Mitigating Decentralized Finance Liquidations with Reversible Call Options

Kaihua Qin[1], Jens Ernstberger[2], Liyi Zhou[1],
Philipp Jovanovic[3], and Arthur Gervais[34]

[1] Imperial College London, United Kingdom
[2] Technical University Munich, Germany
[3] University College London, United Kingdom
[4] UC Berkeley, United States

Abstract. Liquidations in Decentralized Finance (DeFi) are both a blessing and a curse — whereas liquidations prevent lenders from capital loss, they simultaneously lead to liquidation spirals and system-wide failures. Since most lending and borrowing protocols assume liquidations are indispensable, there is an increased interest in alternative constructions that prevent immediate systemic-failure under uncertain circumstances. In this work, we introduce *reversible call options*, a novel financial primitive that enables the seller of a call option to terminate it before maturity. We apply reversible call options to lending in DeFi and devise Miqado, a protocol for lending platforms to replace the liquidation mechanisms. To the best of our knowledge, Miqado is the first protocol that actively mitigates liquidations to reduce the risk of liquidation spirals. Instead of selling collateral, Miqado incentivizes external entities, so-called *supporters*, to top-up a borrowing position and grant the borrower additional time to rescue the debt. Our simulation shows that Miqado reduces the amount of liquidated collateral by 89.82% in a worst-case scenario.

Keywords: DeFi · Liquidation · Reversible call option.

1 Introduction

Recently, there has been an increasing interest in Decentralized Finance (DeFi), a financial ecosystem where users exercise cryptographic control over their financial assets. Commonly, DeFi is enabled by blockchains that support smart contracts (e.g., Ethereum), and financial primitives are instantiated as publicly accessible decentralized applications. A wide variety of traditional financial services that are implemented in DeFi, ranging from asset exchanges, to market making, as well as lending and borrowing platforms [15]. DeFi differs from the traditional, centralized financial system in multiple aspects. For instance, most DeFi services are open-source, such that traders can inspect the protocol rules encoded within immutable smart contracts.

With over 15B USD of total value locked (TVL), DeFi's lending and borrowing services account for 30% of DeFi's locked up assets. Just as in the traditional

centralized finance domain, debt in DeFi is prone to *liquidation events* upon price-swings of the debts' security deposit (subsequently referred to as collateral). A borrowing position becomes "unhealthy" (i.e., liquidatable), whenever the collateral is deemed insufficient to cover the debt, corresponding to a *health factor* inferior to one. The most prevalent liquidation mechanism, fixed spread liquidation (FSL), allows a *liquidator* to repay a fraction of the borrower's debt and acquire its collateral at a discount. The fraction at which the borrowers' debt is repaid in a liquidation is limited to an upper bound, commonly referred to as the *close factor* (e.g., 50%). As such, liquidations intend to protect the lender by preventing a loss of capital by selling a sufficient amount of collateral. However, liquidations serve as a double-edged sword. Selling off collateral causes a price decrease, which potentially leads to further liquidations and market-wide panic [11]. Quantifying the extent of liquidations in DeFi, a recent two-year longitudinal study (April 2019 to April 2021) by Qin *et al.* [16] finds that liquidation events on the Ethereum blockchain amount to over 800M USD in volume, yielding a staggering 64M USD profit to liquidators. Such liquidation profit constitutes a source of miner extractable value (MEV) [5], which grants miners a risk-free opportunity to extract financial profit. MEV, however, negatively affects blockchain consensus security by incentivizing blockchain forks [17].

In this work, we propose MIQADO, a mechanism designed to mitigate liquidation events to *(i)* protect borrowers from excessive collateral liquidation, *(ii)* alleviate MEV sourcing, and *(iii)* mitigate liquidation spirals. To this end, we introduce *reversible call options*, a novel financial primitive that enables the seller of a call option to terminate it at a premium before reaching maturity. MIQADO applies reversible call options to incentivize external support for "unhealthy" borrowing positions, while the original borrower is granted additional time to protect its borrowing position and limit the potential loss.

Thereby, we summarize the contributions of this work as follows.

1. **Quantifying Liquidation Spiral.** We quantify the liquidation spiral caused by the FSL mechanism by analyzing 48,364 past liquidation events over a time-frame of 41 months, capturing 2.32B USD of collateral liquidated. We find the existence of 18,305 short liquidations, where a liquidator immediately sells the acquired collateral. These liquidations account for 1.33B USD sold collateral and a maximal collateral price decline of 26.90%.
2. **A Novel Financial Primitive.** We introduce reversible call options, a novel financial primitive where the seller of a European call option can pay a premium to the buyer to terminate the option before its maturity.
3. **A Protocol for Liquidation Mitigation.** We propose MIQADO, the first protocol that protects DeFi borrowers from excessive liquidation losses. By realizing a reversible call option, MIQADO incentivizes external actors to support "unhealthy" borrowing positions, mitigating liquidations by design. MIQADO serves as a plug-and-play mechanism, which can be integrated into any existing lending platform. We evaluate MIQADO by simulating how it would have performed in past liquidation events. We find that MIQADO reduces the amount of liquidated collateral by 89.82% in a worst-case scenario.

2   Background

2.1   Blockchain & Smart Contract

In essence, a blockchain is a distributed ledger operating on top of a peer-to-peer (P2P) network [4]. The core blockchain functionality is that participants can transfer financial assets (i.e., cryptocurrencies) without any trusted third-party custodian [13]. To send cryptocurrencies, one broadcasts a signed transaction through the blockchain P2P network. The so-called *miners* collect, verify and package transactions into a block which is appended onto the already confirmed blocks forming a linear chain. All peers in the blockchain network are expected to follow a specific consensus mechanism (e.g., Nakamoto consensus [13]) to achieve the consistency of the ledger.

Beyond the simple cryptocurrency transfer, more versatile blockchains (e.g., Ethereum [23]) enable advanced transaction logic through pseudo-Turing complete smart contracts. Similar to regular user accounts, smart contracts can own cryptocurrencies. In addition, every smart contract is bound to a piece of immutable code upon its creation. Users can send a transaction to a smart contract account and trigger the execution of the associated smart contract code. We refer readers to [4] for more detailed explanations of blockchains and smart contracts.

2.2   Decentralized Finance

Smart contracts enable the creation of cryptocurrencies (also known as tokens) on a blockchain in addition to the native cryptocurrency (e.g., ETH on Ethereum). A token smart contract serves as a balance sheet recording the balance of every token holder account. Smart contracts also allow anyone to create any type of imaginable financial product on-chain, by enforcing the rules through the smart contracts' immutable code. The ecosystem as a whole, composed of these tokens and smart contract-based financial products, is referred to as DeFi. At the time of writing, the scale of DeFi has reached over 50B USD, with an abundance of applications such as exchanges, lending platforms, and derivatives.[5]

2.3   Lending/Borrowing in DeFi

Lending and borrowing, with over 15B USD TVL, is one of the most popular DeFi use cases. In a DeFi lending system, a smart contract called *lending pool*, manages the borrowing positions. Lenders provide assets to the lending pool to earn interests from borrowers. To minimize the lenders' risk of losing funds, every borrower is required to provide *collateral* as a guarantee. The lending and borrowing interests are programmatically determined by the contract code.

Lending in DeFi can be divided into *over-collateralized* and *under-collateralized* lending. In over-collateralized lending, the borrower provides a security deposit (i.e., collateral) which *exceeds* the lent assets by a factor of 1.1× to 2× depending on the respective protocol [16]. The borrower may then choose to freely use

---

[5] https://defillama.com/.

the lent asset in any capacity. Contrary to over-collateralized lending, in under-collateralized lending, the borrower only provides a fraction of the lent assets as security, hence achieving a leverage factor beyond $1\times$. For this leveraged borrowing to remain secure, the assets granted through under-collateralization can only be utilized in very specific, hard-coded settings encoded in immutable smart contracts, such that the lending pools stay in control of the lent assets. In this work, we primarily focus on over-collateralized lending.

We refer to the debts of a borrower together with the collateral securing these debts as a *borrowing position*. Due to asset price fluctuations, the collateral of a borrowing position may become insufficient to cover the debt. Therefore, lending pools typically set a threshold for the borrowing positions, at which a position becomes liquidatable. When the collateral value of a borrowing position declines below this threshold, lending pools can then allow the so-called liquidators, to repay the debt for the position, commonly referred to as liquidation. In return, the liquidator is eligible to acquire parts of the collateral from the borrowing position. The acquired collateral exceeds the repaid debt in value, which incentivizes the liquidator to realize a profit.

2.4 Call Options

Call options are financial contracts that grant buyers the right, but not the obligation, to buy an underlying asset (e.g., stocks) at an agreed-upon price (i.e., the exercise price or strike price) and date (i.e., the expiration date or maturity) [20,8]. In general, options are priced using a mathematical model, such as the Black-Scholes [3] or the Binomial pricing model [19]. On a high level, an options price is determined by *(i)* its intrinsic value and *(ii)* its time value. The intrinsic value is a measure of the profitability of an option if it were to be exercised immediately. The time value measures the value of an option arising from the time left to maturity (i.e., volatility). When the strike price of an option increases, the price of the call option consequently increases as well. In traditional finance, there are two styles of option contracts: *(i)* American options can be executed (or exercised) at any time up to the expiration date; *(ii)* European options can be exercised only on the expiration date [8].

3 Preliminaries

In the following, we formalize a collateralized debt model and the fixed spread liquidation, which is the prevalent DeFi liquidation mechanism.

3.1 Collateralized Debt Model

We assume the existence of an on-chain lending pool $\mathcal{L} = \{P_1, P_2, ..., P_n\}$, where P_i is the i-th borrowing position in the lending pool. Each borrowing position $P = \langle D_t, C_t \rangle$ is parametrized by the debt D_t the borrower owes, and the collateral C_t the borrower owns at time t. We denote the price of the debt cryptocurrency towards the collateral cryptocurrency, provided by an oracle [7], as p_t. In

the following, we consider the case where each borrowing position consists of a single debt cryptocurrency and a single collateral cryptocurrency. In practice, a lending pool may allow for mixed borrowing positions by including multiple cryptocurrencies as either debt or collateral. We further assume that a borrower only opens a single borrowing position.

Whether or not a borrowing position is *liquidatable* is determined by the *health factor*.

$$HF_t(P) = \frac{C_t \cdot p_t \cdot \theta}{D_t} \tag{1}$$

$C_t \cdot p_t$ represents the value of the collateral, whereas D_t represents the value of the debt denoted in the same cryptocurrency. θ is the collateral discount, s.t. $0 < \theta < 1$. The collateral discount is configured as a safety margin to ensure the over-collateralization of a position, i.e., the value of the collateral is discounted when calculating the health factor. If $HF_t(P) < 1$, e.g., due to price fluctuations, P is deemed "unhealthy" making it available for liquidations under existing prevalent designs of DeFi lending protocols. Internally, the health factor of a borrowing position relies on the *collateralization ratio*

$$CR_t(P) = \frac{C_t \cdot p_t}{D_t}. \tag{2}$$

The collateralization ratio determines whether a position is over-collateralized or under-collateralized. If $CR_t(P) > 1$ at time t, a position is over-collateralized, and under-collateralized otherwise.

3.2   Fixed Spread Liquidation

We denote a decentralized application for lending and borrowing that applies a fixed spread liquidation mechanism as protocol $\texttt{prot}_{FSL}$. For ease of exposition, we assume that $\texttt{prot}_{FSL}$ hosts a single lending pool $\mathcal{L}$. The liquidation of a position $P = \langle D_t, C_t \rangle$ is determined by a set of variables, including the previously introduced collateral discount θ, the close factor k_{CF} (s.t. $0 < k_{CF} \leq 1$) and the liquidation spread S.

$$\texttt{prot}_{FSL} = \langle \mathcal{L}, \theta, k_{CF}, S \rangle \tag{3}$$

The close factor k_{CF} describes the percentage of debt that the liquidator can repay in a single fixed spread liquidation. The spread S is the discount at which the liquidator can obtain the collateral. S is fixed throughout the execution of the protocol (i.e., the name *fixed spread liquidation*). With the liquidation spread, one can calculate the maximal collateral claimable by the liquidator $\mathcal{Q}$ as $(D_t \cdot k_{CF}) \cdot (1 + S)$. Without consideration of gas fees, the maximal obtainable profit by $\mathcal{Q}$ is $(D_t \cdot k_{CF}) \cdot S$. As the protocol is overall a zero-sum game, and under the assumption of non-existant slippage, the profit of the liquidator is equivalent to the borrowers loss, if denoted in the same cryptocurrency.

Other liquidation mechanisms, though operated differently from the fixed spread liquidations, follow similar high-level designs — debts are repaid in exchange for collateral from the liquidated borrowing position. For example, in MakerDAO auction liquidations, liquidators bid for the liquidation opportunity by submitting transactions [16]. In such a setting, the liquidation spread can hence be considered dynamic during the auction execution.

4   Motivation

We proceed to outline the design flaws of liquidation mechanisms and motivate why mitigating liquidations is necessary.

1. **Over-Liquidation.** DeFi borrowers are exposed to an unnecessarily overwhelming liquidation risk. In regular FSL configurations, $50\% \sim 100\%$ of a borrowing position is liquidated within a single transaction [16,21].
2. **MEV.** Liquidation is one of the major sources of MEV, which disrupts miner incentives and endangers the consensus security of a blockchain [17].
3. **Liquidation Spiral.** A liquidation increases the supply of the collateral cryptocurrencies available for sale. This supply inflation imposes a negative impact on the collateral prices [22] and may result in further liquidations (possibly liquidation spiral [11]). We provide a case study of a real liquidation event to present the impact of liquidations on collateral prices.
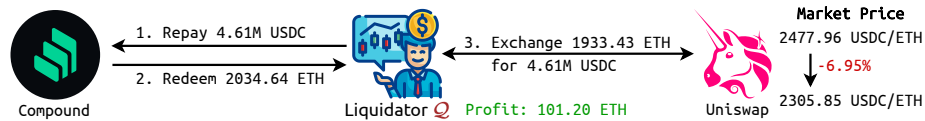
Fig. 1. A real liquidation event with a subsequent downward price trend of the collateral asset. The liquidator $\mathcal{Q}$ immediately sold parts of the redeemed ETH collateral from a Compound liquidation, which decreased the ETH price on Uniswap by 6.95%.

Case Study 1 (Liquidation Spiral) *As shown in Figure 1, two DeFi platforms were involved in this liquidation: (i) Compound, an over-collateralized lending platform; (ii) Uniswap, an on-chain exchange. USDC is a stablecoin, of which the value is pegged to USD.[6] In the studied liquidation, the liquidator mainly took the following three steps.*

1. *The liquidator repaid* 4.61M *USDC for a Compound borrowing position.*
2. *In return, the liquidator was allowed to redeem* 2,034.64 *ETH of collateral.*

---

[6] Transaction hash: 0xe7b6fac6502be7c6659880ff5d342ec470429c6f49cd457945bf07266 67eb689. Note that we ignore the irrelevant execution details to ease understanding.

3. *The liquidator bought* 1,933.43 *ETH from the redeemed collateral and exchanged the ETH for* 4.61*M USDC to cover its repayment cost in Step 1. The liquidator realized a profit of* 101.20 *ETH through this liquidation.*

In the third step, the exchange from ETH to USDC on Uniswap USDC/ETH triggered a price decline from 2,477.96 *USDC/ETH to* 2,305.85 *USDC/ETH* (−6.95%)*. This event shows that even a single liquidation can decrease the collateral price significantly.*

Why collateralization instead of liquidation? In this work, MIQADO requires additional collateral to be locked in the lending pool, reducing the liquid collateral asset supply. Hence, we conclude that MIQADO behaves more positively than a liquidation mechanism on stabilizing lending markets, effectively acting like a price "softening buffer". We empirically confirm this effect in Section 6.

5   MIQADO

In this section, we introduce MIQADO. MIQADO is a debt management mechanism for DeFi lending protocols. It mitigates liquidations through a set of incentives that decrease the likelihood of liquidation spirals. MIQADO relies on *supporters*, which are entities that are willing to top up unhealthy borrowing positions. To enable MIQADO, we introduce *reversible call options*, a novel financial primitive where the seller of a call option can pay a premium to terminate the contract before maturity.
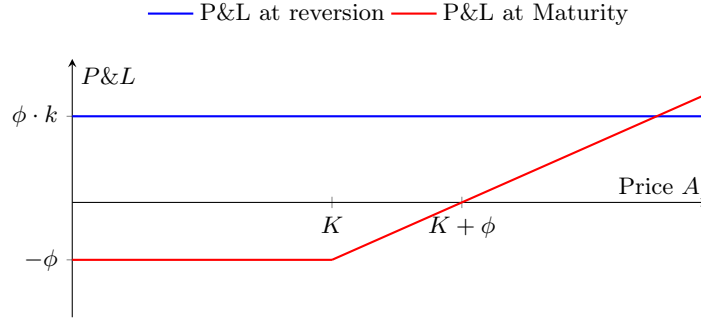
5.1   Reversible Call Option

Recall the notion of European call options as introduced in Section 2.4. In a European call option, the seller offers the option contract whereas the buyer acquires the option to exercise the right to buy an asset at a specific price by buying said option at a premium (i.e., the option price). The outcome of a European call option contract at maturity is binary — *(i)* the buyer exercises its right to buy or *(ii)* the buyer does not exercise its right to buy. We now introduce the *reversible* European call option, which augments the traditional European call option with an additional outcome to the option contract, where the seller is able to terminate the contract at a premium.

We say that a reversible European call option contract gives the buyer $\mathcal{C}_B$ the option, but not the obligation, to buy a specified amount N of an asset A at a specified price K at maturity T, and the seller $\mathcal{C}_S$ the option to terminate the contract at pre-Maturity $t_0 < t < T$. The buyer $\mathcal{C}_B$ pays a premium ϕ at t_0 for the option to exercise the contract at maturity T.

Formally, we define reversible call option as follows:

Definition 1 (Reversible Call Option). *A reversible call option is parameterized by an asset A, the asset amount N, the strike price K, the reimbursement factor k, and the time of maturity T. The mechanics are as follows:*

Fig. 2. Payoff & Loss (P&L) analysis for the Buyer $\mathcal{C}_B$ of the reversible call option. In case of reversion, the payoff for the $\mathcal{C}_B$ is constant. In case of maturity, the payoff is equal to a traditional call option.

t_0: (i) *The contract is agreed upon between $\mathcal{C}_B$ and $\mathcal{C}_S$.*
    (ii) *The buyer $\mathcal{C}_B$ pays a premium ϕ to the seller $\mathcal{C}_S$.*
$t_0 < t < T$: *The seller $\mathcal{C}_S$ of the option can choose to terminate the contract by reimbursing the buyer $\mathcal{C}_B$ with $\phi \cdot k$.*
T: *The buyer $\mathcal{C}_B$ can acquire N units of asset A at strike price K.*

Payoff analysis. The buyer $\mathcal{C}_B$ is the entity which is entitled to execute the option contract at maturity. We assume that $\mathcal{C}_B$ always acts rationally, such that their financial benefit is maximized. In the case of a reversible call option, the payoff which $\mathcal{C}_B$ receives can be categorized into two cases — *(i)* $\mathcal{C}_S$ terminates the option at pre-maturity or *(ii)* the contract is not terminated until maturity at time T. In the first case, the payoff for $\mathcal{C}_B$ is constant, as the seller $\mathcal{C}_S$ reimburses the buyer $\mathcal{C}_B$ with $\phi \cdot k$, where $k > 1$. If the seller $\mathcal{C}_S$ does not terminate the contract, the payoff for $\mathcal{C}_B$ is equivalent to

$$P_{\mathcal{C}_B} = \begin{cases} A(T) - K - \phi & \text{if } A(T) \geq K \\ -\phi & \text{if } A(T) < K \end{cases} \tag{4}$$

Note, that the payoff in this case is equivalent to a traditional European style call option. The visualized payoff curves for $\mathcal{C}_B$ are presented in Figure 2.

5.2 The MIQADO Protocol

We present the MIQADO protocol in the following. On a high-level, MIQADO seeks to mitigate liquidations through supporters that top-up the collateral of an unhealthy borrowing position (i.e., the health factor declined below one). MIQADO allows any external entity to become such a supporter. We start with an overview of MIQADO by outlining the equivalence to reversible call options.
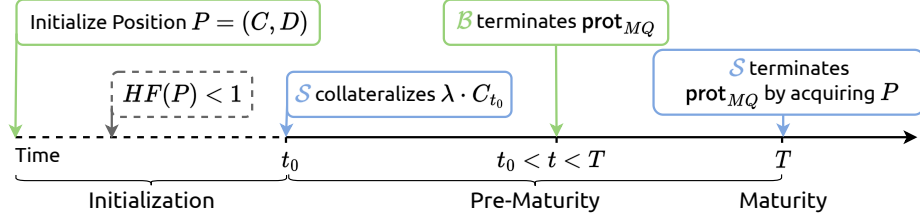
Fig. 3. High-level overview of the MIQADO protocol which realizes a reversible call option in DeFi. Once the borrowing position opened by the borrower $\mathcal{B}$ is unhealthy, yet not liquidated, the supporter $\mathcal{S}$ is able to top up the collateral in position P.

Overview An overview of MIQADO is presented in Figure 3. On a high-level, MIQADO is separated into three phases — *(i)* Initialization, *(ii)* pre-Maturity, and *(iii)* Maturity. We first assume that MIQADO replaces the liquidation mechanism in our exemplary lending/borrowing protocol. We defer practical considerations for co-existence of MIQADO and liquidations to Section 5.4.

1) Initialization. We assume the existence of an on-chain lending pool $\mathcal{L}$ with a single borrowing position $P = \langle D_t, C_t \rangle$ initialized by the borrower $\mathcal{B}$. The supporter can engage at time t_0, if the following condition holds:

$$HF_{t_0}(P) = \frac{C_{t_0} \cdot p_{t_0} \cdot \theta}{D_{t_0}} < 1 \tag{5}$$

In words, the health factor should be lower than one. Note that the position may be over-collateralized ($CR_{t_0}(P) > 1$) or under-collateralized ($CR_{t_0}(P) < 1$), depending on the steepness of the price decline that yields a borrowing position unhealthy. At this point, $\mathcal{S}$ buys a reversible call option by topping-up $\lambda \cdot C_{t_0}$ into P, which grants the right to take over the borrowing position P at maturity T. The price of the reversible call option hence is $\lambda \cdot C_{t_0}$. Note that the premium factor λ is a protocol parameter that can be ruled in the lending pool contract. To decide whether to deposit, a supporter would need to price the reversible call option and estimate its potential profitability, which we detail in Section 5.3.

2) pre-Maturity. Once $\mathcal{S}$ acquires a MIQADO option with maturity T, the pre-maturity stage starts. At any point $t_0 < t < T$, the borrower $\mathcal{B}$ can terminate the MIQADO protocol by repaying $\mathcal{S}$ the premium $\lambda \cdot C_{t_0}$ multiplied by a constant factor k_{re} that incentivizes the initial support of $\mathcal{S}$, hence

$$C_{re} = \lambda \cdot C_{t_0} \cdot (1 + I_{\mathcal{L}}) \cdot k_{re} \tag{6}$$

where $0 < I_{\mathcal{L}} < 1$ is the interest rate which $\mathcal{B}$ agreed to pay for its loan when initiating the position P. The factor $0 < k_{re} < 1$ is implementation dependent and should account for the risk $\mathcal{S}$ has to take when supporting a position.

3) Maturity. At Maturity, there are two possible options how the MIQADO protocol may terminate. The payoff for the supporter $\mathcal{S}$ in the case of maturity is depicted in Figure 2.

1. **Full Takeover.** In general, MIQADO option contracts have an "Out-of-the-Money" strike price K, such that the strike is greater than the collateralization ratio upon initiation of the position P by $\mathcal{B}$. Essentially, as the health factor is lower than one, the intrinsic value of the option is low, whereas the time value based on volatility and time of expiration is high.

2. **Default.** The supporter defaults and does not exercise the option, hence loses the premium ϕ (cf. Figure 2), if the price at Maturity is below the strike price K. In this case, where MIQADO fully replaces the liquidation mechanism, another round of Miqado initiates. Rational supporters initiate a MIQADO session if the condition presented in *1.) Initialization* is fulfilled.

Incentive Discussion A common question is why a supporter would actually engage in the MIQADO protocol and top up liquidity positions that are unhealthy. In general, whether a supporter is incentivized to engage in a MIQADO option in a FSL liquidity pool depends on the price volatility and the selected strike price. Given the volatility of various cryptocurrencies, it is infeasible to draw a general conclusion fitting all scenarios. Supporters can price the MIQADO options and compare to the required cost (i.e., the premium) to evaluate the potential risks. We outline a pricing model for reversible call options in Section 5.3. In practice, we assume that supporters taking a low risk will face termination at pre-maturity by $\mathcal{B}$, yielding a smaller payoff for $\mathcal{S}$. We empirically evaluate MIQADO's ability to prevent liquidation spirals by replacing the liquidation mechanism in Section 6.

5.3   Pricing Reversible Call Option

The reversible call option is equivalent to an European call option in the case of maturity. Therefore, we can apply the widely adopted Black-Scholes pricing model [8] for European call options to MIQADO. We outline the B-S model details in Appendix A. We assume that at initialization t_0, the supporter $\mathcal{S}$ buys a MIQADO option by supplying $\lambda \cdot C_{t_0}$ of additional collateral priced at $\lambda \cdot C_{t_0} \cdot p_{t_0}$. The spot exchange rate is equivalent to p_{t_0}, whereas the domestic interest rate r is equivalent to the borrowing interest rate of the protocol $I_{\mathcal{L}}$. The foreign interest rate r_f remains the same. The volatility σ can be calculated from the price history. Henceforth, the optimal factor λ^* following the B-S model can be calculated as

$$\lambda^* = \frac{p_{t_0} e^{-r_f \cdot T} N(d_1) - K e^{-I_{\mathcal{L}} \cdot T} N(d_2)}{C_{t_0} \cdot p_{t_0}} \tag{7}$$

with equations for d_1 and d_2 outlined in Appendix A. A supporter then compares the actual premium factor λ set by the lending protocol to λ^* and evaluates the profitability. In practice, a supporter would have a personalized pricing model based on the supporter's predictions on the price dynamics and risk preference.

5.4   Practical Instantiation

When there is no supporter $\mathcal{S}$ willing to purchase a reversible call option or when a supporter defaults, the lender $\mathcal{E}$ faces a loss as the borrower $\mathcal{B}$ is not
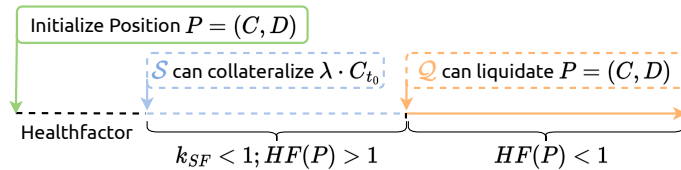
Fig. 4. Practical Instantiation of Miqado on top of a traditional liquidation mechanism. The supporter $\mathcal{S}$ has an advantage over the liquidator $\mathcal{Q}$ to support a temporarily unhealthy position.

incentivized to repay the outstanding debt and $\mathcal{S}$ is not incentivized to take over the position P. In a practical instantiation (cf. Figure 4), a protocol operator may want to operate Miqado options on top of a traditional liquidation mechanism in order to prevent this. As such, the protocol can employ a buffer to derive an additional *support factor* k_{SF}, such that $\mathcal{S}$ can engage in a Miqado option if

$$k_{SF} = CR_{t_0}(P) \cdot (\theta + B) < 1 \tag{8}$$

where B is the buffer parameter, s.t. $B > 1$.

A liquidator can additionally engage when the health factor is lower than one, as traditionally assumed and presented in Equation 5. With this construction, the supporter has an advantage over the liquidator to support a temporarily unhealthy position and make a profit. Effectively, this construction similarly mitigates liquidation spirals, dependent on the buffer B.

5.5 Remarks

Miqado enhances Fixed Spread Liquidations in the following aspects:

Rescue Opportunity. The reversible call option of Miqado offers a time window for a borrower to rescue its borrowing position. With a fixed spread liquidation, the close factor is usually larger than necessary such that more collateral is sold off at a discount, which negatively impacts the borrowers financial interests. With Miqado options, this risk is alleviated, such that over-liquidation is not a concern and the borrower has to pay less to rescue its position.

Collateral Restraint. Miqado absorbs additional collateral and locks it in the lending pool until the reversible call option's maturity. This mitigates the possible liquidation spiral, which we quantitatively show in Section 6.

MEV Mitigation. FSL liquidations provides deterministic and cost-free opportunities for miners to profit through manipulating transaction order and front-running other liquidators. In Miqado, if a miner deems a reversible call option profitable, it still has an advantage over other supporters. This is because a miner can single-handedly front-run any competing transaction and be the first to initiate Miqado. Nevertheless, as shown in Section 6.2, a Miqado reversible call option does not guarantee a profit. Moreover, a supporter bears a capital cost while locking the premium in the lending pool. We hence conclude that Miqado mitigates the MEV problem.

6 Empirical Evaluation

In this section, we evaluate the MIQADO protocol by comparing MIQADO to the dominant liquidation mechanism FSL. To this end, we collect all liquidation events on Aave (both V1 and V2) and Compound from the 1st of May, 2019 to the 30th of September, 2022. Aave and Compound are the top two lending protocols on Ethereum in terms of TVL, according to defillama.com. Both of the two lending protocols follow the FSL mechanism (cf. Section 3.2). In total, we collect 48,364 liquidations (Aave V1: 5,765; Aave V2: 25,576; Compound: 17,023).

6.1 Quantifying Liquidation Spiral

Collateral Release. A lending protocol that applies FSL directly sells the liquidated collateral to the liquidator at a discount. This aggravates the price downtrend of the liquidated cryptocurrency as liquidators may immediately sell of the acquired collateral, which was locked in the lending protocol, to secondary markets. Precisely measuring the impact of FSL on the liquidated collateral price is challenging. We need to devise an accurate economic model to exclude the impact of other factors, such as the demand change for the collateral. We also need to model the liquidity dynamics on various centralized and decentralized exchanges at the time of liquidation. These challenges are however beyond the scope of this study and are left for future work. Therefore, we choose to present the value of collateral that is released in the FSL liquidations (cf. Metric 1) to intuitively quantify the liquidation spiral introduced by the FSL mechanism.

Metric 1 (FSL Collateral Release) *The value of collateral released to the markets in a FSL liquidation.*

Figure 5 presents the monthly collateral release in the past 48,364 FSL liquidations. The total collateral release amounts to 2.32B USD over the 41 months.

Direct Price Decline. In Case Study 1 (cf. Section 4), we show that a liquidator can choose to sell the collateral acquired from the borrower within the liquidation transaction. We observe that such a "sell-after-liquidation" strategy is prevalent, which we define as a short liquidation (cf. Definition 2).

Definition 2 (Short Liquidation). *In a short liquidation, $\mathcal{Q}$ sells (fully or partially) the collateral acquired from $\mathcal{B}$ within the liquidation transaction.*

To identify a short liquidation, we first gather the ERC-20 transfer and asset swap events from a liquidation transaction.[7] With these events, we then filter

---

[7] ERC-20 is a fungible token standard, which is extensively adopted in the Ethereum DeFi ecosystem. An event refers to a log emitted by a smart contract during its execution. These events are identifiable by a unique topic hash and can represent various actions, such as an asset swap on a decentralized exchange. In this work, for asset swap events, we captured the most liquid exchanges on Ethereum including Uniswap V1, V2, V3, Sushiswap, and Curve.
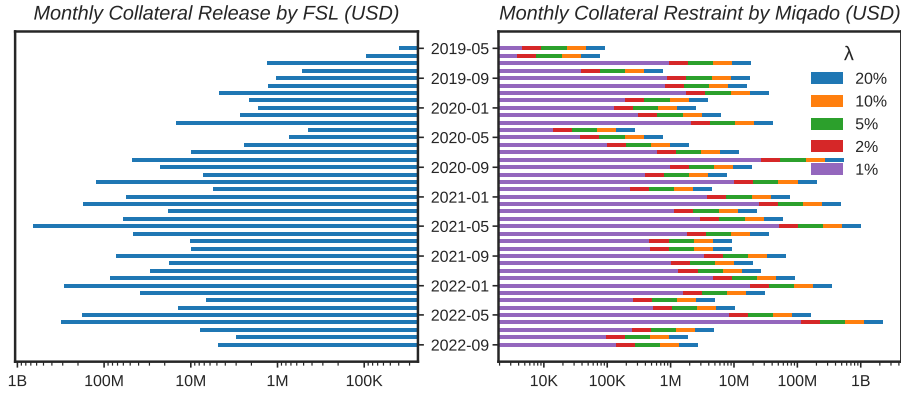
Fig. 5. Over a time-frame of 41 months (from the 1st of May, 2019 to the 30th of September, 2022), the collateral release by the FSL mechanism accumulates to 2.32B USD, with a monthly peak of 653.11M USD in May, 2021. On the contrary, our MIQADO protocol restrains additional collateral in the lending pool instead of releasing and further mitigates the liquidation spiral. The accumulative collateral restraint by MIQADO (cf. Metric 3, Section 6.2) amounts to 5.63B USD when the premium factor λ is set to 20%.

the exchange contracts that are potentially used for collateral selling. The filtering process is based on two criteria: *(i)* the contract emits an asset swap event during the transaction execution; *(ii)* the contract receives the liquidated collateral token (fully or partially). If such an exchange contract is detected, the liquidation transaction is classified as a short liquidation. From the 48,364 studied liquidations, we identify 18,305 short liquidations. In total, 1.33B USD of collateral is sold directly by the liquidators in these short liquidations. We find that in 3,365 of the short liquidations, the acquired collateral is fully sold. On average, 95.95% of the collateral is sold in a short liquidation.

A short liquidation directly leads to a collateral price decline on the exchange where the liquidator sells the acquired collateral. Although a significant price change in a single market will eventually be evened out by arbitrageurs[8] among all available markets, while the negative impact on the collateral price remains. We therefore apply such a price decline as a metric of how FSL liquidations destabilize lending protocols (cf. Metric 2).

Metric 2 (Direct Price Decline) *In a short liquidation, the spot price decline on the exchange where the liquidator sells the acquired collateral.*

We find that the average collateral price decline led by the 18,305 short liquidations is 0.38%, while the maximal decline reaches 26.90%.[9]

---

[8] Entities who profit by leveraging price differences across different markets.

[9] Cf. 0xff2d484638b846a46b203a22b02d71df44bf78346c72b954ad0ad05f34b134c8

6.2   Miqado Evaluation

In the following, we assume that Aave and Compound had adopted Miqado and simulate how Miqado could have outpaced FSL in the past liquidation events. Our simulation is constrained to every single liquidation event, while ignoring the long-term impact of Miqado. For example, Miqado mitigates the price downtrend and hence could have prevented follow-up liquidations in a liquidation spiral, which we leave for future research.

The performance of Miqado is influenced by its parameters. In our simulation, we assume that Miqado follows the corresponding lending protocol's configuration for the collateral discount θ at the time of each liquidation. This implies that Miqado shares the same triggering condition as FSL (i.e., when the health factor declines below one) and hence applies to every liquidated borrowing position. We also need to parameterize the premium factor λ and the time to maturity ΔT for the reversible call option. Similar to how the parameters for lending protocols evolve,[10] these two parameters need to be empirically determined and dynamically adjusted given various market conditions (e.g., the price volatility). We therefore simulate on various specific settings to show how Miqado performs under different configurations.

Collateral Restraint. Miqado absorbs additional collateral, which is restrained in the lending pool during the protocol execution. This collateral restraint, contrary to FSL's supply release (cf. Metric 1), imposes a positive impact on stabilizing collateral price (cf. Metric 3).

Metric 3 (Miqado Collateral Restraint) *The value of collateral deposited by the supporter in a* Miqado *execution.*

We visualize the monthly comparison between the collateral restraint by Miqado and the collateral release by FSL in Figure 5. The accumulative collateral restraint with different parameters is outlined in Table 1, Appendix B. We find that when λ is 20%, the accumulative collateral restraint reaches 5.63B USD. Notably, as a by-product, the restrained additional collateral is counted towards the lending pool's TVL, which is a common protocol success metric.

Health Factor Recovery. One shared target of Miqado and FSL is to increase the health factor of a borrowing position. In Figure 6, we present the health factor distributions before and after the studied FSL liquidations. We further simulate how Miqado could have increased the health factor with different parameters. We find that, 82.25% of the liquidated positions become healthy (the health factor is increased above one) after a FSL liquidation. When λ is set to 5%, Miqado achieves the same performance (82.22% of the borrowing positions become healthy after the supporter deposits).

---

[10] https://docs.aave.com/risk/asset-risk/risk-parameters.
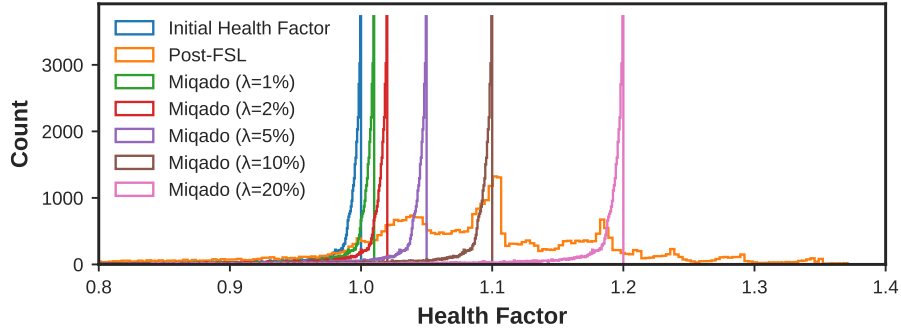
Fig. 6. The health factor distributions pre- and post-FSL liquidations. We also visualize how MIQADO increases the health factor with different premium factors.

Payoffs for Supporter. We proceed to simulate the payoffs of MIQADO supporters. In this section, we assume that the borrowers would not terminate the reversible call options. We parameterize ΔT to 1, 6, and 24 hours and apply the real market price to value every reversible call options at maturity. A supporter then chooses to exercise the option when the value of collateral exceeds the outstanding debt at maturity, and defaults otherwise (cf. Figure 2). In Table 2, Appendix B, we outline the probability that a supporter *(i)* exercises the call option and profits, *(ii)* exercises the call option but loses, *(iii)* defaults, under different parameters. We also present the average profit for every supporter. We show that, to our surprise, the MIQADO premium factor does not impact the probability of the reversible call option in practice. Notably, in Table 2, we assume that the borrowers would not rescue their debts and therefore conjecture that the actual payoffs for supporters would be lower than the presented results.

Collateral Release Reduction In practice, the probability that a MIQADO supporter may default on the reversible call option is up to 13.48%. This implies that the associated borrowing position is under-collateralized at maturity and may be further available for FSL (cf. Section 5.4). We simulate that, in the worst case, the collateral release by FSL after MIQADO (cf. Metric 1) amounts to 236.40M USD, which is a reduction of 89.82% compared the 2.32B USD collateral release by FSL only (cf. Section 6.1).

7   Related Work

Various works in DeFi focus on lending & borrowing protocols from diverse perspectives such as economics, security and formal modeling. Kao *et al.* [9] evaluate the economic security of Compound by using agent-based simulation. Darlin *et al.* [6] investigate the optimal bidding strategies for auction liquidations. Perez *et al.* [14] present an empirical analysis of liquidations on Compound. Qin *et al.* [16]

perform a longitudinal study on the liquidation events of four major Ethereum lending pools (i.e., Aave, Compound, dYdX, and MakerDAO), while showing the over-liquidation problem of the fixed spread liquidations. In this work, we show that the proposed MIQADO protocol mitigates these problems. Bartoletti *et al.* systematize DeFi lending pools [2] and further provide a formal analysis of DeFi lending pools [1]. Wang *et al.* [21] study under-collateralized DeFi lending platforms showing the three main risks of a leverage-engaging borrower, namely, impermanent loss, arbitrage loss, and collateral liquidation. Select stablecoin designs leverage lending and borrowing mechanisms (e.g., DAI from MakerDAO), as studied in [12,10,11].

Besides DeFi lending and borrowing, further studies focus on decentralized exchanges and the security of the DeFi ecosystem [5,24,18,17,25]. Most recently, Zhou *et al.* [25] systematize attacks on DeFi and highlight the need for further research on the protocol layer due to 59% of attacks on lending & borrowing platforms yielding from insufficient protocol design.

Further, there are various non-academic works that offer call options in decentralized applications. Hegic offers gas-free option trading for ETH and BTC. Ribbon supports on-chain options, where the option price, or premium, is set through an auction. However, none of the existing decentralized applications applies an equivalent financial primitive to lending & borrowing platforms to mitigate liquidations.

8   Conclusion

We presented MIQADO, the first liquidation mitigation protocol. Whereas existing lending and borrowing protocols rely on plain liquidation mechanisms, MIQADO secures borrowing positions by incentivizing external entities to provide additional collateral. To facilitate MIQADO, we introduce reversible call options, a novel financial primitive with promising properties for application in MIQADO. To highlight the need for MIQADO, we show that fixed spread liquidations trigger liquidation spirals and destabilize lending markets. We evaluate MIQADO by executing MIQADO logic on past blockchain states. We show that by applying MIQADO, the amount of liquidated collateral can be reduced by 89.82%. By providing a plug-in replacement to existing liquidation mechanisms, MIQADO can prevent systemic-failures without extensive overhead.

References

1. Bartoletti, M., Chiang, J., Junttila, T., Lluch Lafuente, A., Mirelli, M., Vandin, A.: Formal analysis of lending pools in decentralized finance. In: Leveraging Applications of Formal Methods, Verification and Validation. Adaptation and Learning: 11th International Symposium, ISoLA 2022, Rhodes, Greece, October 22–30, 2022, Proceedings, Part III. pp. 335–355. Springer (2022)
2. Bartoletti, M., Chiang, J.H.y., Lafuente, A.L.: Sok: lending pools in decentralized finance. In: International Conference on Financial Cryptography and Data Security. pp. 553–578. Springer (2021)
3. Black, F., Scholes, M.: The pricing of options and corporate liabilities. Journal of political economy **81**(3), 637–654 (1973)
4. Bonneau, J., Miller, A., Clark, J., Narayanan, A., Kroll, J.A., Felten, E.W.: Sok: Research perspectives and challenges for bitcoin and cryptocurrencies. In: Security and Privacy (SP), 2015 IEEE Symposium on. pp. 104–121. IEEE (2015)
5. Daian, P., Goldfeder, S., Kell, T., Li, Y., Zhao, X., Bentov, I., Breidenbach, L., Juels, A.: Flash boys 2.0: Frontrunning in decentralized exchanges, miner extractable value, and consensus instability. In: 2020 IEEE Symposium on Security and Privacy (SP). pp. 910–927. IEEE (2020)
6. Darlin, M., Papadis, N., Tassiulas, L.: Optimal bidding strategy for maker auctions. arXiv preprint arXiv:2009.07086 (2020)
7. Eskandari, S., Salehi, M., Gu, W.C., Clark, J.: Sok: Oracles from the ground truth to market manipulation. In: Proceedings of the 3rd ACM Conference on Advances in Financial Technologies. pp. 127–141 (2021)
8. Hull, J.C.: Options futures and other derivatives. Pearson Education India (2003)
9. Kao, H.T., Chitra, T., Chiang, R., Morrow, J.: An analysis of the market risk to participants in the compound protocol. In: Third International Symposium on Foundations and Applications of Blockchains (2020)
10. Klages-Mundt, A., Harz, D., Gudgeon, L., Liu, J.Y., Minca, A.: Stablecoins 2.0: Economic foundations and risk-based models. In: Proceedings of the 2nd ACM Conference on Advances in Financial Technologies. pp. 59–79 (2020)
11. Klages-Mundt, A., Minca, A.: (in) stability for the blockchain: Deleveraging spirals and stablecoin attacks. arXiv preprint arXiv:1906.02152 (2019)
12. Klages-Mundt, A., Minca, A.: While stability lasts: A stochastic model of noncustodial stablecoins. Mathematical Finance (2022)
13. Nakamoto, S.: Bitcoin: A peer-to-peer electronic cash system (2008)
14. Perez, D., Werner, S.M., Xu, J., Livshits, B.: Liquidations: Defi on a knife-edge. In: International Conference on Financial Cryptography and Data Security. pp. 457–476. Springer (2021)
15. Qin, K., Zhou, L., Afonin, Y., Lazzaretti, L., Gervais, A.: Cefi vs. defi–comparing centralized to decentralized finance. arXiv preprint arXiv:2106.08157 (2021)
16. Qin, K., Zhou, L., Gamito, P., Jovanovic, P., Gervais, A.: An empirical study of defi liquidations: Incentives, risks, and instabilities. In: Proceedings of the 21st ACM Internet Measurement Conference. pp. 336–350 (2021)
17. Qin, K., Zhou, L., Gervais, A.: Quantifying blockchain extractable value: How dark is the forest? In: 2022 IEEE Symposium on Security and Privacy (SP). pp. 198–214. IEEE (2022)
18. Qin, K., Zhou, L., Livshits, B., Gervais, A.: Attacking the defi ecosystem with flash loans for fun and profit. In: International Conference on Financial Cryptography and Data Security. pp. 3–32. Springer (2021)

19. Shreve, S.: Stochastic calculus for finance I: the binomial asset pricing model. Springer Science & Business Media (2005)
20. Stoll, H.R.: The relationship between put and call option prices. The Journal of Finance **24**(5), 801–824 (1969)
21. Wang, Z., Qin, K., Minh, D.V., Gervais, A.: Speculative multipliers on defi: Quantifying on-chain leverage risks. In: Financial Cryptography and Data Security: 26th International Conference, FC 2022, Grenada, May 2–6, 2022, Revised Selected Papers. pp. 38–56. Springer (2022)
22. Whelan, J., Msefer, K., Chung, C.V.: Economic supply & demand. MIT (2001)
23. Wood, G., et al.: Ethereum: A secure decentralised generalised transaction ledger. Ethereum project yellow paper **151**(2014), 1–32 (2014)
24. Zhou, L., Qin, K., Torres, C.F., Le, D.V., Gervais, A.: High-frequency trading on decentralized on-chain exchanges. In: 2021 IEEE Symposium on Security and Privacy (SP). pp. 428–445. IEEE (2021)
25. Zhou, L., Xiong, X., Ernstberger, J., Chaliasos, S., Wang, Z., Wang, Y., Qin, K., Wattenhofer, R., Song, D., Gervais, A.: Sok: Decentralized finance (defi) attacks. arXiv preprint arXiv:2208.13035 (2022)

A   Black-Scholes Model

We apply the Black-Scholes model [3] to price call options under optimal assumptions, such as the non-existence of dividend payouts. The option premium is calculated for European call options on a per-share basis. The payoff for $\mathcal{C}_S$ introduced in Figure 2 is trivial to grasp but it does not yield any insights on the pricing of the option. With the BS model for a European call option determines the option price as

$$c = S_0 e^{-r_f \cdot T} N(d_1) - K e^{-r \cdot T} N(d_2) \tag{9}$$

where

$$d_1 = \frac{\ln(S_0 K) + (r - r_f + \sigma^2 2) \cdot T}{\sigma \cdot \sqrt{T}} \tag{10}$$

and

$$d_2 = d_1 - \sigma \cdot \sqrt{T}. \tag{11}$$

S_0 is the spot exchange rate, r_f is the foreign interest rate, r is the domestic interest rate and σ is the volatility of the underlying asset. For a detailed introduction to the Black-Scholes pricing model for European call options, we refer the interested reader to [8].

We remark that the B-S model does not take into account the decrease in risk and lowered average payoff due to termination by $\mathcal{C}_S$. We defer a more precise pricing model for reversible call options that to future work.

B   Tables

Table 1. Accumulative collateral restraint by MIQADO over a time-frame of 41 months.

MIQADO Premium Factor λ	1%	2%	5%	10%	20%
Accumulative Collateral Restraint (USD)	281.70M	563.40M	1.41B	2.82B	5.63B

Table 2. Payoffs for MIQADO supporters at maturity assuming that borrowers would not rescue. We present the probability that a supporter *(i)* exercises the call option and profits, *(ii)* exercises the call option but loses, *(iii)* defaults. We also simulate the average profit for supporters. our simulations are based on the real market prices.

λ	1%	2%	5%	10%	20%	ΔT
+	87.46%	87.46%	87.46%	87.46%	87.46%	
−	0.29%	0.58%	1.41%	2.47%	4.14%	
#	12.25%	11.96%	11.13%	10.08%	8.41%	1hour
$	125.51K±1.52M	125.51K±1.52M	125.50K±1.52M	125.49K±1.52M	125.48K±1.52M	
+	87.19%	87.19%	87.19%	87.19%	87.19%	
−	0.30%	0.60%	1.50%	2.68%	4.44%	
#	12.51%	12.21%	11.31%	10.13%	8.37%	6 hours
$	154.01K±2.19M	154.01K±2.19M	154.00K±2.19M	154.00K±2.19M	154.98K±2.19M	
+	85.95%	85.95%	85.95%	85.95%	85.95%	
−	0.56%	1.03%	2.16%	3.62%	5.59%	
#	13.48%	13.02%	11.89%	10.42%	8.45%	24 hours
$	144.42K±1.83M	144.40K±1.83M	144.36K±1.83M	144.32K±1.83M	144.29K±1.83M	

+ exercise and profit   − exercise but lose   # default
$ average profit for supporters in USD (mean±std)