Leverage Staking with Liquid Staking Derivatives (LSDs): Opportunities and Risks

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Abstract. Lido, the leading Liquid Staking Derivative (LSD) provider on Ethereum, allows users to stake an arbitrary amount of ETH to receive stETH, which can be integrated with Decentralized Finance (DeFi) protocols such as Aave. The composability between Lido and Aave enables a novel strategy called “leverage staking”, where users stake ETH on Lido to acquire stETH, utilize stETH as collateral on Aave to borrow ETH, and then restake the borrowed ETH on Lido. Users can iteratively execute this process to optimize potential returns based on their risk profile. This paper systematically studies the opportunities and risks associated with leverage staking. We are the first to formalize the leverage staking strategy within the Lido–Aave ecosystem. Our empirical study identifies 262 leverage staking positions on Ethereum, with an aggregated staking amount of 295,243 ETH (482M USD). We discover that 90.13% of leverage staking positions have achieved higher returns than conventional staking. Furthermore, we perform stress tests to evaluate the risk introduced by leverage staking under extreme conditions. We find that leverage staking significantly amplifies the risk of cascading liquidations. We hope this paper can inform and encourage the development of robust risk management approaches to protect the Lido–Aave LSD ecosystem.

1 Introduction

The Ethereum blockchain recently underwent the transition from Proof-of-Work (PoW) [25] to Proof-of-Stake (PoS) [12,20,4,21] to achieve a more sustainable consensus mechanism. In the PoS-based Ethereum, a validator stakes ETH to secure the system [6,18] and receives staking rewards. Nonetheless, solo staking poses significant entry barriers, demanding capital commitment of 32 ETH and technical expertise for maintaining a validator node. Additionally, staked ETH becomes illiquid during the staking period, restricting its availability for trading.

To address these challenges, Liquid Staking Derivatives (LSDs) emerged. Retail users can stake an arbitrary amount of ETH on liquid staking platforms, receiving LSDs in return [19,22]. LSDs are fungible and tradable representations of the staked ETH and the associated rewards. At present, Lido stands as the leading LSD provider in terms of Total Value Locked (TVL) (13.8B USD) [3].

Users can stake ETH on Lido to receive stETH, earning a staking Annual Percentage Rate (APR) of 3.8%\(^4\). stETH can be integrated with DeFi lending platforms such as Aave or Decentralized Exchanges (DEXs) such as Curve. The Aave–Lido LSD ecosystem allows users to earn rewards on their staked ETH while still being utilized as collateral on Aave.\(^5\) The compositability between Lido and Aave enables a novel strategy known as “leverage staking”, where users stake ETH on Lido to receive stETH, which is then used as collateral on Aave to borrow ETH, subsequently restaked on Lido. A financially rational user can iteratively execute this process to optimize potential returns based on their risk profile.

While yielding higher returns, leverage staking also introduces potential risks. Under adverse market conditions that result in a significant stETH price decline, the Aave–Lido LSD ecosystem becomes vulnerable to “cascading liquidations”, a phenomenon where multiple liquidations occur successively, causing a downward spiral in the stETH price. Yet the opportunities and risks associated with leverage staking remain relatively unexplored in academic research. To close this gap, this paper provides a systematic study of the leverage staking strategy with LSDs, shedding light on its mechanics, potential benefits for users, and inherent risks for stakeholders, while investigating its implications for the broader DeFi ecosystem.

We summarize the main contributions of this paper as follows.

- **Strategy Formalization.** We establish a formal framework for leverage staking with stETH, deriving the leverage multiplier and leverage staking APR. To our knowledge, we are the first to model leverage staking strategy with LSDs.

- **Empirical Measurement.** We perform an empirical analysis of leverage staking spanning 963 days, from December 17th, 2020 to August 7th, 2023. We detect 262 leverage staking positions, with an aggregated staking amount of 295,243 ETH (482M USD). Our results show that 90.13% of leverage staking positions have achieved an APR higher than that of conventional staking.

- **User Behavior Analysis.** We explore the stETH price deviation in relation to the Terra crash incident. We analyze how users with leverage staking positions behave when faced with potential liquidations. We discover that users actively deleveraged their positions and collectively repaid a substantial debt amounting to 74,983.6 ETH, further intensifying the selling pressure on stETH.

- **Stress Testing.** We perform stress tests on the Lido–Aave LSD ecosystem to evaluate the risk of cascading liquidations under extreme conditions. We first simulate the liquidation cascades among leverage staking positions. We find that 93.13% of these positions are liquidated. Subsequently, we extend our simulations to include both leverage staking and ordinary positions, showing that leverage staking significantly amplifies the liquidation risk. We find that the stETH selling pressure from both liquidations and the deleverage action create a ripple effect within the system, exacerbating price decline and triggering more liquidations.

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\(^5\) [https://github.com/lidofinance/aave-asteth-deployment](https://github.com/lidofinance/aave-asteth-deployment)
2 Background

2.1 Blockchain and DeFi

Permissionless blockchains are decentralized distributed ledgers that allow any participant to join and engage without requiring authorization. Within this landscape, Ethereum [25] emerges as a pioneering platform. It facilitates the execution of smart contracts, enabling developers to build decentralized applications.

DeFi [24] has recently emerged as a groundbreaking financial segment. DeFi refers to a set of blockchain-based financial services and products that operate without traditional intermediaries, using smart contracts to build an open financial environment. DeFi innovations ranging from lending to DEXs are reshaping the financial system. The TVL in DeFi reached an all-time high of 178B USD in November, 2021, with Ethereum dominating DeFi activities (109B USD, 61%).

2.2 Ethereum PoS

PoS, originally proposed in online forums [1] and later explored by the academic community [8,6,11,14,5], has emerged as an energy-efficient alternative to PoW.

Beacon Chain. On December 1st, 2020, Ethereum introduced its PoS-based Beacon Chain that runs in parallel with Ethereum’s PoW Mainnet. In the Beacon Chain, “staking” is introduced through a deposit mechanism, where participants lock up 32 ETH into the designated contract to become validators.

The Merge. On September 15th, 2022, the Merge enables Beacon Chain to evolve as the consensus mechanism for the entire network [3]. Ethereum now runs on the execution layer and the consensus layer. The execution layer is responsible for executing transactions, defining how the state of the Ethereum network changes over time. The role of the consensus layer entails establishing agreement among validators regarding the state of the execution layer. The Ethereum staking system offers various incentives to validators. Rewards from the consensus layer include block proposal, attestation, and sync committee rewards [12]. The execution layer introduces additional rewards, including priority tips and Miner Extractable Value tips [9,17]. Penalties also apply for dishonest behavior.

The Shapella Upgrade. On April 12th, 2023, Ethereum underwent the “Shapella upgrade”. The Shapella upgrade combines the “Shanghai upgrade” and the “Capella upgrade”, which took place on the Ethereum consensus layer and execution layer simultaneously [10]. The Shapella upgrade primarily introduces the capability to unstake ETH secured within the Ethereum network.

2.3 Staking Options

Ethereum participants are presented with four distinct staking options as follows.

- Solo Staking. In solo staking, individual participants operate their validator nodes by committing a threshold of 32 ETH, thereby maintaining full control over their staking rewards. However, solo staking necessitates technical expertise to run and maintain a validator node. Furthermore, it demands a significant capital commitment, which might be financially unfeasible for retail users.
- **Staking as a Service (SaaS)**. For users with 32 ETH but limited technical expertise, SaaS offers a solution to manage the validator’s hardware and software for the users, utilizing their signing keys to undertake on-chain tasks.\(^6\)

- **Pooled Staking**. For retail users with holdings below the 32 ETH threshold, pooled staking emerges as a feasible alternative, enabling them to collectively participate in the network’s validation process, earn rewards, and capitalize on the broader Ethereum ecosystem without the need for individual, full-node commitments. Typically, staking pools charge fees, which are further split between Node Operators (NOs) and the protocol Decentralized Autonomous Organization (DAO). NOs run and maintain validator nodes on behalf of the staking pool. The DAO selects NOs and configures crucial parameters for the protocol.

- **Centralized Exchange (CEX) Staking**. CEXs, such as Coinbase and Binance, provide centralized and custodial staking services to users. However, this exposes users to potential risks due to the centralized nature of CEX staking.

### 2.4 LSD

Staking offers several advantages, from earning rewards to enhancing network security. However, once ETH is locked for staking, it becomes illiquid for a duration, making it inaccessible for trading. Given this challenge, the concept of LSD emerged, representing staked assets and rewards in a tradable form. Figure 1 provides an overview of the LSD ecosystem. When users stake ETH within an LSD provider (e.g., liquid staking pools), they receive LSDs in return.

**Liquid Staking Providers**. At the time of writing, liquid staking protocols accumulate a TVL of more than 18.94B USD, securing the top position in TVL across various DeFi sectors. Users can obtain LSDs through two primary staking methods: pooled staking and CEX staking (cf. Table I). Pooled staking protocols

\(^6\) [https://ethereum.org/en/staking/saas/]
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1
2
3
4
5

Stake ETH on Lido
Receive stETH
Supply stETH on Aave
Borrow ETH
Repeat

Fig. 2: Overview of Leverage Staking Strategy.

such as Lido, Rocket Pool, Frax, Stakewise, and Swell Network issue LSDs to users. CEXs such as Coinbase and Binance also support LSDs.

Lido is currently the leading LSD provider and ranks as the largest DeFi protocol in terms of TVL (13.8B USD). Users stake ETH on Lido to receive stETH in return. With over 285M stakers, the total amount of ETH staked on Lido reached 8.34M in August 2023, accounting for 74.6% of the total ETH staked on Ethereum. stETH implements the rebasing mechanism, where stETH holders’ account balances get adjusted daily to reflect the accumulated rewards. The rebase can be positive or negative, depending on the validators’ performance.

2.5 DeFi Lending Protocols

DeFi lending protocols are decentralized platforms operating on blockchains that facilitate peer-to-peer lending and borrowing of cryptocurrency assets through the automated execution of smart contracts. At the time of writing, Aave stands as the leading DeFi lending protocol, with a total TVL of 4.5B USD. Notably, Aave follows an over-collateralization model, meaning that users are required to supply more collateral value than the borrowed amount. As an illustration, when the collateral value amounts to $S\cdot ETH$, the user’s borrowing capacity is restricted to no more than $S\cdot ETH$, where $l \in [0, 1]$ denotes the Loan-to-Value (LTV) ratio. In the event that the collateral value falls below a specified threshold, users may need to add more collateral or risk the liquidation of their asset to repay the borrowed amount and accrued interest. To monitor the collateralization status of each position, Aave utilizes Liquidation Threshold (LT) to establish the threshold percentage that designates a position as under-collateralized, and Health Factor (HF) as a key metric to quantify the liquidation status of a position. For example, user $U_i$’s position can be liquidated if $HF(U_i) < 1$ (cf. Equation 1).

$$HF(U_i) = \frac{\sum_j \text{collateralized value of asset}_j \text{ in } ETH \cdot LT_j}{\sum_j \text{borrowed value of asset}_j \text{ in } ETH}$$

3 System Model

3.1 System Participants

We consider an LSD ecosystem with the following participants.

- **Users**: A user \((U_i)\) is a rational participant capable of engaging with diverse DeFi platforms, employing various strategies to optimize its financial gains.

- **Liquid Staking Providers**: \(U_i\) can stake native tokens (e.g., ETH) on liquid staking platforms (e.g., Lido) to receive LSDs (e.g., stETH) that can be used for trading, collateralized borrowing, providing liquidity to DEX pools, etc.

- **Lending and Borrowing Providers**: \(U_i\) can supply one asset on DeFi lending platforms, such as Aave, as collateral to borrow another asset.

### 3.2 Leverage Staking with LSDs

- **Leverage Staking Strategy**: LSDs can be integrated into DeFi in various ways. For instance, DEXs such as Curve allow stETH holders to provide liquidity to the pool, at the risk of potential impermanent loss. Alternatively, users can implement a so-called “leverage staking strategy” which brings higher yield and higher risks. Specifically, \(U_i\) first stakes a principal amount of \(S\) ETH on Lido at time \(t_0\), acquiring \(S\) amount of stETH. Next, \(U_i\) utilizes the stETH as collateral within Aave to borrow \(S \cdot l \cdot P_{st}^{st} t_0\) amount of ETH, where \(l\) denotes the LTV ratio and \(P_{st}^{st} t_0\) denotes the stETH to ETH price at time \(t_0\). \(U_i\) performs this loop for \(n\) times (cf. Figure 2) and ends in a leverage staking position of stETH.

- **Leverage Multiplier.** Assume \(U_i\) acquires a total asset (staked ETH on Lido) of \(A_{(S,n)}\) ETH through leverage staking with an initial principal amount of \(S\) ETH, the leverage multiplier \(LevM_{(S,n)}\) is defined as the ratio between \(A_{(S,n)}\) and \(S\).

### 4 Analytical Study

This section conducts an analytical study of the leverage staking strategy. We begin by examining the standardized case and subsequently offer a generalized formalization encompassing other potential scenarios.

We assume that \(U_i\) is capable of completing \(n\) loops within a short time interval such that the stETH price remains unchanged. As a rational and risk-averse participant, \(U_i\) determines the value of \(n\) according to its risk profile. By applying the leverage staking strategy, \(U_i\) acquires a total investment of \(A_{(S,n)}\) ETH, collateral of \(C_{(S,n)}\) stETH, and debt of \(B_{(S,n)}\) ETH (cf. Equation 2).

\[
A_{(S,n)} = S \times \left[ 1 + l \cdot P_{st}^{st} t_0 + ... + (l \cdot P_{st}^{st})^n \right] = S \times \frac{1 - (l \cdot P_{st}^{st})^{n+1}}{1 - l \cdot P_{st}^{st}} \\
C_{(S,n)} = S \times \left[ 1 + l \cdot P_{st}^{st} + ... + (l \cdot P_{st}^{st})^{n-1} \right] = S \times \frac{1 - (l \cdot P_{st}^{st})^{n}}{1 - l \cdot P_{st}^{st}} \\
B_{(S,n)} = S \times \left[ l \cdot P_{st}^{st} + ... + (l \cdot P_{st}^{st})^{n} \right] = S \times \frac{l \cdot P_{st}^{st} - (l \cdot P_{st}^{st})^{n+1}}{1 - l \cdot P_{st}^{st}} \tag{2}
\]

**Leverage Multiplier.** Equation 3 derives the leverage multiplier \((LevM_{(S,n)})\). Figures 3 and 4 show how \(LevM_{(S,n)}\) changes in response to variations in \(P_{st}^{st} t_0\) and LTV ratio respectively. It is evident that \(LevM_{(S,n)}\) increases with the increase of
Fig. 3: $LevM(S, n)$ with varying $P_{stETH}^{t_0}$. Fig. 4: $LevM(S, n)$ with varying LTV.

either stETH price or LTV. In addition, we can observe that $LevM(S, n)$ gradually converges to $\frac{1}{1-l \cdot P_{stETH}^{t_0}}$ when the number of leverage staking loops ($n$) increases.

$$LevM(S, n) = \frac{A(S, n)}{S} = \frac{1 - (l \cdot P_{stETH}^{t_0})^{n+1}}{1 - l \cdot P_{stETH}^{t_0}}; \lim_{n \to \infty} LevM(S, n) = \frac{1}{1 - l \cdot P_{stETH}^{t_0}} \quad (3)$$

**Health Factor.** The leverage staking strategy, although capable of generating substantial returns, concurrently magnifies the risk of liquidation. $U_i$’s position may be susceptible to liquidation should the value of collateralized stETH decrease due to the decline of the stETH price (i.e., $P_{stETH}^{t_c} < P_{stETH}^{t_0}$). As discussed in Section 2.5, Aave uses HF to track the status of each position. $U_i$’s can be liquidated if HF is less than 1 (cf. Equation 4). In our leverage staking example, the LTV and LT are 69% and 81% respectively (see Table 2 for the historical changes of Aave parameter configurations). Equation 5 suggests that, to uphold a secure position, the largest acceptable percentage decrease in stETH price is $\frac{l}{LT} - 1 = \frac{12}{81} \approx 14.8\%$. In the event of liquidation, the user’s entire collateralized stETH amount of $C(S, n)$ will be liquidated, and this effect becomes more pronounced as the number of loops ($n$) increases, as indicated by $LevM(S, n)$.

$$HF_{U_i}(P_{stETH}^{t_c} | P_{stETH}^{t_0}) = \frac{\sum_{k=1}^{n} k^{th} \text{ collateralized stETH value in ETH} \cdot LT}{\sum_{k=1}^{n} k^{th} \text{ borrowed ETH value}} = \frac{C(S, n) \cdot P_{stETH}^{t_c} \cdot LT}{B(S, n)} \Rightarrow P_{stETH}^{t_c} \cdot \frac{LT}{P_{stETH}^{t_0}} \geq \frac{P_{stETH}^{t_c}}{P_{stETH}^{t_0}} \geq \frac{l}{LT} \Rightarrow \Delta \% \frac{P_{stETH}^{t_c}}{P_{stETH}^{t_0}} \geq \frac{l}{LT} - 1 \quad (4)$$

**APR.** Equation 6 calculates leverage staking profitability. Let $r_s$, $r_c$, and $r_b$ represent the storing APR offered by Lido and the supply and borrow interest rates provided by Aave, respectively. It is worth noting that $r_s$ changes in accordance with the validator performance, while $r_c$ and $r_b$ vary based on Aave’s interest rate model. $U_i$ earns a staking APR of $R_s(n)$ from Lido, a supply APR of $R_c(n)$ while pays a borrow APR of $R_b(n)$ to Aave. As such, $U_i$ obtains a net APR of

8 https://docs.aave.com/risk/liquidity-risk/borrow-interest-rate
\[ R_{Net}(n) = R_s(n) + R_c(n) - R_b(n). \] The necessary condition for a rational \( U_i \) to apply leverage staking rather than conventional staking is \( R_{Net}(n) > r_s. \)

\[ R_{Net}(n) = R_s(n) + R_c(n) - R_b(n) = r_s \cdot \frac{A(S,n)}{S} + r_c \cdot \frac{C(S,n)}{S} - r_b \cdot \frac{B(S,n)}{S} \]
\[ = r_s \cdot \text{LevM}(S,n) + r_c \cdot (\text{LevM}(S,n) - (1 \cdot P^{st}_{0})) - r_b \cdot (\text{LevM}(S,n) - 1) \] (6)

In addition to the standardized case discussed above, real-world leverage lending situations can exhibit variation among users. For example, some users may not supply all the received stETH as collateral on Aave. We refer interested readers to Appendix B for a generalized formalization of leverage staking.

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5 Empirical Study

We outline the empirical evaluation of leverage staking across Aave and Lido.

**Data Collection.** We crawl the historical submitted events related to Lido stETH Token when users stake ETH on Lido. We crawl the on-chain events involving users’ historical actions for adjusting positions on Aave V2 lending pool, including deposit, borrow, withdraw, and repay events. We use an Ethereum Geth node on a Linux machine running Ubuntu 22.04 LTS, which is equipped with AMD 48-core CPU, 256 GB of RAM, and 12 \times 2 TB SSD. We capture all the targeted events from block 11,473,216 (December 17th, 2020) to block 17,866,191 (August 7th, 2023), 963 days in total. We identify 290,984 submitted events on Lido, 449,528 deposit, 238,388 borrow, 336,746 withdraw and 173,596 repay events on Aave V2 lending pool.

**Leverage Staking Detection.** We proceed to analyze the users who adopt leverage staking across Lido and Aave. From the 449,528 deposit and 238,388 borrow events on Aave V2, we find that 743 addresses are used to deposit stETH as collateral and then borrow ETH. We then propose an algorithm (cf. Algorithm[1]) to identify the addresses involving leverage staking. Basically, we extract the event sequence (submitted, deposit, borrow, submitted) in chronological order, which follows the leverage staking process shown in Figure 2.
Our investigations reveal the existence of 262 addresses that have been engaging in leverage staking activities across Lido and Aave V2 lending pools, spanning the timeframe from December 17th, 2020 to August 7th, 2023. Cumulatively, these addresses have amassed a total staking amount of 295,243 ETH. The distribution of leverage borrowing and staking amounts is depicted in Figure 5. Interestingly, we observe that the volume of leverage staking was substantially impacted by the Terra crash in May 2022, leading to a drastic decline from the peak monthly staking amount of 93,661 ETH in May 2022 to just 11 ETH in August 2022. Moreover, the Ethereum Merge brought about a resurgence in leverage staking, with a staking amount of 9,814 ETH in October 2022.

**Leverage Staking Loops and Multipliers.** Among the 262 addresses that have adopted leverage staking, we conduct an analysis focusing on two key elements: the number of loops (denoted as $n$) and the leverage multiplier (denoted as $\text{LevM}(S, n)$), derived from their extracted action sequence $E_s$ (cf. Algorithm 1). To calculate the number of leverage staking loops, we identify consecutive subsequences in $E_s$ consisting of (submitted, deposit, borrow). The results, as depicted in Figure 6, reveal that 145 addresses (55.35%) performed leverage staking with a single loop ($n = 1$). Notably, a smaller subset of 12 addresses have engaged in leverage staking with more than eight loops, and their cumulative staking activity amounts to an impressive amount of 102,998 ETH.

Furthermore, we compute $\text{LevM}(S, n)$ for each address, taking into account their initial stake amount and the cumulative sum of stake amounts (cf. Equation 3). Figure 7 illustrates the distribution of $\text{LevM}(S, n)$ across various $n$. The trend indicates that an increasing loop count $n$ is associated with a higher leverage multiplier in practical scenarios. Additionally, it is noteworthy that the majority (87.57%) of addresses exhibit a $\text{LevM}(S, n)$ smaller than 3.5.

**Leverage Staking APR.** We proceed to analyze the practical implications of leverage staking APR. Our analysis centers on a subset of 152 addresses that have successfully repaid their debts and withdrawn their collateral from Aave stETH–ETH positions. To calculate their actual APR, as outlined in Equation 8, we consider the net earnings from deposit and withdraw actions, balanced against the ETH accrued through borrow and repay actions. Additionally, we account for the conversion of accrued ETH to stETH, factoring in the stETH price at the time.
of the last withdraw action. The distribution of APR for these 152 addresses is visually depicted in Figure [8] Notably, our findings reveal that a significant majority, precisely 137 leverage staking addresses (90.13%), have realized APR higher than the APR of conventional staking on Lido.

6 Cascading Liquidation

In this section, we offer an overview of the stETH price deviation in relation to the Terra crash incident. We illustrate how the stETH price can potentially lead to liquidation cascades within the Lido–Aave LSD ecosystem, especially in the context of leverage staking. Furthermore, we conduct stress tests to evaluate the risk of cascading liquidations under extreme conditions.

6.1 stETH Price Deviation and Terra Crash

As a rebasing LSD, stETH changes its token supply to distribute rewards to stakers (cf. Section 2.4). As such, the stETH to ETH price in the primary market (i.e., Lido) is 1. While stETH is not required to trade on par with ETH in the secondary market (e.g., Curve), the price is anticipated to converge to 1. Our empirical data show that stETH did maintain a loose peg to ETH for most of its history. However, the stETH price began to drop from May 12th, 2022, reaching its lowest point of 0.931 on May 18th, 2022 (cf. Figure [9]).

In fact, the stETH price decline can date back to the UST/LUNA depeg. The Terra collapse undoubtedly instilled fear and triggered selling pressure throughout the market [16][17]. Specifically, following the UST/LUNA depeg incident between May 7th and 16th, 2022, investors grew concerned about the security and stability of the Terra network. Amidst prevailing bearish sentiment, investors swiftly moved to bridge back bETH (a wrapped version of stETH on Terra) from Terra to Ethereum via the Wormhole contract. Our data show that 614K bETH was bridged to Ethereum, with a remarkable 98% of these bETH converted back to stETH. This mass conversion reflects the widespread desire to exit Terra-based
6.2 Cascading Liquidation and User Behaviors

The decline in stETH price may trigger liquidation cascades within the Lido–Aave LSD ecosystem, especially in the context of leverage staking (cf. Figure 10). Specifically, the decline in stETH price reduces the HFs of stETH collateralized borrowing positions on Aave, potentially leading to liquidations. In response to liquidations, users with leverage staking positions can either take no action and undergo liquidation or choose to deleverage their positions.

On the one hand, users with leverage staking positions may take no action when their HFs approach the critical threshold of 1. In this case, their collateralized stETH might be liquidated. The liquidators repay ETH to acquire stETH, with the liquidation amount being amplified by \( \text{LevM}_{(S,n)} \). Subsequently, a significant amount of stETH is sold in the Curve pool, contributing to additional selling pressure on stETH. This extensive selling further imbalances the Curve stETH-ETH pool, resulting in a further decline in stETH price. Consequently, an increasing number of positions, including both leverage staking and ordinary positions, are vulnerable to liquidation as a result of declining HFs.

On the other hand, users can choose to deleverage their positions on Aave to restore HFs. Assuming \( U_i \) has executed a leverage staking strategy with \( n \) loops,
$U_i$ can initiate the deleveraging process with the following steps. (i) $U_i$ executes a swap to convert stETH into ETH within the Curve stETH–ETH pool. (ii) The received ETH is then used to repay the ETH borrowed in the $n^{th}$ loop. (iii) $U_i$ then withdraws the stETH that was supplied in the $n^{th}$ loop from Aave and continues converting it into ETH using the Curve pool. This “swap-repay-withdraw” process is repeated as necessary to deleverage the position until HF remains above 1. Taking address 0x27...701 as an example, the overall trends of HF and leverage multiplier during the deleveraging process (cf. Figure 12) exhibit a remarkable degree of symmetry when compared to those observed in the lever-aging process (cf. Figure 11). With each repay action, the HF of the address increases, as indicated by the red line, while the leverage multiplier decreases, as shown by the blue line. During the period from May 8th, 2022 to May 18th, 2022, i.e., the first ten days after the Terra crash (cf. Figure 9), we observed 13 users actively deleveraging their leverage staking positions, resulting in a total debt repayment of 74,983.6 ETH. However, even if a user manages to avoid liquidation by deleveraging, the additional selling pressure generated by the swap transactions on Curve can still intensify the decline in stETH price and make other leverage staking and ordinary positions susceptible to liquidation.

To summarize, users with leverage staking positions can take different actions in response to potential liquidations. However, regardless of their choice, these actions may contribute to additional selling pressure on stETH, further exacerbating the price decline and potentially triggering liquidation cascades.

6.3 Stress Testing

**Motivation.** By crawling the liquidationcall events on Aave V2 lending pool from December 17th, 2020 to August 7th, 2023, we identify 18 liquidations for the positions where users supplied stETH to borrow ETH and 7 liquidations for leverage lending positions. However, drawing from the LUNA–UST incident, we recognize that a token may become entirely devalued. In the event that stETH faces a fate similar to LUNA’s devaluation, it could lead to a surge in liquidations. Considering that stETH has historically only experienced a relatively modest price decline (reaching a low of 0.931), it is imperative to conduct stress tests to assess the risk of cascading liquidations under a worst-case scenario.

Therefore, we perform stress tests on the Lido–Aave LSD ecosystem under extreme conditions, simulating potential selling pressure and subsequent liquidation cascades if the stETH experiences a dramatic decline. Specifically, we divide the Aave collateralized stETH borrowing positions into the leverage staking group ($G_L$) and ordinary group ($G_O$). We simulate the following cases:

**Case 1:** We simulate liquidation cascades within $G_L$, with selling pressure originating from the liquidation of leverage staking positions. We analyze the changes in HFs and how leverage staking amplifies the risk of cascading liquidations.

**Case 2:** We simulate liquidation cascades across both $G_L$ and $G_O$ to explore their mutual impact. The selling pressure is generated by liquidations.
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Fig. 13: Simulated HF distribution.

Fig. 14: Simulated HF results.

Fig. 15: stETH price and liquidation amount during the liquidation cascades.

**Case 3:** We simulate liquidation cascades across $G_L$ and $G_O$, assuming that users in $G_L$ choose to deleverage their positions when HFs approach a threshold of 1.1. The selling pressure arises from deleveraging and potential liquidations.

**Simulation Setup.** We initialize the Curve stETH–ETH pool by forking its state at block 17,500,000 (June 17th, 2023), with reserve of 265,972 ETH and 266,966 stETH. Subsequently, we mimic the institutional selling pressure (e.g., Celsius, see Figure 10) after Terra crash by simulating a sale of 200,000 stETH on Curve. This sizable transaction leads to the decline in the stETH price, resulting in a new exchange rate of $100 \text{ stETH} = 83.76 \text{ ETH}$, denoted as $p_0 = 0.8376$.

**Simulation of Case 1.** We initialize 262 leverage staking positions, each with an address that we have detected in Section 5. For each position, the values of totalDebtETH, totalCollateralETH, and HF are set to the corresponding values recorded in the transaction logs of that position’s most recent borrowing transaction. Furthermore, the stETHPrice for all positions is initialized as $p_0$.

**Simulation Process.** The simulation unfolds through a series of sequential rounds. In each round, the stETHPrice for all positions is updated as the current stETH price in the Curve stETH–ETH pool. Subsequently, the HF for each position is recalculated, using the updated stETHPrice. If, at any point, a position’s HF drops below the critical threshold of 1, a simulated liquidation event is triggered.
In this scenario, a designated liquidator steps in to settle the debt by repaying it in ETH. In return, the liquidator receives the collateral in stETH. All received stETH is converted to ETH in the Curve stETH–ETH pool, as shown in Figure 10. This process continues until no more liquidatable positions remain.

**Simulation Results.** We analyze the liquidation amount, HFs, and stETH price during the simulation process. As shown in Figure 13, the simulation terminates after 11 rounds, and 244 (93.13%) positions are liquidated. A noteworthy observation is that HFs of all positions exhibit a gradual decrease, as depicted in Figure 14. This is directly attributed to the successive price drops of stETH, as visualized in Figure 15. The cascading liquidations result in a total liquidation amount of 128,998 ETH, ultimately driving the stETH price down to 0.15.

As a comparison, we simulate the scenario where the above-mentioned 262 positions do not utilize the leverage staking strategy. This involves setting the initial values for totalCollateralETHs, totalDebtETHs, and HFs as the values recorded in the transaction logs when the first borrowing action for the position occurred. As illustrated in Figure 15, the red bars and lines represent the outcome of these simulations. Notably, the cascading liquidation triggered by positions without leverage staking ceases after only three rounds. Merely 13,329 ETH (19.68% of the case with leverage staking) will be liquidated, and the stETH price remains more than 0.79 ETH. Our simulation findings indicate that leverage staking significantly amplifies the risk of cascading liquidation.

- **Simulation of Case 2.** We simulate the scenario where GL and GO co-exist on Aave. We initialize a total of 524 positions, equally divided into two groups. We then execute an identical simulation process as in Case 1, recording the number of liquidated addresses and the stETH price throughout the simulation.

**Simulation Results.** As depicted in Figure 16, the simulation terminates after just 7 rounds, resulting in an aggregate liquidation amount of 146,330 ETH and a significant drop in the stETH price to 0.11. Clearly, the situation in Case 2 is more severe than in Case 1. This is due to the liquidation of both leverage staking and ordinary positions, further intensifying the decline in the stETH price.

- **Simulation of Case 3.** We proceed to simulate the scenario where GL and GO co-exist on Aave, with users in GL opting to deleverage their positions.
We initiate 256 leverage staking addresses and 256 ordinary positions. At the beginning of each round, users in $G_L$ monitor their positions' HF's and initiate the deleveraging if $HF < 1.1$. The deleveraged stETH is then swapped for ETH in the Curve stETH–ETH pool, causing a subsequent drop in the stETH price. Subsequently, the HF for each position is recalculated based on the updated stETH price. The remainder of the simulation process mirrors that of Case 1.

**Simulation Results.** In this case, the stETH price declines due to deleveraging and liquidation, as depicted in Figure 17. Notably, the price swiftly declines to 0.03 within just three rounds. In this case, although users in $G_L$ avoid liquidation by closing positions before reaching $HF < 1$, their deleveraging actions exacerbate the stETH price drop, heightening liquidation risks for users in $G_O$.

**Limitation.** A notable limitation of our simulation is the omission of arbitrage activities. Should sizable arbitrage transactions be executed, they could act as stabilizing forces to restore the price equilibrium and prevent continuous declines.

### 6.4 Discussion

Our simulation results reveal important insights. If stETH faces extreme conditions and undergoes a significant price decline, the Aave–Lido LSD ecosystem is at risk of cascading liquidation, especially with the presence of leverage staking. The stETH selling pressure, arising from both liquidations and deleveraging, can initiate a ripple effect within the system, resulting in a further decline in the stETH price and more liquidations. As such, it is imperative for Lido and Aave to develop robust approaches to mitigate the risk of cascading liquidations, particularly during periods of significant market volatility. Proactive risk management is essential for building a stable staking and lending environment.

### 7 Related Work

There is currently limited academic literature on liquid staking. Scharnowski et al. [19] analyze the liquid staking basis (e.g., the discrepancy) between the prices of LSDs in the primary and secondary market. They observe that the liquid staking basis widens during times of increased cryptocurrency volatility and decreased liquidity in the secondary market. Cintra et al. [7] utilize the Bayesian Online Changepoint Detection (BOCD) algorithm to identify potential depeg incidents using price data from the curve stETH–ETH pool. This research shows that the proposed approach can assist users in managing potential risks.

There are also several studies on DeFi lending platforms. For example, Heimbach et al. [13] conduct a study on the impact of the Ethereum merge on two DeFi lending platforms, Compound and Aave. They investigate the actions taken by Aave to mitigate the liquidation risk of collateralized stETH positions. Wang et al. [23] present a formal model for evaluating under-collateralized DeFi lending platforms and conduct a risk assessment for leverage lending positions.
8 Conclusion

This paper systematically studies leverage staking with LSDs. We propose a formal model to capture the leverage staking strategy within the Lido–Aave ecosystem. We empirically detect and analyze leverage staking positions, assessing the leverage staking amount, leverage multiplier, and APR. We analyze the volatility of stETH price and its impact on liquidations. We analyze the deleveraging actions undertaken by users and the selling pressure arising from the liquidation, recognizing their potential to exacerbate declines in the stETH price, thereby possibly triggering cascading liquidations. We conduct stress tests to evaluate the risk introduced by leverage staking under extreme conditions. Our simulation results indicate that leverage staking can amplify the risks of cascading liquidations. We hope that our work will inform and encourage DeFi lending and staking protocols to develop robust risk assessment approaches for effectively monitoring and mitigating the risks associated with leverage staking, as well as enhancing the protection of stakeholders within the LSD ecosystem.

References


A Supplementary Figures and Tables

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Type</th>
<th>Mechanism</th>
<th>LSD</th>
<th>TVL(USD)</th>
<th>Staked ETH</th>
<th>Fee</th>
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Table 1: Statistics of top LSD providers on Ethereum, as of August 23rd, 2023.
Table 2: Historical changes of Aave V2 parameter configurations.

A.1 Liquid Staking Providers

Table 1 provides the statistics of top LSD providers on Ethereum.

A.2 Aave Parameter Configuration

Table 2 depicts the historical changes of Aave parameter configurations. We crawl the collateralConfigurationChanged events for Aave V2 lending pool.

B Generalized Formalization For Leverage Staking

In addition to the standardized cases discussed in Section 4, real-world leverage lending situations can exhibit substantial variation among users. Specifically, we consider the following variations. (i) Within each leverage staking loop, \( U_i \) may choose not to supply all the stETH acquired from Lido as collateral on Aave. Instead, in the \( k \)th loop, \( U_i \) may opt to supply only \( c_k \) (\( c_k \in [0, 1] \)) percent of the stETH. (ii) In the \( k \)th loop, \( U_i \) has the option to borrow an amount of ETH that is less than the maximum borrowing capacity. In this scenario, \( U_i \)’s effective borrowing capacity becomes \( b_k \cdot l \), where \( b_k \in [0, 1] \). (iii) In the \( k \)th loop, \( U_i \) has the flexibility to restake part of the borrowed ETH on Lido. In this scenario, \( U_i \) may choose to restake only \( s_k \) (\( s_k \in [0, 1] \)) percent of the borrowed ETH.

Let \( LevM(S,n) \), \( ColM(S,n) \), and \( BorM(S,n) \) be the leverage multiplier, collateral multiplier, and borrowing multiplier respectively. We know that \( LevM(S,n) = \frac{A(S,n)}{S} \), \( ColM(S,n) = \frac{C(S,n)}{S} \) and \( BorM(S,n) = \frac{B(S,n)}{S} \). Equation 7 introduces a more generalized formalization to accommodate these variations:

\[
LevM(S,n) = \frac{\prod_{k=1}^{n+1} s_i \cdot \prod_{j=1}^{k-1} c_j \cdot \prod_{m=1}^{k-1} b_m \cdot (l \cdot P_{st}^{\text{ext}})^{k-1}}{s_i \cdot \prod_{j=1}^{k-1} c_j \cdot \prod_{m=1}^{k-1} b_m \cdot (l \cdot P_{st}^{\text{ext}})^{k-1}}
\]

\[
ColM(S,n) = \frac{\prod_{k=1}^{n} s_i \cdot \prod_{j=1}^{k-1} c_j \cdot \prod_{m=1}^{k-1} b_m \cdot (l \cdot P_{st}^{\text{ext}})^{k-1}}{s_i \cdot \prod_{j=1}^{k} c_j \cdot \prod_{m=1}^{k} b_m \cdot (l \cdot P_{st}^{\text{ext}})^{k-1}}
\]

\[
BorM(S,n) = \frac{\prod_{k=1}^{n} s_i \cdot \prod_{j=1}^{k} c_j \cdot \prod_{m=1}^{k} b_m \cdot (l \cdot P_{st}^{\text{ext}})^{k}}{\prod_{k=1}^{n} s_i \cdot \prod_{j=1}^{k} c_j \cdot \prod_{m=1}^{k} b_m \cdot (l \cdot P_{st}^{\text{ext}})^{k}}
\]

\[
HF(U_i | P_{st}^{\text{ext}}) = \frac{ColM(S,n) \cdot P_{st}^{\text{ext}} \cdot LT}{BorM(S,n)}
\]
Algorithm 1: Leverage Staking Detection.

**Input:** An address `addr`

**Output:** `addr`’s leverage staking actions.

1. Extract `addr`’s deposit events `{\( w_i \)}_i` and borrow events `{\( b_j \)}_j` on Aave, and submitted events `{\( s_k \)}_k` on Lido;
2. Let \( \mathcal{E} = \{w_i\}_i \cup \{b_j\}_j \cup \{s_k\}_k \);
3. Convert \( \mathcal{E} \) to a sequence \( \mathcal{E}_s \) by sorting \( \mathcal{E} \) in chronological order;
4. if \( \mathcal{E}_s \) contains a sub-sequence with a order of (submitted, deposit, borrow, submitted) then
   5. if For the sub-sequence \((\text{submitted}_0, \text{deposit}, \text{borrow}, \text{submitted}_1)\): (i) The stETH amount received in \( \text{submitted}_0 \) event \( \approx \) the stETH amount in \( \text{deposit} \) event; (ii) The stETH amount in \( \text{deposit} \) event > the ETH amount in \( \text{borrow} \) event; (iii) The ETH amount in \( \text{borrow} \) event \( \approx \) the ETH amount in \( \text{submitted}_1 \) event then
      6. return \( \mathcal{E}_s \);
   7. return \( \emptyset \);
5. else
   6. return \( \emptyset \);

C Leverage Staking Detection Algorithm

Algorithm 1 depicts our approach to detect leverage staking addresses.

D Additional Leverage Staking Measurement Results

D.1 Actual APR Computation

Equation 8 represents our proposed method for calculating the actual APR in the context of leverage staking. This approach involves the net earnings yielded from deposit and withdraw actions, which are then offset against the ETH consumed during borrow and repay actions. Furthermore, our calculation takes into consideration the conversion of consumed ETH to stETH, factoring in the stETH price at the moment of the last recorded deposit action.

\[
\text{actualAPR} = \frac{\left(\text{earnedstETH} - \text{accruedETH}\right)}{\text{totalDepositstETH} \cdot (\text{lastWithdrawBlock} - \text{firstDepositBlock})} \cdot \frac{3600 \cdot 24 \cdot 365}{12}
\]

\[
\text{accruedstETH} = \text{totalWithdrawstETH} - \text{totalDepositstETH}
\]

\[
\text{accruedETH} = \text{totalRepayETH} - \text{totalBorrowETH}
\]