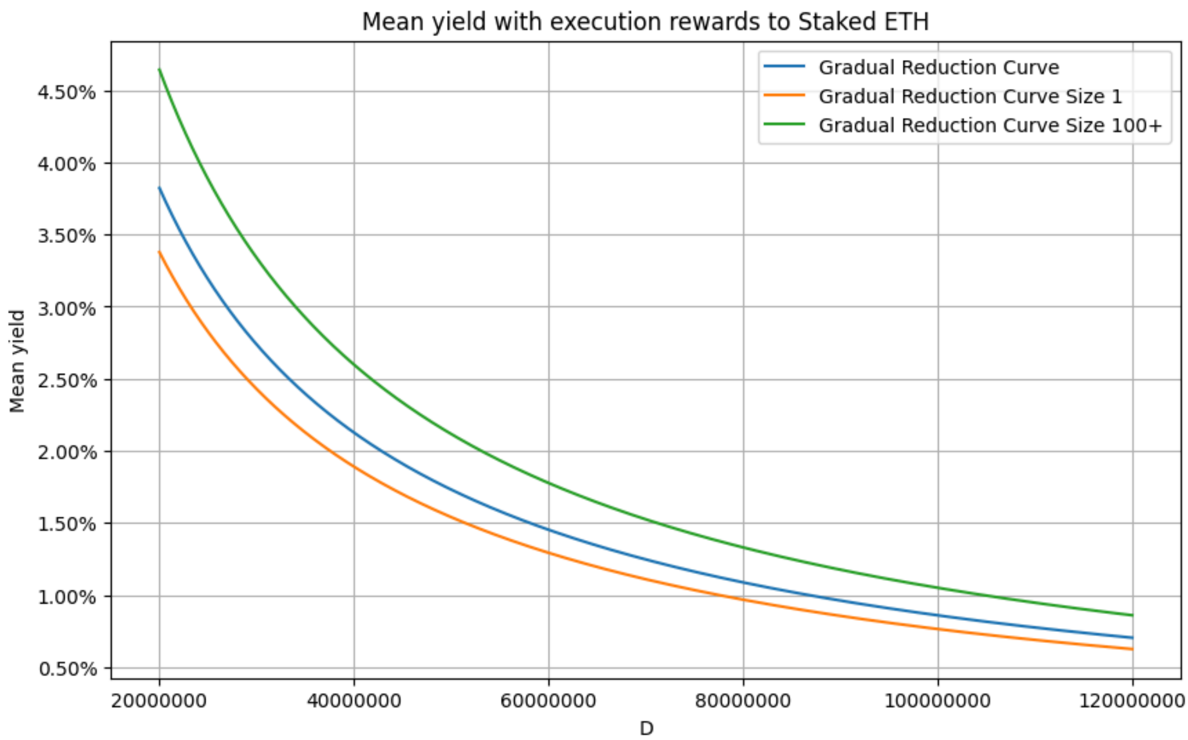

Figure 3: Mean yield of gradual issuance curve reduction by pool size with execution rewards

3.1.3. Substantial reward curve reduction

Anders also proposed an alternative reward curve with substantial reward reduction where the yield of consensus rewards follows a formula $y_i = \frac{cF}{\sqrt{D}(1+D/k)}$ and $k = 2^{25}$. The decrease in the mean rewards with and without execution rewards is visualized in Figures 2 and A1. The decrease in the median rewards with execution rewards is visualized in Figure A2.

Based on the analyzed sample if the issuance curve was to be changed and MEV-burn was not implemented this would result in a situation where staking pools with the size of 1 validator would have a mean APY of 2.63% while the pools with the size of 100+ validators would have a mean APY of 3.02% when considering the execution rewards. This means rewards for pools with a size of 100+ would be 15% higher than that of pools with a size of 1. Figure 4 illustrates these differences in rewards of differently sized pools at different points of the proposed issuance curve assuming MEV-burn is not implemented.

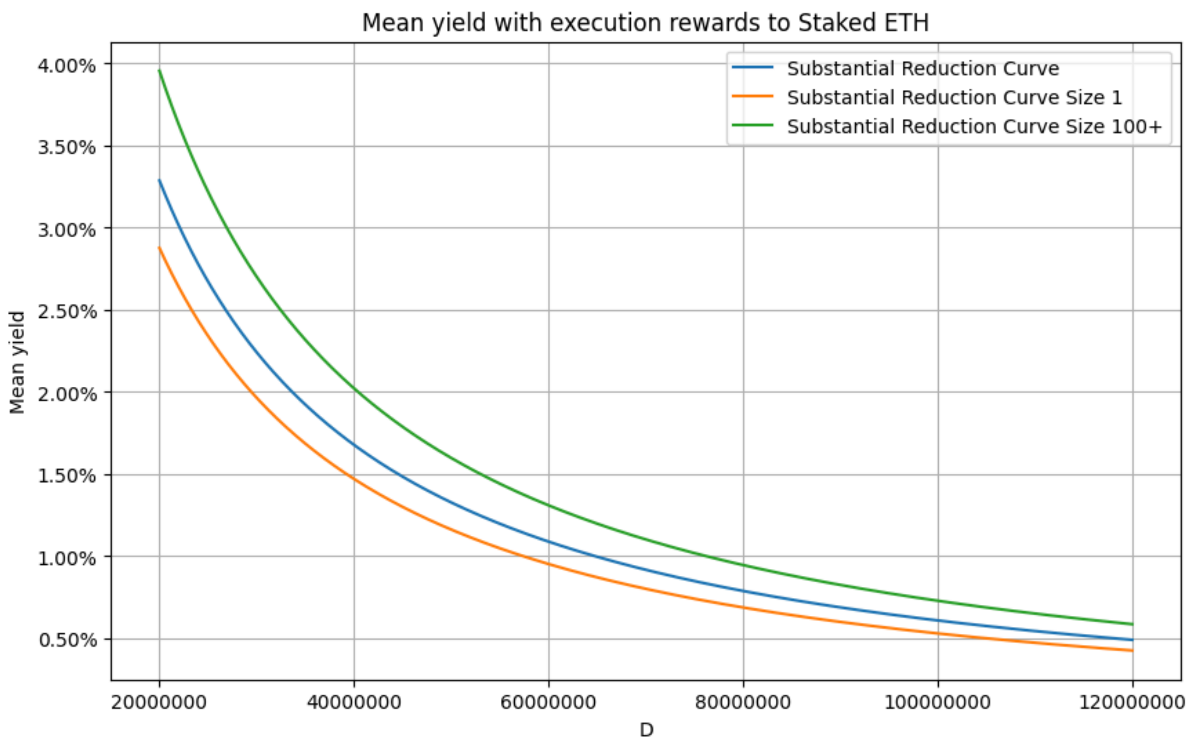

Figure 4: Mean yield of substantial issuance curve reduction by pool size with execution rewards

3.1.4. Economically capped curve

Vitalik proposed an economically capped reward issuance curve in his blog post. Under this curve, staking yield would follow $y_i = cF(\frac{1}{\sqrt{D}} - \frac{0.5}{\sqrt{2^{25} - D}})$ and become negative after a certain threshold staking amount is met. Figure 5 illustrates the economically capped curve compared to the current curve.

Based on the analyzed sample if the issuance curve were to be changed and MEV-burn was not implemented this would result in a situation where staking pools with the size of 1 validator would have a mean APY of 1.65% while the pools with the size of 100+ validators would have a mean APY of 1.97% when considering the execution rewards. Figure 6 illustrates these differences in rewards of differently sized pools at different points of the proposed issuance curve assuming MEV-burn is not implemented. In the figure, the smallest-sized pools have negative APY if the staked eth exceeds around 28,300,000 while the biggest-sized pools have negative APY if the staked eth exceeds around 28,700,000.

Figure 5: Mean yield of current and economically capped issuance curves with execution rewards

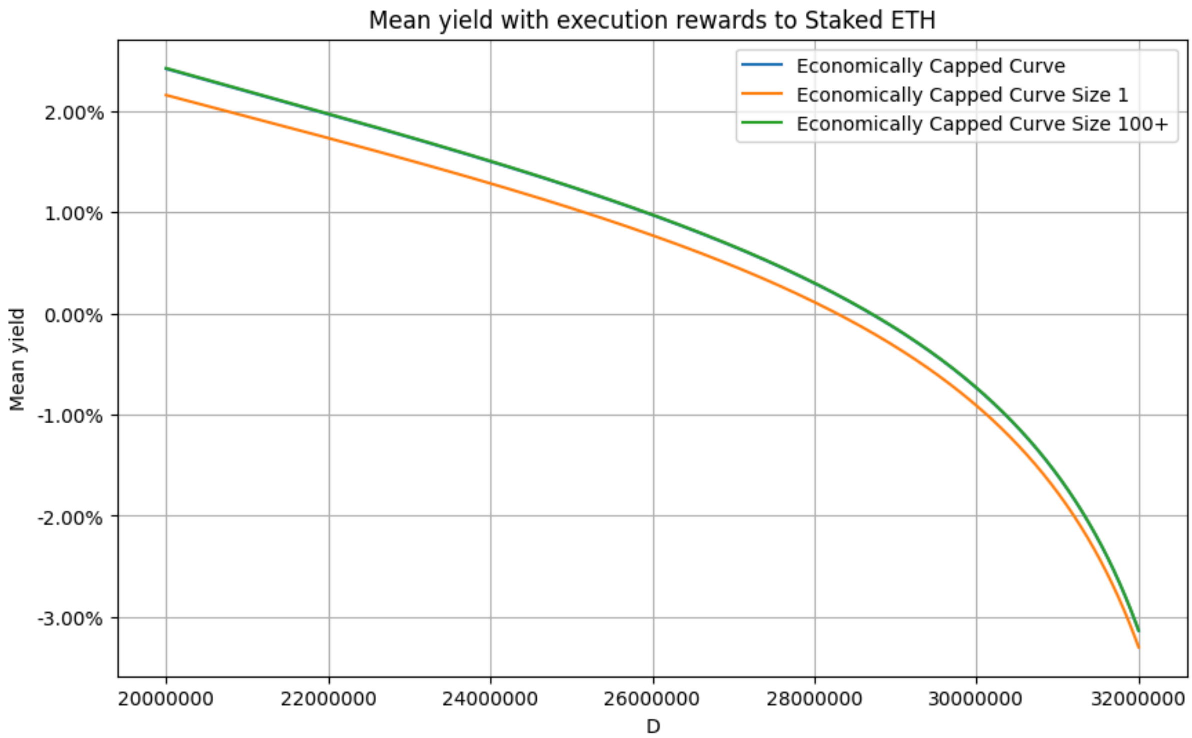

Figure 6: Mean yield of economically capped issuance curve reduction by pool size with execution rewards

3.2. Elasticity Analysis

3.2.1. Validator ETH Price Elasticity

We investigate the sensitivity of validator behavior to changes in the Ethereum price by calculating elasticities for validator exits, deposits, and total validator count changes relative to the overall dataset. Table B1, visualized in Figure B1, presents the results for subgroups based on pool size, category, and individual entity using a two-sample t-test against a null hypothesis of no elasticity difference compared to the complete dataset.

When grouping by category, solo stakers exhibit a statistically significant negative elasticity of -0.4031 at 1% significance, indicating they are less elastic and less likely to exit their validators when Ethereum prices rise. Staking pools display a positive elasticity of 1.1772 at 10% significance, suggesting they are more elastic, with a higher propensity to exit validators as prices increase. The liquid restaking category has a negative elasticity of -6.2982 at 10% significance for total validator count changes, implying it is less elastic than the full dataset and tends to decrease its overall validator set during Ethereum price increases.

Among the largest individual entities, Lido and Binance demonstrate negative elasticities of -0.0585 at 5% significance and -0.7476 at 10% significance, respectively, suggesting they are less elastic and less likely to exit validators when Ethereum prices rise. OKX exhibits a statistically significant negative elasticity of -1.0009 at 1% significance for changes in total validator count, indicating it decreases its validator set when Ethereum prices increase. Conversely, Ledger Live and Mantle exhibit positive elasticities of 4.1524 at 10% significance and 6.8474 at 10% significance, respectively, indicating higher elasticity and an increased likelihood of exiting validators during Ethereum price increases relative to other stakers. Bitcoin Suisse shows a statistically significant positive elasticity of 4.0668 at 1% significance for changes in total validator count, suggesting an increase in its validator set as Ethereum prices rise.

3.2.2. Validator Staking Yield Elasticity

Validator Staking Yield

Table B2, visualized in Figure B2, reports the elasticity estimates of validator exits, deposits, and total validator count changes with respect to the staking annual percentage yield between slots 6,840,000 and 8,985,900.

Among different pool sizes, pools with 2-5 validators and 6-19 validators exhibit statistically significant negative elasticities of -0.4600 at 10% significance and -1.1733 at 10% significance, respectively, for changes in total validator count. This suggests a decrease in their overall validator set as the staking APY rises.

When grouping by category and individual entities, there are no statistically significant elasticity findings at conventional levels. Low statistical significance shows short-term changes in staking APY have little effect on staker behavior.

Validator Staking Yield Difference

We analyze the elasticity of validator exits, deposits, and total validator count changes with the respect to the difference in staking annual percentage yield compared to other stakers. Table B3, visualized in Figure B3, presents these elasticity estimates between slots 6,840,000 and 8,985,600.

Regarding pool sizes, pools with 20-99 validators are the only group exhibiting a statistically significant elasticity, with a positive value of 0.0616 at 10% significance for changes in total validator count with the respect to the APY difference from the largest 100+ validator pools. This suggests that as their APY becomes higher relative to the largest pools, mid-sized pools with 20-99 validators tend to increase their overall validator set.

Solo stakers' validator deposits exhibit statistically significant negative elasticity with the yield difference compared to the liquid restaking, liquid staking, and staking pools categories. The elasticities are -0.9277 at 5% significance for liquid restaking, -0.9153 at 10% significance for liquid staking, and -1.274 at 5% significance for staking pools. However, solo stakers did not show statistical elasticities for validator exits, deposits, or total validator count changes when their APY differed from the CEX category.

3.2.3. Validator DeFi Yield Elasticity

Tables B4 and B5, visualized in Figures B4 and B5, present the elasticity estimates of validator exits, deposits, and total validator count changes in response to Aave v3 WETH supplier yield and Curve stETH-WETH liquidity yield between slots 6,206,400 and 8,985,900.

The analysis reveals no statistically significant effect of DeFi yield changes on staker behavior across deposits, exits, or total validator counts.

3.3. Event studies

3.3.1. Rocket Pool mainnet launch - 9th November 2021

The Rocket Pool mainnet launch on November 9th, 2021 introduced a new decentralized liquid staking protocol to the Ethereum ecosystem. [6]

Analyzing the impact of the Rocket Pool's mainnet launch, Table C1, visualized in Figure C1 reveals no statistically significant differences in validator deposits before and after the event. All of the pool sizes in Panel A, as well as the pool categories in Panel B, do exhibit a lack of robust statistical significance. These results suggest that the Rocket Pool's mainnet launch did not significantly influence the willingness to stake across the various pool classifications.

3.3.2. First 0.75% FED interest hike - 16th June 2022

The first major interest rate hike by the Federal Reserve on June 16th, 2022 was one of the largest single increases in decades, signaling a shift towards an aggressive tightening monetary policy cycle by the Fed to combat high inflation. This increased the opportunity cost of capital tied up in illiquid staking positions compared to other yield opportunities. It also applied downward pressure on risk assets like cryptocurrencies, affecting the risk/reward dynamics of staking returns.

Table C2, visualized in Figure C2, presents the results of the event study analyzing the impact of the first 0.75% FED interest rate hike on validator deposits. The results suggest that the first 0.75% FED interest rate hike did not significantly impact the willingness to stake, as evidenced by the lack of statistically significant differences in validator deposits before and after the event across the dataset and various pool categories.

3.3.3. Ethereum Staking Withdrawals Open - 12th April 2023

The enabling of Ethereum staking withdrawals through the Shanghai/Capella upgrade on April 16th, 2023 was significant for providing liquidity to previously inaccessible and illiquid staked ETH after over two years of lockup. It removed a major opportunity cost associated with staking by allowing validators to access and manage their staked capital and rewards more flexibly. The upgrade also marked meaningful progress in Ethereum's transition to proof-of-stake consensus, demonstrating advancement toward the network's final architecture. [7]

Table C3, visualized in Figure 7, shows statistically significant increases in mean validator deposits for the 20-99 validator pool size at 5% significance, the Solo Stakers category at 5% significance, and the CEX category at 1% significance after the upgrade. However, no significant changes were observed for other groups.

Complementing these findings, Figures 8 and 9 illustrate the cumulative validator exits across pool sizes and categories after the upgrade, respectively. These figures reveal higher exit levels for larger pool sizes of 20-99 and 100+ and certain categories like CEX and Liquid Staking.

The statistically significant increase in validator deposits for larger pool sizes, coupled with the observed higher exit levels post-upgrade, suggests the newfound ability to withdraw staked ETH

appears to have influenced the staking behavior of these pools, potentially due to the increased liquidity and flexibility in managing their staked capital and rewards.
However, the lack of significant differences for smaller pool sizes indicates that the impact of the upgrade on the willingness to stake was more pronounced for larger pools, while smaller pools and the overall staking ecosystem remained relatively unaffected.

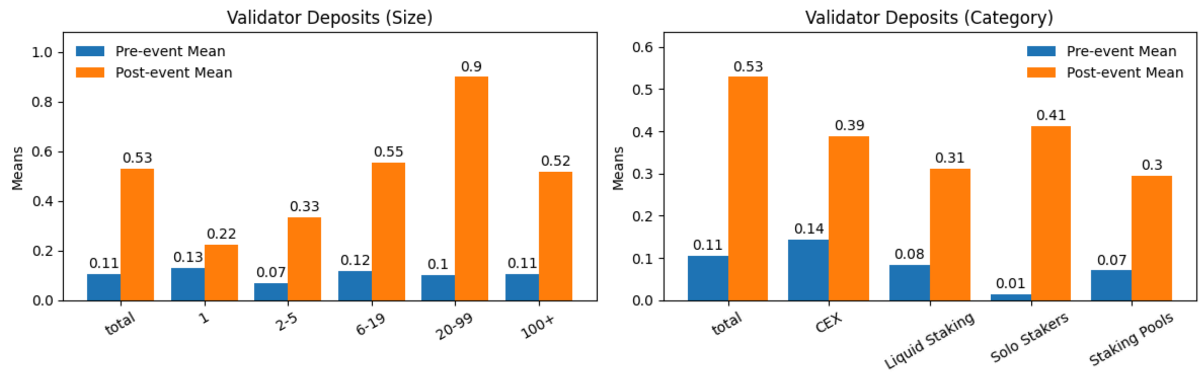

Figure 7: Validator deposits one week before and after the Ethereum Shanghai/Capella upgrade that allowed staker withdrawals. The deposits have been normalized by the net deposits of the subgroup.

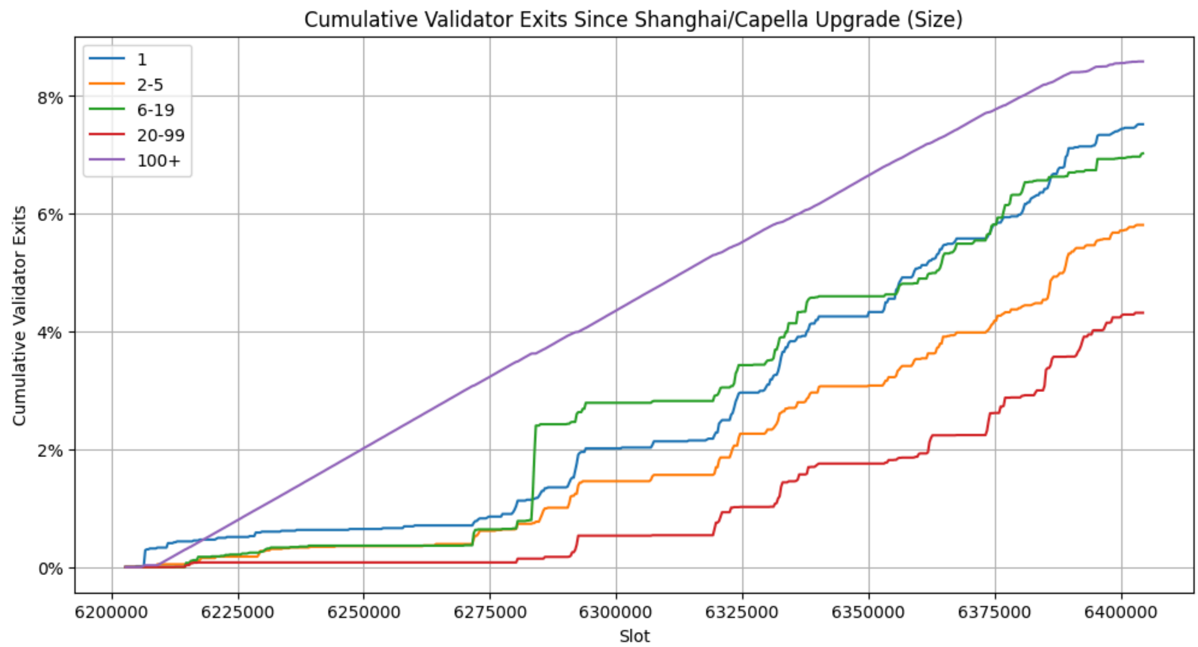

Figure 8: Cumulative validator exits by pool size for one month after the Shanghai/Capella upgrade. The exits have been normalized by the subgroup validator count at slot 6202800.

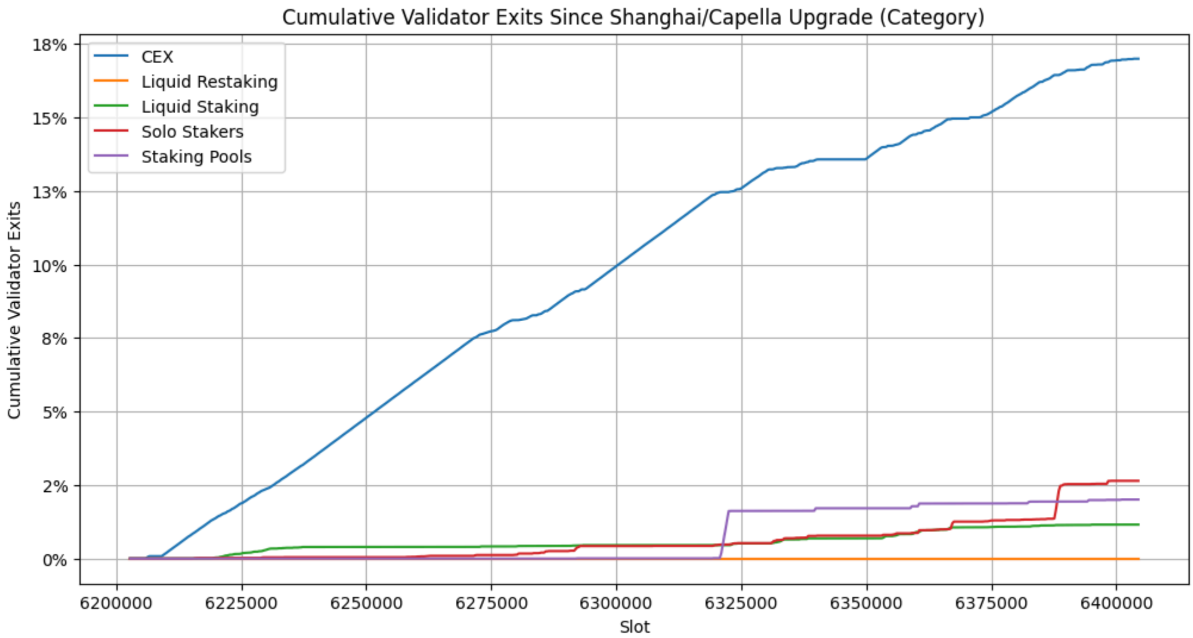

Figure 9: Cumulative validator exits by category for one month after the Shanghai/Capella upgrade. The exits have been normalized by the subgroup validator count at slot 6202800.

3.3.4. Bitcoin ETF Launch - 11th January 2024

As seen in Table C4, and visualized in Figures 5 and 6, the launch of the first Bitcoin ETF in the US on January 11th, 2024 marked a significant shift in mainstream cryptocurrency adoption and legitimacy. These regulated investment vehicles allowed investors to gain exposure to cryptocurrencies through conventional financial products, signifying their integration into traditional finance.

The Bitcoin ETF launch had a significant impact on validator exits across most pool sizes and categories. The 1, 2-5, and 6-19 validator pool sizes exhibited statistically significant increases in mean exits post-event at the 1% significance level. The 20-99 pool size showed a significant increase at the 5% level, while the 100+ pool size experienced a significant decrease in exits at the 1% level. Among categories, the CEX group had a significant increase in exits at the 1% level. The Liquid Staking and Solo Stakers categories also saw significant increases at the 5% level. Conversely, the Staking Pools category experienced a significant decrease in exits at the 1% level.

The event did not significantly affect validator deposits for most groups at the 10% significance level. The exceptions were the 100+ pool size with a significant increase at the 5% level, the Liquid Staking category with a significant decrease at the 10% level, and the Liquid Restaking category with a significant increase at the 5% level.

These results suggest the Bitcoin ETF launch primarily influenced validator exits, with most groups increasing exits, except larger pools and staking pools. Validator deposits remained largely unchanged, with only marginal effects observed for the 100+ pool size and Liquid Staking category.

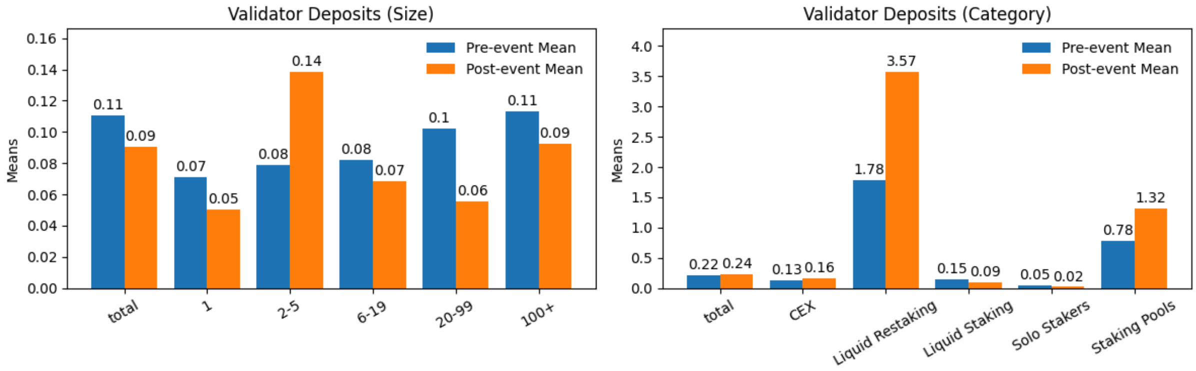

Figure 5: Validator deposits one week before and after the launch of the first Bitcoin ETF. The deposits have been normalized by the net deposits of the subgroup.

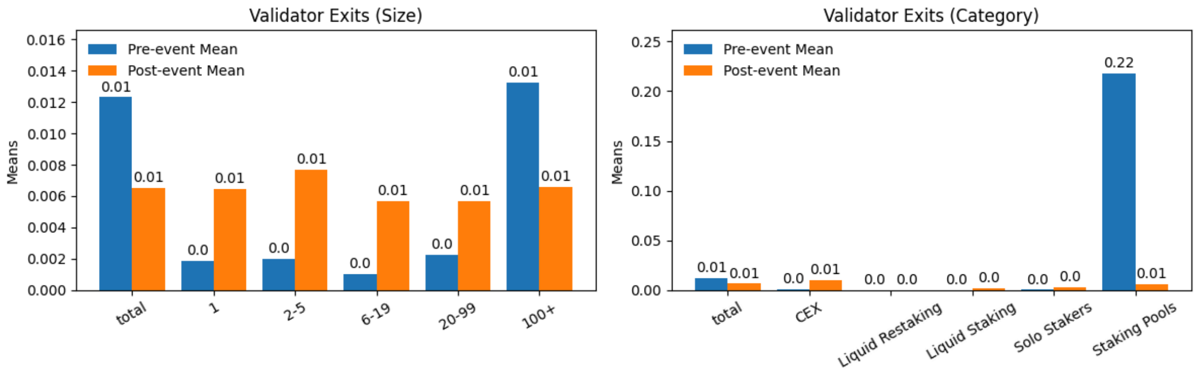

Figure 6: Validator exits one week before and after the launch of the first Bitcoin ETF. The exits have been normalized by the active validator count of the subgroup.

4. Findings and discussion

4.1. Summary of results

4.1.1. Current competitive landscape and comparing curve candidates

Under the current issuance curve, the consensus rewards increase as the pool size increases. We believe this is caused by an increase in the number of compounding periods as the pool size increases resulting in higher APY. Similarly, the median of consensus rewards increases as the pool size increases.

The median of execution rewards increases as the pool size increases. This indicates that the smallest pools rake smaller execution rewards than the largest pools. It is also important to note that when considering pools on the individual level the expected execution rewards are smaller for pools with few validators compared to bigger pools due to the variability of rewards as discussed by Anders [8].

A combination of both inferior consensus rewards and inferior execution rewards leads to a situation where the total rewards APY of our sample are 12% lower for pools with a size of 1 compared to pools with a size of 100+.

Anders proposed two issuance curve candidates that would decrease the issuance of consensus rewards. Without making additional modifications these issuance curves would lead to both an increase in the importance of execution rewards for validators leading to an increase in competitive advantage big pools have due to superior execution reward capturing, but also a decrease in a competitive advantage for big pools due to higher number of compounding periods becoming a smaller advantage. We estimate that if the sample utilized the gradual issuance curve decrease candidate the total rewards APY would have been 13% lower for pools with the size of 1 compared to pools with the size of 100+. If the sample utilized the significant issuance curve decrease candidate the total rewards APY would have been 15% lower.

Vitalik proposed an economically capped reward issuance curve in his blog post. Under this curve, the staking yield becomes negative after a certain threshold staking amount is met. Due to differences in execution rewards between different sized pools the big pools would remain profitable for longer than smaller pools under this proposal. The smallest-sized pools would have negative APY if the staked eth exceeds around 28,300,000 while the biggest-sized pools would have negative APY if the staked eth exceeds around 28,700,000. This creates a scenario where the biggest pools could operate profitably while smaller pools would be losing money.

4.1.2. Elasticity Analysis

Solo stakers are less likely to exit when Ethereum prices rise, showing resilience and a long-term commitment to staking. In contrast, staking pools and entities like Ledger Live and Mantle are more reactive to price fluctuations, possibly due to their stakers' need to manage risk and liquidity more actively. This variation underscores the different risk profiles and operational strategies among Ethereum stakers.

Smaller pools tend to reduce their validator count as staking APY increases, likely due to higher operational sensitivity to yield changes. Mid-sized pools, however, expand their validator set when their APY is higher relative to larger pools, indicating competitive behavior driven by relative yield advantages. Solo stakers show significant sensitivity to comparative yields, especially when their returns are lower than those of liquid staking categories. This highlights the importance of a relatively level competitive field to the decentralization of the Ethereum validator set. Changes in DeFi yields, on the other hand, do not significantly impact validator behavior, suggesting that validators prioritize the stability and predictability of staking over short-term yield fluctuations in DeFi platforms.

4.1.3. Event Study

The event study reveals varied validator responses to significant market events. The Rocket Pool mainnet launch did not significantly change validator deposits, indicating that new staking protocols might not immediately influence staking behavior. The FED's first major interest rate hike similarly had no significant impact, suggesting that validators are less sensitive to short-term macroeconomic fluctuations due to their long-term commitment.

However, the Ethereum Shanghai/Capella upgrade, which enabled staking withdrawals, resulted in increased deposits for larger pools and higher exit levels for categories like CEX and Liquid Staking. This underscores the importance of liquidity and flexibility in staking decisions, with larger pools benefiting more due to their better capital management capabilities. The differing responses to the opening of the staking withdrawals also may indicate differing time preferences among stakers.

The launch of the first Bitcoin ETF significantly increased validator exits across most pool sizes and categories, except for the largest pools and staking pools, which saw decreased exits. This behavior, particularly the increased exits in the retail-heavy CEX category, may reflect a "sell the news" phenomenon, where stakers capitalize on the price gains from positive news and anticipate a subsequent price correction.

4.2. Implications of the study

MEV-Burn has been widely discussed as an improvement that would decrease the importance of execution rewards for validators and the variance of execution rewards. We believe that in an ideal situation, MEV-Burn should be implemented in parallel or before a consensus reward reduction to minimize the competitive advantage the current execution rewards give to big pools. However, our analysis concludes that if the consensus rewards were decreased according to gradual or substantial consensus reward reduction curves before the implementation of MEV-Burn the competitive advantage big pools would get would be a few percentage points. On the other hand, this means that combining consensus rewards reduction even with an inefficient implementation of MEV-Burn that would, for example, burn half of the execution rewards would result in a smaller difference in percentwise total rewards between the big and small pools.

Adopting an economically capped curve proposed by Vitalik or some other economically capped issuance curve could lead to a situation where big pools operate at a profit while small pools are losing money. This could lead to a situation where big pools capture the majority of the staking market share pushing small pools out of the market leading to an oligopoly. This could happen even if MEV-Burn was highly effective as big pools could be willing to operate at a loss to gain market share.

Additionally, even if the notional yield of big pools was negative some of them could still be willing to operate at a loss if they are charging a higher management fee for staking the assets.

The elasticity analysis revealed solo stakers exhibited highly statistically significant negative elasticity for validator deposits in response to decreases in their staking yield relative to other categories like liquid restaking, liquid staking, and staking pools. This suggests solo stakers are particularly sensitive to negative changes in their yield competitiveness compared to other staking vehicles. In contrast, total staking yield changes and fluctuations in DeFi yields did not elicit such pronounced effects, highlighting the importance of balancing the relative staking yield differences among validator segments for solo stakers and smaller entities to retain their portion of the validator set.

The findings indicate addressing execution reward imbalances is crucial before implementing major issuance changes. A balanced approach involving MEV-Burn and gradual issuance adjustments may better maintain a healthy, decentralized validator ecosystem, preserving incentives for diverse participation.

5. Conclusion

The purpose of this study is to analyze the current differences in competitive advantages between stakers and what these differences would look like if a different issuance curve was adopted today, the elasticity of different stakers to identify how likely their stake is to change if issuance or other variables change, and event studies to analyze whether different stakers have changed their stake due to certain events.

This study analyzes a dataset consisting of historical beacon chain data, validator metadata, DeFi data, and Ethereum price data for the Ethereum ecosystem. The dataset spans from the genesis of the beacon chain to slot 8,984,512 on May 2, 2024, 08:22:47 AM UTC. The historical beacon chain data, acquired from Rated Network, includes deposits, withdrawals, validator activations, exits, and rewards (attestation, consensus, and execution), providing insights into validator performance metrics, staking ratios, and distribution patterns. The validator metadata, collected from Rated Network, Dune, and Etherscan, comprises validator private keys, indices, entity labels, activation/exit epochs, and deposit/withdrawal addresses, supplemented with entity labels from Dune and Etherscan for comprehensive labeling. The DeFi data, obtained from Dune and TradingStrategy.ai, includes Curve's ETH-stETH liquidity APR and historical liquidity returns for Aave v3 on WETH and wstETH, enabling the analysis of DeFi yield influence on staking decisions and lending market dynamics. Additionally, historical Ethereum market price data is acquired from CoinGecko to study price movements and their effects on validator behavior. The data is processed by grouping validators into entities, computing historical counts of active validators and exits, categorizing rewards by entity size and category, and calculating daily historical validator APYs for elasticity analysis. DeFi yield data is averaged daily, and slots are added for integration with other datasets.

This study analyzes differences in current competitive advantages between subgroups. We find that pools with a size of 100+ have 12% higher mean returns than pools with a size of 1. Assuming MEV-Burn was not implemented, gradual and substantial issuance curve reductions proposed by Anders [4] would result in competitive advantages of 13% and 15%, respectively. Due to these differences, if MEV-Burn was implemented and it was inefficient, the combination of the new consensus issuance curve and MEV-Burn would lead to a better situation where the competitive advantage of big pool operators compared to small pools would diminish. In addition, we want to point out that adopting an economically capped curve such as the one proposed by Vitalik [5] could lead to a situation where big pool operators are operating at a profit while small pools are operating at a loss due to differences in the ability to capture execution rewards.

We analyze the elasticity of stakers relative to issuance rates and different variables. We find that solo stakers are highly sensitive to decreases in their staking yield relative to other categories like liquid staking and staking pools. This suggests solo stakers are particularly vulnerable to negative changes in their yield competitiveness compared to other staking vehicles. In contrast, total staking yield changes and fluctuations in DeFi yields did not elicit such pronounced effects.

Our study also considers different staker reactions to major events. The Rocket Pool mainnet launch and the FED's first major interest rate hike did not significantly impact validator deposits, suggesting new staking protocols and macroeconomic fluctuations have limited immediate influence on staking behavior. However, the Ethereum Shanghai/Capella upgrade enabling staking withdrawals resulted in increased deposits for larger pools and higher exit levels for certain categories like CEXs and Liquid Staking providers. This highlights the importance of liquidity and capital management flexibility in staking decisions for larger entities.

The launch of the first Bitcoin ETF significantly increased validator exits across most pool sizes and categories, except for the largest pools and staking pools. This behavior, prevalent in the retail-heavy CEX category, may reflect a "sell the news" phenomenon where stakers capitalize on positive news by exiting their positions.

In conclusion, this study provides insights into the competitive dynamics, elasticities, and event responses within the Ethereum validator ecosystem. The findings underscore the importance of addressing execution reward imbalances and balancing relative staking yield differences among validator segments. A balanced approach involving MEV-Burn and gradual issuance adjustments may better maintain a healthy, decentralized validator set, preserving incentives for diverse participation. Future research could explore the impact of regulatory changes, technological advancements, and alternative staking models on validator behavior, accounting for potential time lags and non-linear effects.

5.1. Future research directions

Our study considers notional yields. Future research could extend the analysis to consider real yields in addition to notional yields.

Our study analyzes direct and linear relationships between data points. Future research could also consider non-linear relationships and time lags in effects.

The analyzed events in the event studies are limited. Future research could consider additional events. These could include launches of staking service providers incentivizing stakers to stake with them by offering airdrops. In the future, the historical dataset for validator exits will grow and offer a new dimension to event studies in addition to deposits used in most of our events. In addition, future research could also analyze the impact of events based on announcements of events happening in the future instead of the time the event actually takes place.

For geographic decentralization of the validator set, investigating regional regulatory and taxation impacts could prove insightful. Evolving regulatory frameworks and taxation policies across jurisdictions may influence stakers' operational viability, profitability, and locational preferences.

Future research could also investigate the effects of upgrades or technological improvements to staking infrastructure, such as advancements in hardware or software that could impact operational efficiencies and costs for validators.

References

[1] https://ethereum-magicians.org/t/electra-issuance-curve-adjustment-proposal/18825/
[2] https://ethresear.ch/t/endgame-staking-economics-a-case-for-targeting/18751
[3] https://notes.ethereum.org/@mikeneuder/iiii
[4] https://ethresear.ch/t/reward-curve-with-tempered-issuance-eip-research-post/19171
[5] https://notes.ethereum.org/@vbuterin/single_slot_finality#Economic-capping-of-total-deposits
[6] https://rocketpool.net/protocol/about
[7] https://ethereum.org/en/staking/withdrawals/
[8]
https://ethresear.ch/t/properties-of-issuance-level-consensus-incentives-and-variability-across-potential-reward-curves/18448

Appendices

A. Issuance Curves

Table A1

Current Issuance Curve

This table reports results on analysis of consensus and execution rewards and their differences between different entities between slots 7 984 513 and 8 984 512. Panel A reports mean, t-statistic of whether the subgroup's mean is different from dataset's mean, and median for whole dataset as well as by different pool sizes. Panel B reports the same values grouped by different categories. Panel C reports the same values for the 10 biggest pools. ***, **, and * denote statistical significance of two-sample t-test at the 1%, 5%, and 10% levels.

Panel A. Whole dataset and pools by size

	Consensus + Execution Rewards			Consensus Rewards			Execution Rewards			
Subgroup	Mean	t(Mean)	Median	Mean	t(Mean)	Median	Mean	t(Mean)	Median	N
Whole dataset	4.41%	-	4.07%	3.54%	-	3.67%	0.87%	-	0.37%	1000000
1	3.947%***	-4.59	3.95%	3.3156%***	-28.47	3.64%	0.6314%**	-2.34	0.27%	9699
2-5	4.39%	-0.2	3.97%	3.3996%***	-18.97	3.66%	0.99%	1.24	0.27%	10735
6-19	4.238%**	-2.39	4.00%	3.4673%***	-13.46	3.66%	0.77%	1.34	0.31%	19307
20-99	4.34%	-1.31	4.00%	3.5239%***	-5.43	3.66%	0.82%	-0.93	0.30%	46178
100+	4.42%	0.93	4.08%	3.5509%***	6.04	3.67%	0.87%	0.42	0.38%	914081

Panel B. Pools by category

	Consensus + Execution Rewards			Consensus Rewards			Execution Rewards			
Category	Mean	t(Mean)	Median	Mean	t(Mean)	Median	Mean	t(Mean)	Median	N
CEX	4.42%	0.58	4.09%	3.5505%***	3.75	3.67%	0.87%	0.27	0.40%	273776
uid Restaki	4.40%	-0.25	3.98%	3.4932%***	-10.98	3.59%	0.90%	0.52	0.36%	29205
Liquid Staking	4.43%	1.12	4.07%	3.5564%***	8.09	3.67%	0.88%	0.46	0.38%	357121
Solo Stakers	4.31%	-1.33	4.06%	3.5049%***	-6.28	3.69%	0.80%	-0.84	0.35%	16007
Staking Pools	4.46%	1.09	4.10%	3.5544%***	2.77	3.66%	0.91%	0.87	0.41%	46703

Panel C. Largest pools

	Consensus + Execution Rewards			Consensus Rewards			Execution Rewards			
Pool	Mean	t(Mean)	Median	Mean	t(Mean)	Median	Mean	t(Mean)	Median	N
Lido	4.444%*	1.65	4.07%	3.5642%***	12.65	3.67%	0.88%	0.64	0.38%	312012
Coinbase	4.42%	0.17	4.10%	3.5327%***	-5.25	3.67%	0.88%	0.6	0.40%	147345

Binance	4.47%	1.19	4.11%	3.5973%***	13.23	3.68%	0.87%	0.14	0.40%	39461
Rocketpool	4.2986%*	-1.86	4.05%	3.4655%***	-16.3	3.66%	0.83%	-0.57	0.36%	27308
Kraken	4.39%	-0.4	4.07%	3.5613%***	3.48	3.68%	0.83%	-0.67	0.37%	25731
OKX	4.53%	1.43	4.12%	3.5937%***	7.94	3.70%	0.93%	0.81	0.40%	15914
Bitcoin Suisse	4.40%	-0.11	4.10%	3.5265%***	-2.78	3.68%	0.88%	0.11	0.41%	15462
Ledger Live	4.52%	1.29	4.14%	3.55%	0.38	3.67%	0.97%	1.26	0.45%	14977
Ether.Fi	4.29%	-1.45	3.99%	3.4688%***	-11.53	3.59%	0.82%	-0.55	0.38%	14258
Mantle	4.40%	-0.08	4.05%	3.54%	-0.13	3.64%	0.86%	-0.07	0.39%	12962

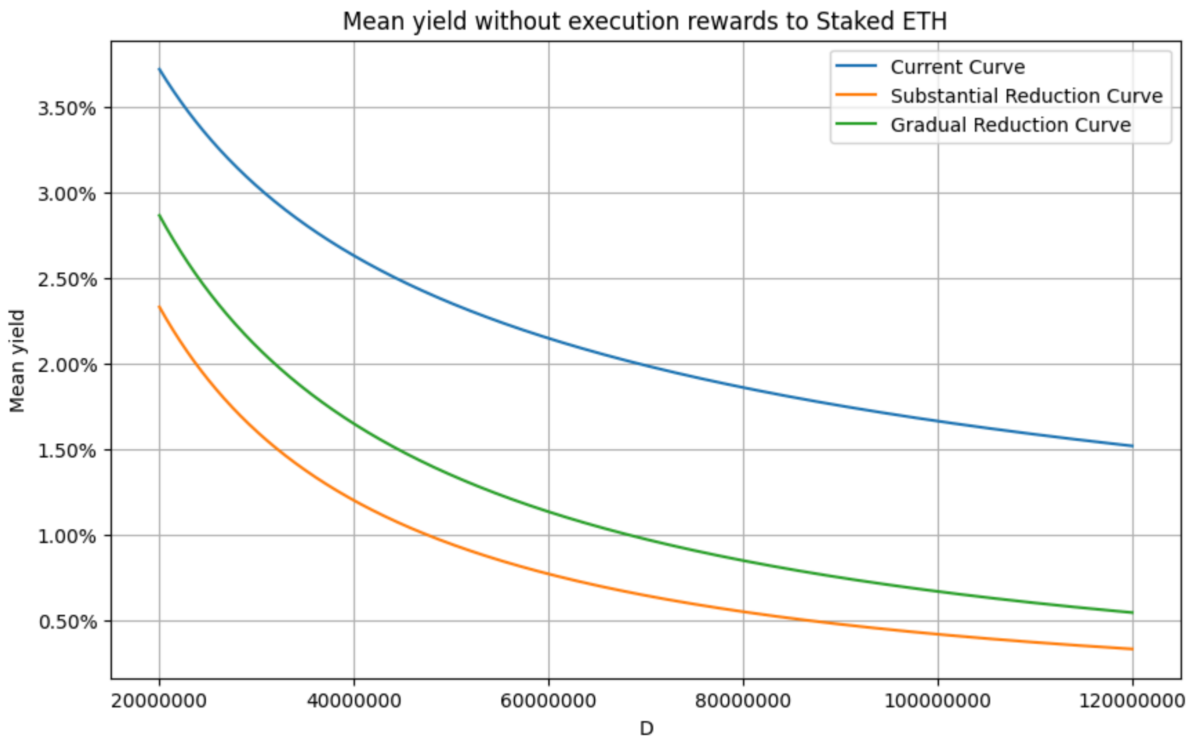

Figure A1: Mean yield of different issuance curves without execution rewards

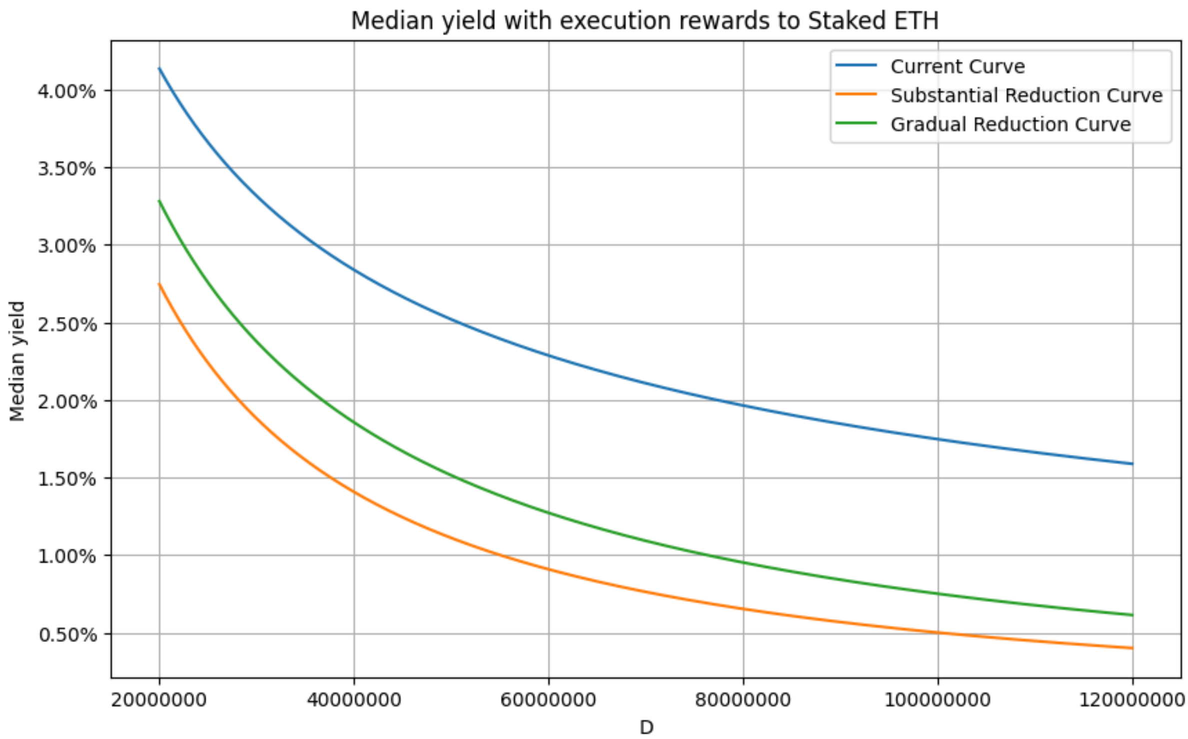

Figure A2: Median yield of different issuance curves with execution rewards

B. Elasticity

Table B1

Ethereum Price Elasticity

This table reports elasticity estimates of validator exits, validator deposits, and the change in total validator count with respect to the price of Ethereum hourly between slots 6,206,400 and 8,985,900. Panel A reports the mean elasticity, t-static, and standard deviation for the whole dataset as well as by different pool sizes. Panel B reports the same values grouped by different categories of staking entities. Panel C reports the same values for the largest individual staking pools. ***, **, and * denote statistical significance of two-sample t-test at the 1%, 5%, and 10% levels against a null hypothesis of no elasticity difference compared to the whole dataset.

Panel A. Whole dataset and pools by size										
	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
Whole dataset	0.096	-	6.2555	0.0001	-	0.1859	-0.0275	-	10.6454	9266
1	-0.0166	-0.95	9.589	0.0005	0.18	0.1892	-0.0949	-0.22	27.4506	9266
2-5	-0.0541	-1.18	10.5836	0.0022	0.71	0.2129	-0.1582	-0.56	19.653	9266
6-19	0.0704	-0.16	14.5326	0.0012	0.32	0.2821	0.1464	0.56	27.824	9266
20-99	0.158	0.40	13.5522	-0.0015	-0.51	0.2217	0.2849	0.85	33.5914	9266
100+	0.0959	0.00	6.6641	0.0001	0.00	0.1932	-0.0427	-0.09	11.289	9266
Panel B. Pools by category										
	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
CEX	0.1351	0.26	13.0568	0.0023	0.69	0.2536	0.1432	0.70	20.9308	9266
Liquid Restaking	0.5032	1.41	27.0534	-0.0802	-0.79	9.8377	-6.2982*	-1.83	329.957	9266
Liquid Staking	0.0036	-1.12	4.939	-0.0021	-0.76	0.2054	-0.2414	-1.16	14.282	9266
Solo Stakers	-0.4031***	-2.78	16.1427	-0.0003	-0.11	0.2366	0.3272	1.55	19.2289	9266
Staking Pools	1.1772*	1.81	57.1452	-0.0006	-0.14	0.4081	0.0617	0.12	71.6029	9266
Panel C. Largest pools										
	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
Lido	-0.0585**	-1.99	4.1272	-0.0039	-1.40	0.2002	-0.1621	-0.70	15.0589	9266
Coinbase	0.1259	0.29	7.5226	0.0045	1.02	0.3757	0.0886	0.40	25.5882	9267
Binance	-0.7476*	-1.92	41.7772	-0.0011	-0.18	0.6107	0.6435	1.45	43.26	9268
Rocketpool	0.1379	0.22	17.62	-0.0001	-0.04	0.2341	-0.3758	-0.72	45.0988	9269
Kraken	0.2409	0.71	18.4889	0.0047	0.93	0.4438	-0.0744	-0.15	27.7324	9270
OKX	-0.0626	-0.72	20.19	0.0062	0.85	0.6754	-1.0009*	-2.57	34.9165	9271

							**			
Bitcoin Suisse	-0.0177*	-1.70	1.4897	-0.0014	-0.62	0.1191	4.0668***	3.00	131.111	9272
Ledger Live	4.1524*	1.96	199.5568	0.0094	1.06	0.8268	-3.3666	-1.46	219.6608	9273
Ether.Fi	7.0115	1.61	310.6214	0.3372	1.30	18.804	-25.0225	-0.18	9893.341	5247
Mantle	6.8474*	1.68	281.1932	-0.0154	-0.06	17.2844	-7.2857	-0.33	1553.384	4887
Other Stakers	0.0594	-0.33	8.8241	0.0013	0.36	0.2848	0.0412	0.29	20.3249	9276

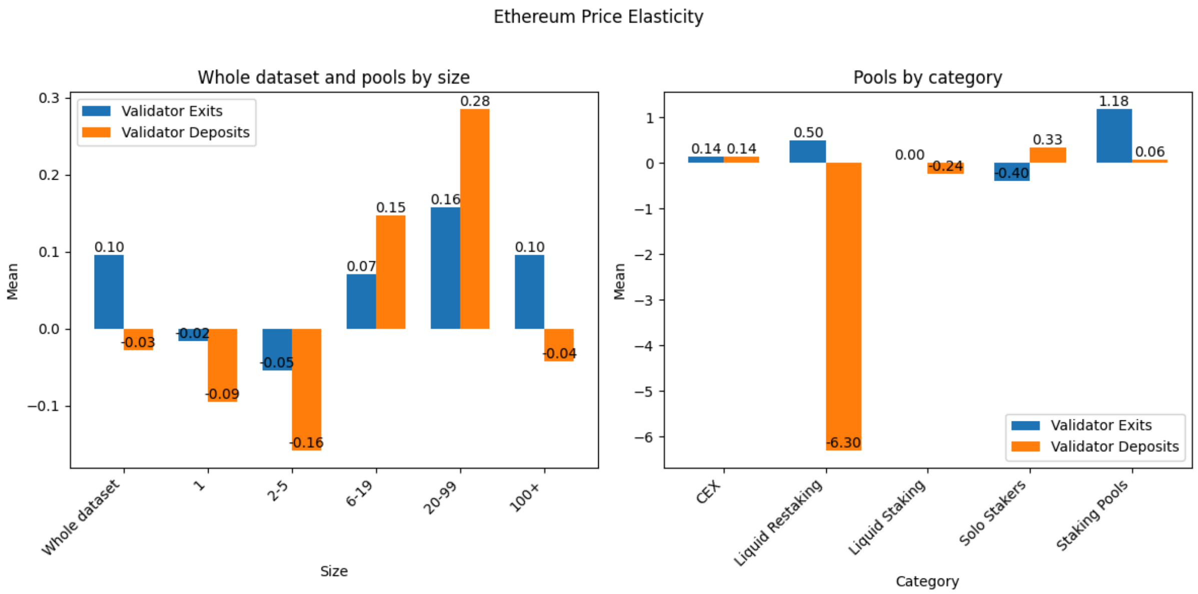

Figure B1: Validator exits and total count change relative to Ethereum price. The amounts are normalized relative to subgroups.

Table B2

Staking APY Elasticity

This table reports elasticity estimates of validator exits, validator deposits, and the change in total validator count with respect to the staking APY daily between slots 6,840,000 and 8,985,600. Panel A reports the mean elasticity, t-static, and standard deviation for the whole dataset as well as by different pool sizes. Panel B reports the same values grouped by different categories of staking entities. Panel C reports the same values for the largest individual staking pools. ***, **, and * denote statistical significance of two-sample t-test at the 1%, 5%, and 10% levels against a null hypothesis of no elasticity difference compared to the whole dataset.

Panel A. Whole dataset and pools by size

	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
Whole dataset	14.4308	-	218.4485	56.9506	-	685.5406	3.8742	-	42.8035	298
1	5.0082	-0.71	66.3333	-3.3040	-1.50	111.7696	-0.1657	-1.60	7.5863	298
2-5	12.4533	-0.10	253.6697	-1.1851	-1.44	129.013	-0.4600*	-1.68	12.089	298

6-19	-8.3294	-1.51	141.909	-4.8866	-1.43	295.6051	-1.1733*	-1.67	29.9475	298
20-99	106.5238	0.87	1810.773	74.5275	0.28	850.2656	-21.0260	-1.08	397.4911	298
100+	123.2935	0.69	2723.667	852.7969	1.00	13757.4837	-27.3605	-1.09	491.6845	298
Panel B. Pools by category										
	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
CEX	-12.9753	-0.45	560.8725	41.7387	1.52	370.1452	2.5641	1.08	20.8675	298
Liquid Restaking	0.4965	-0.16	25.6381	-189.6798	-1.31	2395.1657	-27.9477	-1.02	478.8957	298
Liquid Staking	-5.1982	-0.47	201.5205	-4.0196	0.04	287.5772	-0.8883	-0.67	25.3425	298
Solo Stakers	-8.3848	-0.81	127.9088	-1.6572	0.15	30.3316	1.2195	0.37	21.5389	298
Staking Pools	0.5033	-0.11	195.7062	-22.1302	-0.62	281.7663	0.1264	-0.20	19.8394	298
Panel C. Largest pools										
	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
Lido	-6.9421	0.57	178.3498	0.5916	0.40	262.9217	0.1009	0.32	12.1665	298
Coinbase	12.6800	0.83	500.8729	26.1315	0.60	992.6826	2.3591	1.06	33.5537	298
Binance	-15.6369	0.42	183.3799	4.8730	0.48	123.9306	1.6150	0.96	19.5617	298
Rocketpool	-6.1248	0.59	116.7748	0.3977	0.41	61.1904	1.3612	0.95	8.8483	298
Kraken	21.0061	0.99	437.8077	48.7953	1.00	633.8088	0.9299	0.63	23.3169	298
OKX	-9.5339	0.53	124.2035	-21.2453	0.08	272.3651	0.1488	0.36	5.9919	298
Bitcoin Suisse	9.6249	0.88	128.8742	1.9622	0.43	51.9266	-0.0048	0.27	11.6407	298
Ledger Live	36.5668	1.22	493.7663	39.6782	0.90	559.0886	0.0505	0.30	9.3323	298
Ether.Fi	-2.2131	0.67	23.7612	-506.3010	-0.87	8034.9361	0.6125	0.53	15.2424	217
Mantle	2.9227	0.76	54.2478	-29.1855	0.00	7194.892	-0.2379	0.15	12.0873	203
Other Stakers	21.3271	1.06	231.8739	138.3665	1.41	1676.2228	0.0246	0.20	37.1115	298

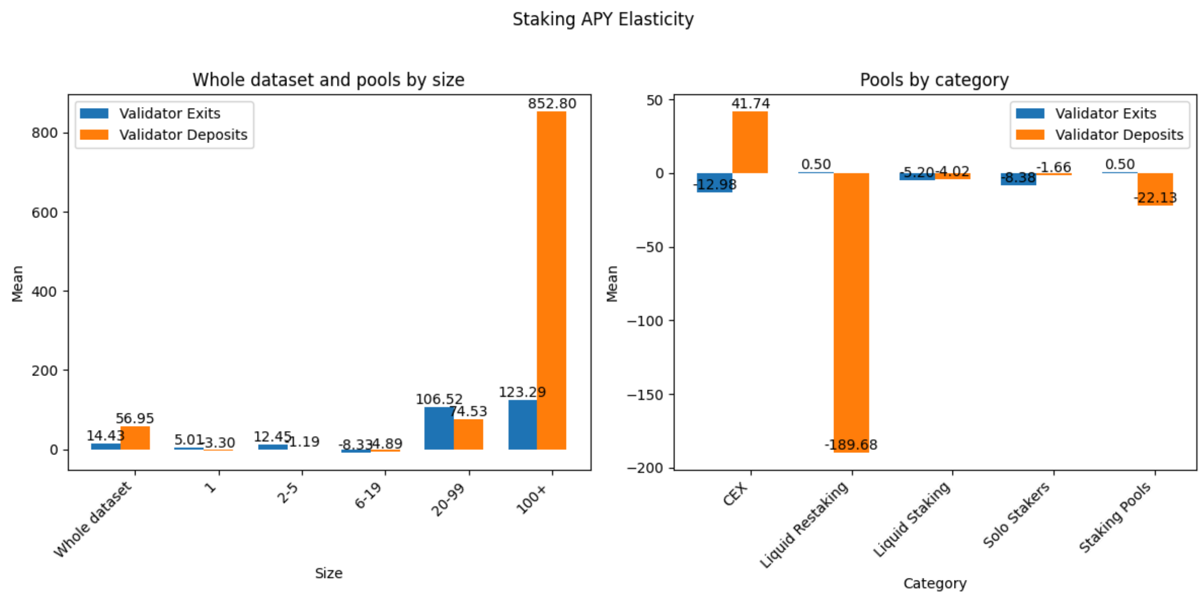

Figure B2: Validator exits and total count change relative to staking APY. The amounts are normalized relative to subgroups.

Table B3

Staking APY Difference Elasticity of Small and Solo Stakers

This table reports elasticity estimates of validator exits, validator deposits, and the change in total validator count with respect to the staking APY difference between stakers daily between slots 6,840,000 and 8,985,600. Panel A reports the mean elasticity, t-static, and standard deviation for the whole dataset as well as by different pool sizes. Panel B reports the same values grouped by different categories of staking entities. Panel C reports the same values for the largest individual staking pools. ***, **, and * denote statistical significance of one-sample t-test at the 1%, 5%, and 10% levels against a null hypothesis of no elasticity difference compared to the whole dataset.

Panel A. Pools by size compared to 100+

	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
1	0.8184	1.20	11.7467	69.2844	1.29	928.9801	0.004	0.16	0.4305	298
2-5	0.0629	0.77	1.4042	2.9616	0.79	64.7791	0.0014	0.15	0.156	298
6-19	0.1686	0.49	5.9964	-14.039	-1.08	223.8343	-0.0068	-0.58	0.202	298
20-99	-0.195	-0.82	4.1246	-5.9817	-0.80	129.7086	0.0616*	1.89	0.561	298

Panel B. Solo Stakers compared to other categories

	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
CEX	0.1204	1.24	1.676	-0.9661	-1.16	14.3917	-0.0006	-0.11	0.0922	298
Liquid Restaking	-0.0774	-1.22	1.0938	-0.9277**	-2.27	7.0447	-0.0032	-0.86	0.064	298
Liquid Staking	0.2681	1.39	3.3198	-0.9153*	-1.87	8.4538	-0.0057	-0.80	0.1228	298
Staking Pools	0.3922	0.95	7.1359	-1.274**	-2.35	9.3765	-0.0136	-1.08	0.2186	298

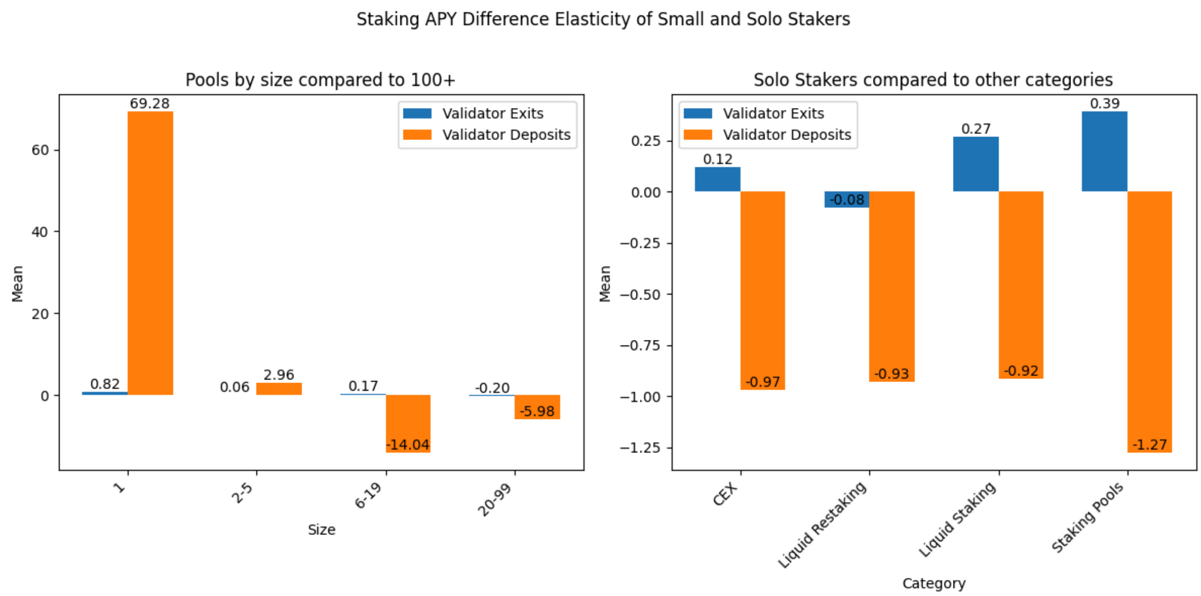

Figure B3: Validator exits and total count change relative to staking APY difference of small and solo stakers. The amounts are normalized relative to subgroups.

Table B4

Aave v3 WETH Supply APR Elasticity

This table reports elasticity estimates of validator exits, validator deposits, and the change in total validator count with respect to the Aave v3 WETH Supply APR daily between slots 6,206,400 and 8,985,600. Panel A reports the mean elasticity, t-static, and standard deviation for the whole dataset as well as by different pool sizes. Panel B reports the same values grouped by different categories of staking entities. Panel C reports the same values for the largest individual staking pools. ***, **, and * denote statistical significance of two-sample t-test at the 1%, 5%, and 10% levels against a null hypothesis of no elasticity difference compared to the whole dataset.

Panel A. Whole dataset and pools by size

	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
Whole dataset	-0.2077	-	5.7005	0.0051	-	0.1428	-0.0473	-	4.0027	387
1	-0.1536	0.17	2.9008	0.0014	-0.50	0.0306	0.2537	1.09	3.6612	387
2-5	0.1275	0.81	5.8543	-0.0019	-0.92	0.0394	-0.4217	-0.79	8.4595	387
6-19	0.379	1.34	6.4486	0.0021	-0.37	0.0691	-0.5132	-0.98	8.4703	387
20-99	-0.2984	-0.27	3.2713	0.0016	-0.41	0.0844	0.1252	0.52	5.1453	387
100+	-0.2214	-0.03	6.1878	0.0055	0.04	0.1523	-0.0427	0.02	4.4229	387

Panel B. Pools by category

	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
CEX	-1.0142	-0.77	19.8695	0.005	0.00	0.2562	0.736	0.73	20.7499	387
Liquid Restaking	-0.0201	0.65	0.3956	0.0042	-0.02	1.1935	0.2612	0.22	27.5972	387
Liquid Staking	0.029	0.69	3.5453	0.0037	-0.18	0.0551	0.1547	0.45	7.9588	387
Solo Stakers	-0.3923	-0.40	7.196	0.0029	-0.29	0.0439	0.2121	0.60	7.4822	387
Staking Pools	0.652	0.68	24.3983	0.016	0.83	0.2142	-1.0075	-0.76	24.6376	387

Panel C. Largest pools

	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
Lido	0.1727	1.14	3.2087	0.0037	-0.18	0.0576	0.1771	0.47	8.3925	387
Coinbase	-0.0481	0.54	1.2338	0.0054	0.01	0.3752	-0.3808	-0.58	10.4889	387
Binance	-6.7885	-0.99	130.431	0.0028	-0.29	0.0556	6.7009	1.02	130.4586	387
Rocketpool	-0.0959	0.33	3.5718	0.0103	0.36	0.2444	-0.1068	-0.17	5.6388	387
Kraken	0.2371	1.13	5.2252	-0.0117	-1.21	0.2321	0.413	0.42	21.2743	387
OKX	-2.999	-0.99	55.2635	0.0021	-0.40	0.0341	3.4799	1.25	55.5155	387

Bitcoin Suisse	0.0183	0.77	0.8265	-0.0002	-0.72	0.004	-0.2636	-0.59	6.0359	387
Ledger Live	-0.1581	0.17	1.3094	0.0241	0.75	0.48	-0.3288	-0.45	11.5039	387
Ether.Fi	0	0.72	0	0.1674	0.98	2.447	-1	-0.57	24.5197	219
Mantle	7.9208	1.00	115.633	-0.0003	-0.74	0.0126	-8.0955	-0.99	116.2026	204
Other Stakers	0.1449	0.90	5.1361	0.0066	0.12	0.2174	-0.882	-1.57	9.6589	387

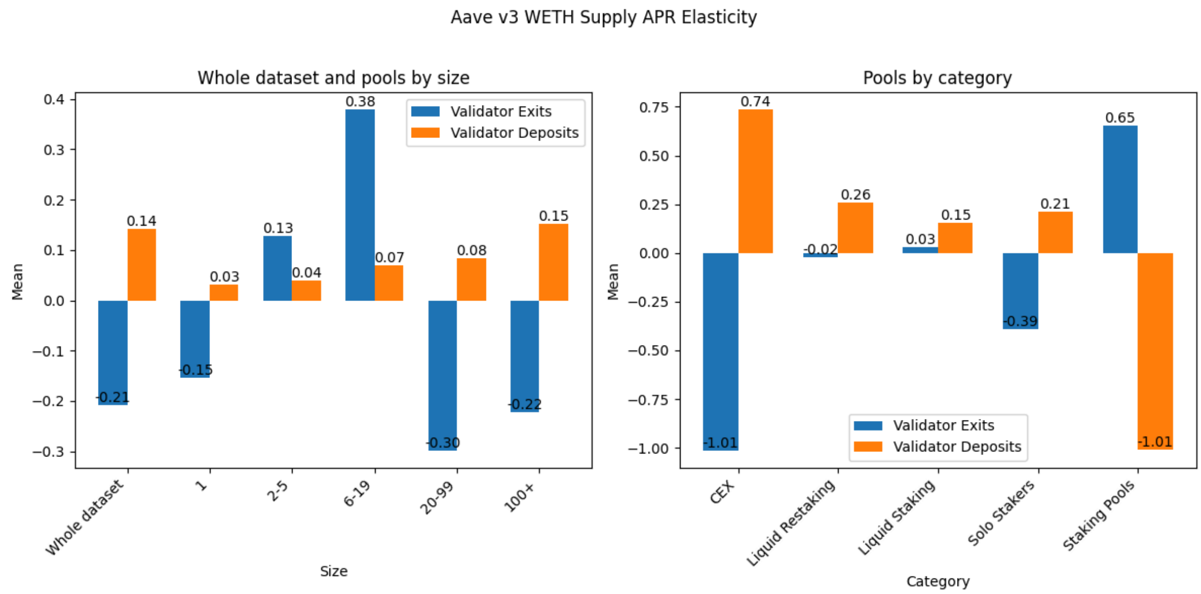

Figure B4: Validator exits and total count change relative to Aave v3 WETH supply APR. The amounts are normalized relative to subgroups.

Table B5										
Curve stETH-WETH Liquidity APR Elasticity										
This table reports elasticity estimates of validator exits, validator deposits, and the change in total validator count with respect to the Curve stETH-WETH Liquidity APR daily between slots 6,206,400 and 8,985,600. Panel A reports the mean elasticity, t-static, and standard deviation for the whole dataset as well as by different pool sizes. Panel B reports the same values grouped by different categories of staking entities. Panel C reports the same values for the largest individual staking pools. ***, **, and * denote statistical significance of two-sample t-test at the 1%, 5%, and 10% levels against a null hypothesis of no elasticity difference compared to the whole dataset.										
Panel A. Whole dataset and pools by size										
	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
Whole dataset	0.1266	-	2.6925	0.001	-	0.0433	0.0665	-	2.3916	387
1	0.2182	0.37	4.0394	0.0014	0.16	0.0285	-0.1807	-0.93	4.6424	387
2-5	0.1609	0.20	2.102	0.0024	0.48	0.0384	-0.2801	-1.56	3.65	387
6-19	0.0169	-0.66	1.8142	0.0019	0.26	0.0534	-0.0129	-0.40	3.1066	387
20-99	1.0467	0.86	20.8397	0.0008	-0.08	0.0091	-1.3049	-1.32	20.2786	387
100+	0.0817	-0.27	1.9394	0.001	0.00	0.0461	0.1426	0.37	3.2961	387
Panel B. Pools by category										
	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
CEX	0.0577	-0.46	1.1206	0.0012	0.05	0.06	-0.1034	-1.15	1.654	387
Liquid Restaking	-0.0076	-0.98	0.1493	0.0268	1.37	0.3677	12.9867	1.17	217.5147	387
Liquid Staking	-0.0819	-1.29	1.6898	-0.0003	-0.31	0.0716	0.2465	0.83	3.5507	387
Solo Stakers	0.0787	-0.32	1.1593	0.0045	0.71	0.0873	-0.1044	-1.26	1.1847	387
Staking Pools	-0.0771	-1.25	1.7511	0.0058	0.89	0.0968	0.0371	-0.13	3.7352	387
Panel C. Largest pools										
	Validator Exits			Validator Deposits			Validator Total Count Change			
Size	Mean	t(Mean)	SD	Mean	t(Mean)	SD	Mean	t(Mean)	SD	N
Lido	-0.1035	-1.36	1.9416	-0.0005	-0.32	0.0807	-0.0035	-0.43	2.112	387
Coinbase	0.0852	-0.27	1.3842	0.0045	0.58	0.1102	-0.0155	-0.48	2.403	387
Binance	-0.0958	-1.37	1.6979	0.0003	-0.31	0.0062	0.0654	-0.01	2.0653	387
Rocketpool	0.0351	-0.61	1.1591	0.0008	-0.07	0.0496	1.1243	1.31	15.7073	387
Kraken	0.2545	0.43	5.125	0.0007	-0.12	0.0091	-0.2991	-1.18	5.6093	387
OKX	0.1886	0.28	3.357	0.0007	-0.13	0.0131	-0.6449	-1.42	9.5604	387
Bitcoin Suisse	0.2126	0.38	3.5883	0	-0.44	0.0005	-0.2858	-1.53	3.8548	387

Ledger Live	0.0374	-0.64	0.4942	0.0063	0.71	0.1398	-0.3105	-0.84	8.4885	387
Ether.Fi	0	-0.92	0	-0.004	-0.84	0.0814	48.8121	1.07	676.989 6	219
Mantle	3.4748	0.98	48.5938	0.0003	-0.32	0.0044	-4.0207	-1.16	50.2721	204
Other Stakers	0.3703	0.64	7.0348	0.0012	0.07	0.0304	-0.3065	-1.43	4.5327	387

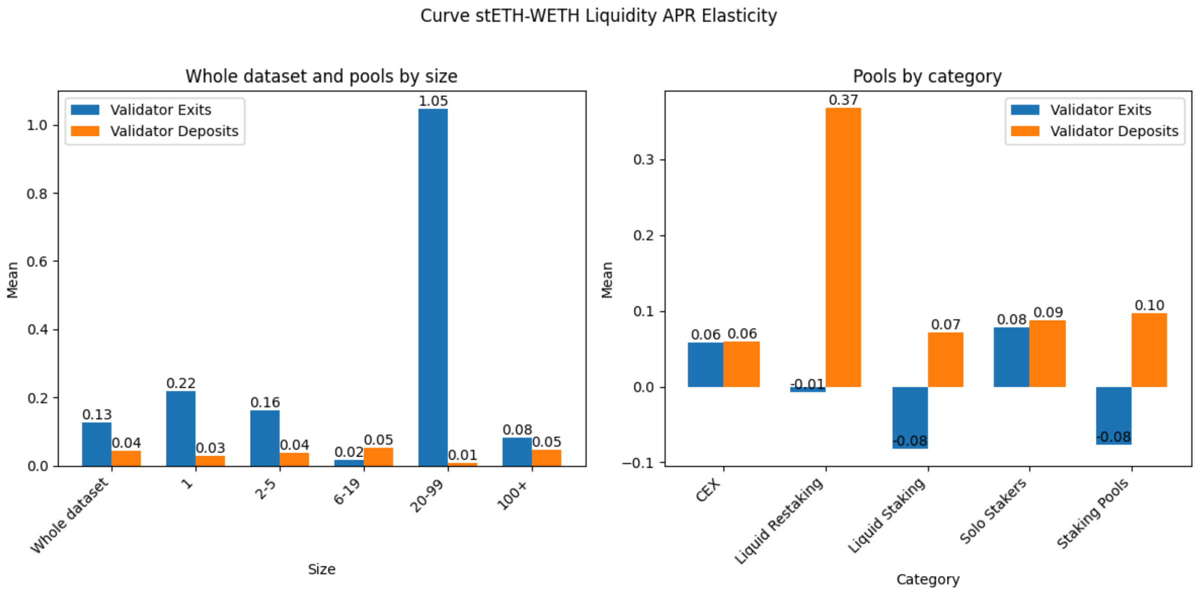

Figure B5: Validator exits and total count change relative to Curve stETH-WETH liquidity APR. The amounts are normalized relative to subgroups.

C. Event studies

Table C1						
Rocket Pool Mainnet Launch						
This table reports the results of an event study analyzing the impact of the Rocket Pool Mainnet launch (slot 2,466,000) on validator deposits. The study uses one-week (50,400 slots) pre-event and post-event windows and calculates the values on an hourly level. Panel A presents the mean and standard deviation of the result for the full dataset and across different pool sizes, both before and after the event. Panel B reports the same metrics grouped by different staking entity categories. ***, **, and * denote statistical significance of two-sample t-test at the 1%, 5%, and 10% levels against a null hypothesis of no elasticity difference compared to the whole dataset.						
Panel A. Whole dataset and pools by size						
	Validator Deposits					
Size	Mean Pre-Event	SD Pre-Event	Mean Post-Event	SD Post-Event	t(Mean)	N
Whole dataset	0.2548	1.4151	0.1122	0.367	-	336
1	0.1754	1.0944	0.0984	0.4397	1.30	336
2-5	0.1333	0.5096	0.1154	0.3958	0.38	336
6-19	0.9198	9.9784	0.1645	0.8117	0.77	336
20-99	0.0675	0.5291	0.1162	0.7107	-0.88	336
100+	0.2481	1.3135	0.11	0.397	-0.28	336
Panel B. Pools by category						
	Validator Deposits					
Size	Mean Pre-Event	SD Pre-Event	Mean Post-Event	SD Post-Event	t(Mean)	N
CEX	0.3195	1.6385	0.1714	0.6762	0.49	336
Liquid Restaking	-	-	-	-	-	0
Liquid Staking	0.2922	3.7477	0.0287	0.1682	-0.62	336
Solo Stakers	0.187	1.5944	0.1386	0.7611	-0.15	336
Staking Pools	0	0	0.0183	0.2014	-1.40	336

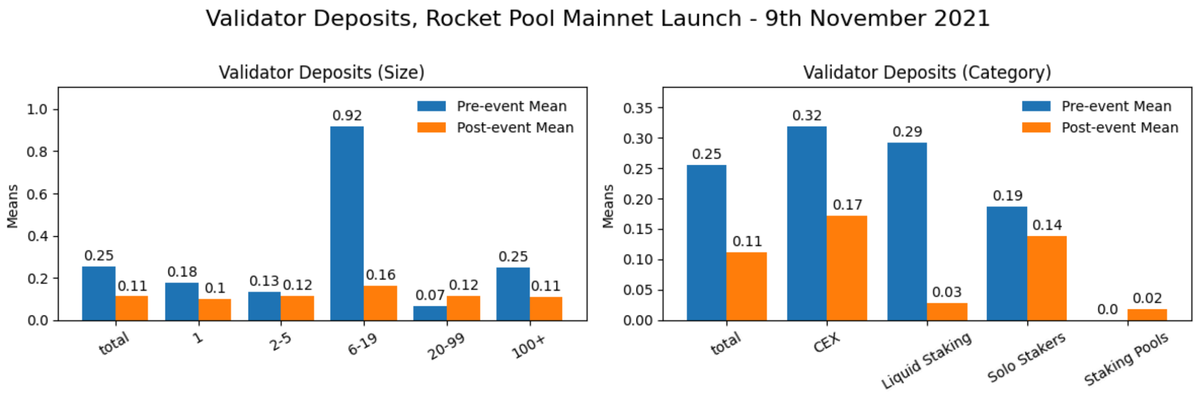

Figure C1: Validator deposits one week before and after Rocket Pool mainnet launch. The deposits have been normalized by the net deposits of the subgroup.

Table C2						
First FED 0.75% Rate Hike						
This table reports the results of an event study analyzing the impact of the first FED 0.75% rate hike (slot 4,042,800) on validator deposits. The study uses one-week (50,400 slots) pre-event and post-event windows and calculates the values on an hourly level. Panel A presents the mean and standard deviation of the result for the full dataset and across different pool sizes, both before and after the event. Panel B reports the same metrics grouped by different staking entity categories. ***, **, and * denote statistical significance of two-sample t-test at the 1%, 5%, and 10% levels against a null hypothesis of no elasticity difference compared to the whole dataset.						
Panel A. Whole dataset and pools by size						
	Validator Deposits					
Size	Mean Pre-Event	SD Pre-Event	Mean Post-Event	SD Post-Event	t(Mean)	N
Whole dataset	0.1105	0.5944	0.0903	0.3435	-	336
1	0.0711	0.2864	0.0506	0.2134	-0.77	336
2-5	0.0791	0.3326	0.1383	0.5297	-1.23	336
6-19	0.0821	0.4884	0.0688	0.3269	-0.41	336
20-99	0.1024	0.7906	0.0554	0.2544	0.06	336
100+	0.113	0.6515	0.0925	0.3704	0.66	336
Panel B. Pools by category						
	Validator Deposits					
Size	Mean Pre-Event	SD Pre-Event	Mean Post-Event	SD Post-Event	t(Mean)	N
CEX	0.2408	1.5392	0.1547	0.7567	0.98	336
Liquid Restaking	-	-	-	-	-	0
Liquid Staking	0.0193	0.0755	0.0206	0.0864	-0.23	336
Solo Stakers	0.0962	0.5656	0.4518	3.7664	-0.87	336
Staking Pools	0	0	0	0	-	336

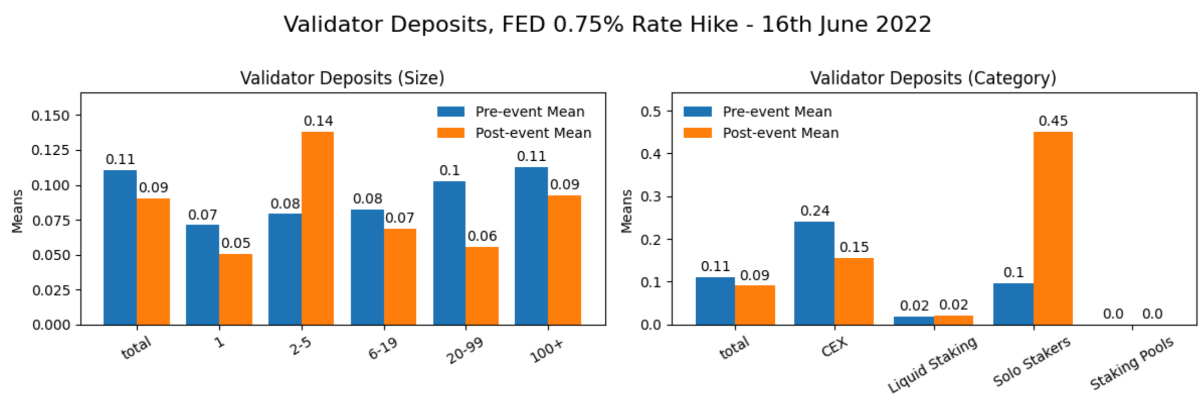

Figure C2: Validator deposits one week before and after the first 0.75% rate hike of the Federal Reserve. The deposits have been normalized by the net deposits of the subgroup.

Table C3

Ethereum Staking Withdrawals Open

This table reports the results of an event study analyzing the impact of the Ethereum staking withdrawals opening (slot 6,202,800) on validator deposits. The study uses one-week (50,400 slots) pre-event and post-event windows and calculates the values on an hourly level. Panel A presents the mean and standard deviation of the result for the full dataset and across different pool sizes, both before and after the event. Panel B reports the same metrics grouped by different staking entity categories. ***, **, and * denote statistical significance of two-sample t-test at the 1%, 5%, and 10% levels against a null hypothesis of no elasticity difference compared to the whole dataset.

Panel A. Whole dataset and pools by size						
	Validator Deposits					
Size	Mean Pre-Event	SD Pre-Event	Mean Post-Event	SD Post-Event	t(Mean)	N
Whole dataset	0.1059	0.2919	0.529	1.6221	-	336
1	0.1293	1.0617	0.2239	0.6801	1.19	336
2-5	0.0677	0.2666	0.3332	0.9785	0.04	336
6-19	0.1177	0.5851	0.5543	1.6367	-0.67	336
20-99	0.1001	0.4286	0.8990**	3.6011	-2.07	336
100+	0.1062	0.297	0.5160*	1.6456	1.88	336
Panel B. Pools by category						
	Validator Deposits					
Size	Mean Pre-Event	SD Pre-Event	Mean Post-Event	SD Post-Event	t(Mean)	N
CEX	0.1445	0.4588	0.3882***	1.5009	3.53	336
Liquid Restaking	-	-	-	-	-	0
Liquid Staking	0.0828	0.2841	0.311	1.1248	0.13	336
Solo Stakers	0.0141	0.0761	0.4123**	2.0632	-2.44	336
Staking Pools	0.0706	0.4228	0.2953	0.9209	0.46	336

Table C4

Bitcoin ETF Launch

This table reports the results of an event study analyzing the impact of the Bitcoin ETF launch (slot 8,175,600) on validator deposits and exits. The study uses one-week (50,400 slots) pre-event and post-event windows and calculates the values on an hourly level. Panel A presents the mean and standard deviation of the result for the full dataset and across different pool sizes, both before and after the event. Panel B reports the same metrics grouped by different staking entity categories. ***, **, and * denote statistical significance of two-sample t-test at the 1%, 5%, and 10% levels against a null hypothesis of no elasticity difference compared to the whole dataset.

Panel A. Whole dataset and pools by size

	Validator Exits					Validator Deposits					
Size	Mean Pre-Event	SD Pre-Event	Mean Post-Event	SD Post-Event	t(Mean)	Mean Pre-Event	SD Pre-Event	Mean Post-Event	SD Post-Event	t(Mean)	N
Whole dataset	0.0123	0.0037	0.0065	0.0063	-	0.2195	0.6904	0.2361	0.6867	0	336
1	0.0019	0.0085	0.0065***	0.0143	-4.11	0.2331	0.7646	0.1888	0.5538	0.81	336
2-5	0.002	0.011	0.0077***	0.0189	-3.57	0.1974	0.5978	0.2052	0.6242	0.64	336
6-19	0.001	0.0053	0.0057***	0.0166	-2.96	0.2119	0.7318	0.198	0.7447	1.64	336
20-99	0.0022	0.0134	0.0057**	0.0225	-2.20	0.5159	4.3083	0.1574	0.8221	1.00	336
100+	0.0133	0.0042	0.0066***	0.0066	6.48	0.2056	0.6566	0.2416*	0.7181	-2.04	336

Panel B. Pools by category

	Validator Exits					Validator Deposits					
Size	Mean Pre-Event	SD Pre-Event	Mean Post-Event	SD Post-Event	t(Mean)	Mean Pre-Event	SD Pre-Event	Mean Post-Event	SD Post-Event	t(Mean)	N
CEX	0.0012	0.0056	0.0102***	0.0158	-9.35	0.1278	0.4419	0.1589	0.542	-0.77	336
Liquid Restaking	0	0	0	0	-	6.612	6.612	3.5688**	14.0832	2.40	336
Liquid Staking	0.0002	0.001	0.0021***	0.007	-3.55	0.1503	0.8737	0.0938*	0.5747	1.87	336
Solo Stakers	0.0004	0.0042	0.0027**	0.0144	-2.59	0.0546	0.5662	0.0248	0.1457	0.81	336
Staking Pools	0.2178	0.0922	0.0057***	0.021	24.63	0.7776	3.8646	1.3224	7.5208	-0.43	336