

# The Economics of DeFi Lending: A Model of Smart Contract Parameter Choice

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## Abstract

We propose a simple model to analyze the optimal design of a decentralized finance (DeFi) lending protocol. We focus on two key smart contract parameters: the loan-to-value ratio and liquidation threshold. Our model reveals fundamental trade-offs between borrower leverage and lender security, with important implications for protocol governance and design. We show that the optimal liquidation threshold should be set to its maximum value, benefiting both borrowers and liquidity providers. However, this theoretical prediction stands in contrast to observed protocol implementations, where thresholds are typically set lower. The model also demonstrates how governance structure affects parameter choices: borrower-dominated governance leads to higher loan-to-value ratios, while liquidity provider-dominated governance leads to lower ratios. These findings have significant implications for protocol design, particularly in light of the efficiency of modern liquidation mechanisms enabled by flash loans and automated bots. Our analysis provides a framework for understanding how protocol parameters are determined through the interaction of governance structure, market competition, and stakeholder interests.

## 1 Introduction

Decentralized finance (DeFi) has emerged as a significant innovation in financial markets, with lending protocols representing one of its most important applications. These protocols allow users to borrow cryptocurrency against collateral without intermediaries, using smart contracts to automate lending operations. A critical aspect of these protocols is the

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choice of risk parameters that govern lending activities, such as the loan-to-value (LTV) ratio and the liquidation threshold. These parameters are typically not hardcoded but can be modified through protocol governance, usually implemented through a Decentralized Autonomous Organization (DAO). This creates an interesting economic problem: how should these parameters be set to balance the interests of different stakeholders?

This paper develops a theoretical framework to analyze this question. We consider a model with three key participants: a borrower, a liquidity provider (LP), and the protocol governance (DAO). The borrower deposits collateral to take a loan, which they can invest in private projects. The LP provides the loanable funds in exchange for interest. The DAO, an agent representing the community of stakeholders, sets the protocol parameters to maximize a weighted average of borrower and LP welfare.

Our analysis yields several important results. First, we show that the optimal liquidation threshold should be set to its maximum value (1 in our model). This finding stands in contrast to observed protocol implementations, where thresholds are typically set lower. We demonstrate that higher thresholds benefit both borrowers and LPs: borrowers face lower expected costs due to reduced liquidation probability, while LPs benefit from increased collateral provision.

Second, we analyze the optimal loan-to-value ratio and find that it creates a fundamental trade-off between borrower leverage and LP security. The optimal ratio depends on the relative influence of different stakeholders in protocol governance. Specifically, borrower-dominated governance leads to higher LTV ratios, while LP-dominated governance leads to lower ratios. This might create a natural tension in DAO governance between borrower and LP interests.

In addition, we show that increased competition (higher outside options) leads to parameter choices favoring the group with better alternatives. This may result in protocols specializing in serving different user types based on competitive pressures. Parameter choices should reflect the relative bargaining power of borrowers versus LPs, which can be influenced by the competitive landscape.

Our paper contributes to the emerging literature on DeFi lending protocols and their governance mechanisms. The rest of the paper is organized as follows. Section 2 reviews the related literature. Section 3 presents the model setup. Section 4.1 analyzes the borrower’s cost minimization problem and the effects of protocol parameters on borrower incentives. Section 4.2 examines liquidity provider payoffs and how they are affected by protocol parameters. Section 5 analyzes the optimal parameter choice for the DAO. Section 6 discusses the implications of our findings and compares them with observed protocol implementations. Section 7 concludes and suggests directions for future research.

## 2 Related Literature

This paper contributes to the emerging literature on decentralized finance (DeFi) lending protocols and their governance mechanisms. Our work relates to several strands of literature.

First, we build on studies examining the fundamental characteristics of DeFi lending protocols. [Irresberger et al. \(2024\)](#) define lending protocols as marketplaces for digital assets in which: i) blockchains are used as settlement layers, ii) smart contracts are employed

to govern the interactions between borrowers and liquidity suppliers, iii) only cryptoassets are (currently) supported, iv) maintenance of the code is performed by a community of governance token holders, and v) liquidity supply and trust mediation are conducted by market participants who collectively share the benefits and costs of decentralized provision. A key aspect of their analysis is how protocol governors calibrate liquidation thresholds and penalties to balance liquidation risk mitigation against borrowers’ ability to take leveraged positions.

Second, our work relates to research on how parameter changes affect borrower and lender behavior. [Wang \(2024\)](#) explore the effects of margin requirement relaxations on borrower behavior using data from Aave and Compound. They find that looser requirements increase borrowing, particularly among highly leveraged positions, and lead to higher utilization ratios and interest rates. Complementing this analysis, [Mueller \(2022\)](#) examines the effects of liquidation incentives on liquidation behavior, documenting that insufficient incentives can result in positions remaining unliquidated. Their work also analyzes how blockchain transaction fees affect leveraged traders’ behavior.

Third, we contribute to the literature on systemic risk and liquidation mechanisms in DeFi markets. [Lehar and Parlour \(2022\)](#) examine the price impact of collateral liquidations in decentralized lending platforms, focusing on Compound and Aave. They find that liquidations, especially those involving flash loans, can create both temporary and permanent price impacts on decentralized exchanges, potentially triggering negative feedback loops and increasing systemic fragility. [Campello et al. \(2023\)](#) also contribute to this area by investigating the systemic risks of over-collateralization in a decentralized lending platform (Venus) and introducing the concept of zombie debt, which are loans near liquidation yet unresolved, revealing distinct short- and long-term risks associated with varying degrees of leverage. [Chiu et al. \(2022\)](#) develop a dynamic model of DeFi lending where pre-specified and rigid smart contract terms, including collateral haircuts, can introduce significant fragilities. They demonstrate that this rigidity, coupled with information friction between borrowers and lenders, can lead to a price-liquidity feedback loop. This feedback mechanism can result in multiple self-fulfilling equilibria where lending activity and asset prices co-move based on market sentiment, making the system vulnerable to sentiment-driven cycles and hindering the ability of the protocol to dynamically respond to evolving market conditions

Our theoretical framework complements these empirical studies by providing a formal model on the factors driving how protocol parameters protocol optimization, taking into account the competing interests of different stakeholders. The model generates testable predictions about the relationship between governance structure and parameter choices, helping explain several empirical findings in the literature while providing new hypotheses for future research.

### 3 Model Setup

Consider a two-period model ( $t = 0, 1$ ) featuring three types of agents: borrowers, liquidity providers, and a decentralized autonomous organization (DAO) that sets the protocol parameters. A lending smart contract facilitates overcollateralized borrowing by borrowers and interest earnings by liquidity providers. The smart contract operates on two crypto-assets:

the loanable currency and the collateral asset. The exogenous exchange rate, defined as the price of the loanable currency in terms of the collateral asset, is denoted by  $p$  and represents the sole source of uncertainty in the model.

The model is designed to capture key features of decentralized finance (DeFi) lending protocols while maintaining analytical tractability. For simplicity, we initially treat the interest rate (denoted  $i$ ) and the liquidation bonus rate (i.e., the additional compensation awarded to liquidators, denoted  $b$ ) as exogenously given. These parameters analyzed in greater detail in subsequent extensions of the model.

## 3.1 Agents and Timeline

### 3.1.1 DAO

At  $t = 0$ , the DAO chooses two key parameters:

- The loan-to-value ratio ( $\lambda$ ), which determines the maximum amount that can be borrowed against collateral
- The liquidation threshold ( $\delta$ ), which determines when a position becomes eligible for liquidation

These parameters must satisfy  $0 < \lambda < \delta < 1$  to ensure economic viability of the protocol.

### 3.1.2 Borrowers

Borrowers are risk-neutral agents who:

- At  $t = 0$ , want to borrow a fixed amount  $L$  and must decide how much collateral  $C$  to deposit (subject to the borrowing constraint  $L \leq \lambda C$ )
- Face an opportunity cost rate  $r_o$  for the capital used as collateral
- Pay the smart contract's interest rate  $i$  on the loan if no liquidation occurs
- Face additional costs if liquidation occurs, including a bonus rate  $b$  paid to liquidators

### 3.1.3 Liquidity Providers

LPs are risk-neutral agents who:

- At  $t = 0$ , provide funds to the lending pool
- Earn interest rate  $i$  on loans that are repaid
- Face potential losses if liquidation value is insufficient

### 3.2 Price Uncertainty and Returns

The exchange rate  $p_t$  follows a stochastic process with known distribution  $F(p)$  and density  $f(p)$ . We assume:

- $p_t > 0$  for all  $t$
- The distribution  $F(p)$  is common knowledge

### 3.3 Liquidation Mechanism

At  $t = 1$ , a loan position faces liquidation if:

$$\frac{p_1 L(1+i)(1+b)}{C} > \delta \quad (1)$$

This occurs when the debt value relative to collateral exceeds the liquidation threshold.<sup>1</sup> When liquidation occurs:

- The loan is automatically repaid by the smart contract through a liquidation mechanism, which deducts the corresponding amount from the borrower's collateral.
- Under this mechanism, third-party liquidators repay the outstanding loan and, in return, receive a liquidation bonus at rate  $b$  applied to the liquidated amount. We assume the bonus provides sufficient incentive to ensure prompt liquidation. If the value of the collateral is insufficient to cover the debt, the entire collateral is liquidated.
- LPs recover the lesser of the outstanding debt or the collateral value, with each amount adjusted to account for the liquidation bonus.

### 3.4 Payoff Structure

The payoff structure depends on three key events that can be expressed in terms of the exchange rate price  $p_1$ :

1. Whether liquidation occurs ( $p_1 > \frac{\delta C}{(1+i)(1+b)L}$ )
2. Whether the liquidation occurs after debt exceeds the collateral value ( $p_1 > \frac{C}{(1+i)(1+b)L}$ )
3. Whether the position is liquidated before debt exceeds the collateral value ( $\frac{\delta C}{(1+i)(1+b)L} < p_1 \leq \frac{C}{(1+i)(1+b)L}$ )

These events determine the borrower's costs and the payoffs to both borrowers and LPs.

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<sup>1</sup>We include the bonus in the liquidation rule for analytical simplicity but could be removed without loss of generality. For instance, we note that in protocols such as AAVE the liquidation rule does not include the bonus. See [AAVE \(2020\)](#).

## 4 Analysis

### 4.1 The Borrower's Cost Minimization Problem

The borrower's objective is to choose the optimal amount of collateral to deposit,  $C$ , so as to minimize the expected borrowing cost, subject to the protocol's loan-to-value constraint.

The borrowing costs include the opportunity cost of providing collateral ( $r_o C$ ), plus the following contingent costs:

- $p_1 L i$ : The interest cost if no liquidation occurs
- $p_1 L(i + b + ib)$ : The cost if liquidation occurs while collateral is sufficient to cover the debt. Notice in this case the borrower keeps the loan ( $p_1 L$ ) but loses the value of debt plus the liquidation costs ( $p_1 L(1 + i)(1 + b)$ ) from the collateral deposited in the protocol
- $C - p_1 L$ : The cost if liquidation occurs when collateral is insufficient to cover the debt. Notice in this case the borrower loses the entire collateral deposited in the protocol.

The contingent costs are shown in the Figure 1.

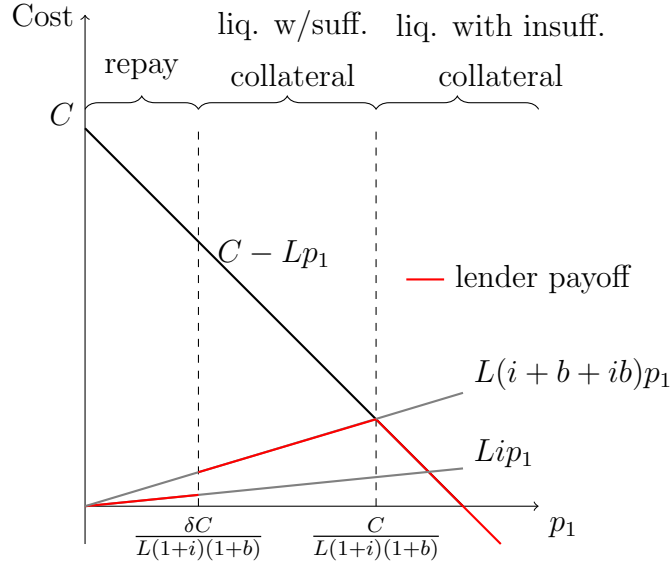


Figure 1: Borrower's cost structure and payoff regions. The graph shows the borrower's cost (in red) across different price regions: repayment (no liquidation), liquidation with sufficient collateral, and liquidation with insufficient collateral. The vertical dashed lines indicate the price thresholds that separate these regions.

Notice that at low values of  $p_1$ , the costs increase linearly with  $p_1$ . There is also a jump at the liquidation threshold, given by the added costs of the liquidation. Finally, the borrower's costs decrease when the debt exceeds the collateral value. This could eventually turn to a benefit if  $p_1$  is sufficiently high.

The cost minimization problem can be formulated as:

$$\begin{aligned}
\min_C E[\text{BC}] = & r_o C + P \left( p_1 \leq \frac{\delta C}{(1+i)(1+b)L} \right) p_1 L i \\
& + P \left( \frac{\delta C}{(1+i)(1+b)L} < p_1 \leq \frac{C}{(1+i)(1+b)L} \right) p_1 L (i + b + ib) \\
& + P \left( p_1 > \frac{C}{(1+b)(1+i)L} \right) (C - p_1 L) \\
\text{s.t. } & L \leq \lambda C
\end{aligned} \tag{2}$$

**Proposition 1.** *For some parameter and distribution assumptions, the borrower's problem has an interior solution, meaning that the borrower will provide more collateral than what is required by the protocol's loan-to-value ratio ( $C^* > \frac{L}{\lambda}$ ). If the marginal costs are sufficiently high, the borrower will choose to provide the minimum collateral required by the protocol's loan-to-value ratio (i.e.,  $C^* = \frac{L}{\lambda}$ ).*

*Sketch.* The proof follows from analyzing the Kuhn-Tucker conditions of the borrower's cost minimization problem. When the constraint is non-binding ( $L < \lambda C$ ), setting  $\mu = 0$  in the first-order condition reveals that the optimal collateral amount balances several effects:

- The marginal cost for providing collateral.
- The lower interest cost due to the increase in the probability of non-liquidation.
- The increased costs of liquidation in the event that the loan is liquidated before the debt exceeds the value of the collateral.
- The higher loss in the event that collateral is completely liquidated.

For some parameter configurations, these effects can exactly offset each other at a point where  $L < \lambda C$ , leading to an interior solution. See section A.1 in Appendix A for the complete proof.  $\square$

#### 4.1.1 Effects of Protocol Parameters on the Borrower's Incentives

We now analyze how changes in the protocol parameters affect the borrower's decisions. We start by analyzing the effect of changing the liquidation threshold  $\delta$ .

**Proposition 2.** *The borrower's expected cost decreases with the liquidation threshold  $\delta$ . Specifically,  $\frac{\partial}{\partial \delta} E[\text{BC}] < 0$ .*

This result is intuitive: a higher liquidation threshold reduces the probability of liquidation, thereby reducing the expected costs associated with liquidation events. The proof follows from analyzing the derivative of the cost function with respect to  $\delta$ , which shows that all terms in the derivative are negative. See Section A.2 in Appendix A for the complete derivation.

**Proposition 3.** *The optimal collateral amount increases with the liquidation threshold. Specifically,  $\frac{dC}{d\delta} > 0$ .*

This result shows that borrowers optimally respond to higher liquidation thresholds by increasing their collateral. While higher thresholds reduce liquidation risk, they also allow borrowers to take on more risk. The optimal response is to increase collateral to maintain the same level of risk protection for the protocol. The proof follows from analyzing the implicit derivative of the first-order condition with respect to  $\delta$ . See Section A.3 in Appendix A for the complete derivation.

We now analyze the effect of changing the loan-to-value ratio  $\lambda$ .

**Proposition 4.** *The effect of the loan-to-value ratio  $\lambda$  on the borrower's cost depends on whether the constraint  $L \leq \lambda C$  is binding in the borrower's cost minimization problem:*

1. *If the constraint is not binding (interior solution), then  $\frac{\partial E[\text{BC}]}{\partial \lambda} = 0$*
2. *If the constraint is binding, then  $\frac{\partial E[\text{BC}]}{\partial \lambda} < 0$ , as increasing  $\lambda$  allows the borrower to provide less collateral while maintaining the same loan amount*

*Sketch.* The proof follows from analyzing the borrower's cost minimization problem with the constraint  $L \leq \lambda C$ . When the constraint is not binding, changes in  $\lambda$  have no effect on the optimal solution. When the constraint is binding, the first-order condition implies that  $\frac{\partial E[\text{BC}]}{\partial C} > 0$  at the optimum. This means that increasing  $\lambda$  relaxes the constraint, allowing the borrower to reduce their collateral while maintaining the same loan amount, thereby reducing their expected cost. See Section A.4 in Appendix A for the complete proof.  $\square$

The first implication of this result is that increases in  $\lambda$  may not always imply changes in borrowers behavior. If the borrower is already overcollateralizing its position, there will be no change to the expected cost. However, if this is not the case, increasing  $\lambda$  will reduce the borrower's expected cost by allowing them to provide less collateral while maintaining the same loan amount.

## 4.2 Liquidity Provider Payoffs

The liquidity provider (LP) deposits loanable currency with the expectation of receiving an interest rate  $i$ . The payoff for the LP is guaranteed as long as the collateral is sufficient to cover for the lender's debt and liquidation costs. If this does not happen, the LP will receive only what can be recovered from the collateral after liquidation costs.

Therefore, the contingent payoffs for the LP, in collateral currency units, are the following:

- $Lip_1$ : Obtains interest  $i$  in the scenarios where there is repayment (no liquidation) or there is a liquidation before debt exceeds the collateral value (plus liquidation costs) ( $p_1 < \frac{C}{L(1+i)(1+b)}$ )
- $\frac{C}{(1+b)}$  when the collateral cannot cover the lender's debt.

Therefore the expected return for a lender that deposits  $L$  is

$$E[l] = p_1 Li \cdot P \left( p_1 \leq \frac{C}{(1+i)(1+b)L} \right) + \frac{C}{(1+b)} \cdot P \left( p_1 > \frac{C}{(1+i)(1+b)L} \right) \quad (3)$$

The expected return for the LP is shown in the Figure 2.



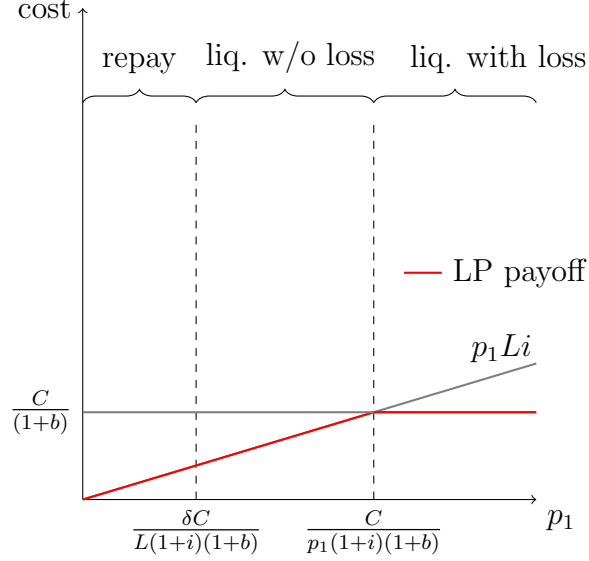


Figure 2: Liquidity provider's payoff. The graph shows the liquidity provider's payoff in collateral currency units across different price regions: repayment (no liquidation), liquidation before debt exceeds the collateral value, and liquidation after debt exceeds the collateral value. The vertical dashed lines indicate the price thresholds that separate these regions.

### 4.3 Effects of Protocol Parameters in the Liquidity Provider Pay-off

**Proposition 5.** *A higher collateral provision increases the expected return for the LP.*

A higher collateral provision implies higher interest payments in the case there is repayment (or early liquidation) and a higher recovery amount in case of liquidation (debt exceeding the collateral value case).

The proof follows from analyzing the derivative of the expected return function with respect to collateral. See Section A.5 in Appendix A for the complete derivation.

**Corollary 5.1.** *A higher liquidation threshold increases the expected return for the LP.*

This follows from Proposition 3 where we showed that increases in the liquidation threshold increase the collateral provision.

**Proposition 6.** *If the borrower is optimally allocating collateral above of what is required by the protocol (interior solution) there will be no marginal effect on the LP expected return from changing the loan-to-value parameter ( $\lambda$ ). When the collateralization requirement is binding, increasing  $\lambda$  implies a reduction in the LP expected return ( $\frac{\partial E[\Pi]}{\partial \lambda} < 0$ ).*

Increasing  $\lambda$  implies less collateral required per value loan, meaning a reduction in the required optimal collateralization of the borrower (Proposition 4). Since we have shown that collateralization increases the expected return of the LP (Proposition 5), therefore increasing  $\lambda$  means a reduction in the LP expected return.

## 5 Optimal Parameter Choice

### 5.1 The DAO's Problem

The DAO's objective function reflects the interests of the protocol community, which comprises both the borrower and the LP. The governance chooses parameters  $\lambda$  and  $\delta$  to maximize the weighted surplus:

$$W(\lambda, \delta) = \alpha(-E[\text{BC}])(\lambda, \delta) + (1 - \alpha)E[\text{I}](\lambda, \delta) \quad (4)$$

where  $\alpha \in [0, 1]$  represents the relative weight given to borrower interests in the governance process. This weight could reflect either the explicit voting power distribution in the DAO or the implicit influence of different stakeholder groups. Note that we maximize the negative of the borrower's cost ( $-E[\text{BC}]$ ) since we have been working with the borrower's cost minimization problem throughout the paper.

### 5.2 Participation Constraints

The optimization is subject to participation constraints that ensure both borrowers and LPs find it optimal to use the protocol:

$$E[\text{BC}](\lambda, \delta) \leq \text{BC}^0 \quad (\text{PC-B})$$

$$E[\text{I}](\lambda, \delta) \geq \text{I}^0 \quad (\text{PC-I})$$

where  $\text{BC}^0$  and  $\text{I}^0$  represent the outside options (costs and expected returns respectively) for the borrower and the LP respectively. These outside options might include alternative DeFi lending protocols, centralized exchanges, etc.

### 5.3 Optimal Parameter Choice

We now analyze the optimal parameter choice for the DAO.

**Proposition 7.** *The optimal liquidation threshold  $\delta^*$  is equal to 1, the maximum possible value.*

*Sketch.* The proof follows from analyzing the DAO's optimization problem with respect to  $\delta$ . From Proposition 2, we know that  $\frac{\partial E[\text{BC}]}{\partial \delta} < 0$ , meaning the borrower's cost decreases with  $\delta$ . From Corollary 5.1, we know that  $\frac{\partial E[\text{I}]}{\partial \delta} > 0$ , meaning the LP's expected return increases with  $\delta$ .

Since both the borrower's cost decreases and the LP's return increases with  $\delta$ , the participation constraints will never bind for  $\delta < 1$ . This means the objective function is strictly increasing in  $\delta$  for all  $\delta < 1$ , and therefore the optimal value is  $\delta^* = 1$ . See Section A.6 in Appendix A for the complete proof.  $\square$

**Proposition 8.** *The optimal loan-to-value ratio  $\lambda^*$  depends on the relative weights of borrower and LP interests in the DAO's objective function:*

1. *If the borrower's weight  $\alpha$  is sufficiently high,  $\lambda^*$  will be set to its maximum value (1) to minimize borrower costs*
2. *If the LP's weight  $(1 - \alpha)$  is sufficiently high,  $\lambda^*$  will be set to its minimum value to maximize LP returns*
3. *For intermediate values of  $\alpha$ ,  $\lambda^*$  will be determined by the binding participation constraint*

*Sketch.* The proof follows from analyzing the DAO's optimization problem with respect to  $\lambda$ . From Proposition 4, we know that  $\frac{\partial E[\text{BC}]}{\partial \lambda} < 0$  when the constraint is binding, and from Proposition 6, we know that  $\frac{\partial E[\text{I}]}{\partial \lambda} < 0$  when the constraint is binding.

The DAO's first-order condition with respect to  $\lambda$  is:

$$\frac{\partial W}{\partial \lambda} = -\alpha \frac{\partial E[\text{BC}]}{\partial \lambda} + (1 - \alpha) \frac{\partial E[\text{I}]}{\partial \lambda} \quad (5)$$

Since both derivatives are negative when the constraint is binding, the sign of  $\frac{\partial W}{\partial \lambda}$  depends on the relative weights  $\alpha$  and  $(1 - \alpha)$ . This creates a trade-off between borrower costs and LP returns, leading to the three cases described in the proposition. See Section A.7 in Appendix A for the complete proof.  $\square$

## 5.4 Comparative Statics and Predictions

This framework generates several testable predictions about protocol parameter choices:

1. **Governance Composition:** Higher values of  $\alpha$  (greater borrower influence) lead to:
  - Higher loan-to-value ratios ( $\lambda$ )
2. **Competition Effects:** Increased competition (higher  $\text{BC}^0$  or  $\text{I}^0$ ) leads to:
  - Parameter choices that favor the group with more competitive outside options
  - Possible specialization across protocols in serving different user types

These predictions suggest that observed parameter choices should systematically vary with:

- The composition of protocol governance
- The competitive environment
- The relative bargaining power of borrowers versus LPs

The model thus provides a framework for understanding how protocol parameters are determined through the interaction of governance structure, market competition, and stakeholder interests.

## 6 Discussion

Our theoretical framework generates several important implications for DeFi lending protocol design and governance. The model’s predictions regarding optimal liquidation thresholds and loan-to-value ratios provide insights into the trade-offs faced by protocol designers and governance participants.

### 6.1 Theoretical Predictions versus Protocol Implementations

A key finding of our model is that the optimal liquidation threshold should be set to its maximum value of 1. This prediction stands in contrast to observed protocol implementations, where liquidation thresholds are typically set below 1, and often below the liquidation bonus-adjusted value of  $1/(1+b)$ . This discrepancy warrants careful consideration.

Protocols commonly set different thresholds for different collateral types, with the stated aim of preventing scenarios where price increases above the threshold eliminate repayment incentives. However, our model demonstrates that such concerns may be misplaced, as the threshold does not alter the underlying probability distribution. Partial liquidations, when they occur, impose costs on borrowers while benefiting liquidators.

The efficiency of liquidation mechanisms in DeFi protocols further complicates this analysis. The widespread availability of flash loans and automated liquidation bots ensures that any liquidation opportunity is likely to be exploited with minimal delay. This technological infrastructure allows protocols to maintain lower liquidation bonuses while still ensuring effective risk management.

### 6.2 Governance and Parameter Choice

Our model highlights the fundamental trade-offs in setting protocol parameters, particularly the loan-to-value ratio. Higher LTV ratios benefit borrowers by allowing more leverage, while lower LTV ratios benefit liquidity providers by ensuring greater security. The optimal LTV ratio depends on the relative influence of different stakeholders in protocol governance, creating a natural tension in DAO governance between borrower and LP interests.

The model’s predictions regarding governance structure have important implications for protocol design. Borrower-dominated governance (high  $\alpha$ ) leads to higher LTV ratios, while LP-dominated governance (low  $\alpha$ ) leads to lower LTV ratios. This suggests that protocol governance should carefully consider stakeholder representation and the potential impact on parameter choices.

### 6.3 Competition and Protocol Design

The model also provides insights into how competition affects protocol parameter choices. Increased competition (higher outside options) will lead to parameter choices favoring the group with better alternatives. This may result in protocols specializing in serving different user types based on competitive pressures. Parameter choices should reflect the relative bargaining power of borrowers versus LPs, which can be influenced by the competitive landscape.

## 7 Conclusion

This paper provides a theoretical framework for understanding parameter choice in DeFi lending protocols. Our results highlight the fundamental trade-offs between borrower leverage and LP security, and how these trade-offs are resolved through DAO governance. The model generates testable predictions about how protocol parameters should vary with stakeholder composition and market conditions.

The analysis reveals several important implications for protocol design and governance. First, the optimal liquidation threshold should be set to its maximum value, though this stands in contrast to current protocol implementations. Second, the loan-to-value ratio creates a natural tension between borrower and LP interests, with the optimal choice depending on governance structure. Third, competition between protocols can lead to specialization and parameter choices that reflect the relative bargaining power of different stakeholders.

### 7.1 Next Steps and Research Directions

There are several avenues for future research related with the analysis presented in this paper:

1. **Empirical Testing:** The model’s predictions can be tested using on-chain data from major DeFi lending protocols. This includes analyzing the relationship between governance structure and parameter choices, the effects of parameter changes, studying the impact of competition on parameter choices, and examining actual collateralization behavior.
2. **Model Extensions:** The framework could be extended by endogenizing interest rates, modelling liquidation events (incorporating technology characteristics), and the impact of multiple collateral types. This would provide a more comprehensive understanding of protocol design choices.

These research directions would help bridge the gap between theoretical predictions and observed protocol implementations, providing valuable insights for protocol designers and governance participants.

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## A Detailed Proofs

### A.1 Proof of Proposition 1: Optimal Overcollateralization by Borrowers

Here we show that for some parameters and density function configurations, the borrower's problem has an interior solution, meaning that the borrower will borrow less than the maximum allowed by the protocol's loan-to-value ratio. To solve the borrower's cost minimization problem, we use the Kuhn-Tucker conditions. We first define the Lagrangian:

$$\begin{aligned}\mathcal{L}(C, \mu) = & r_o C + P\left(p_1 \leq \frac{\delta C}{(1+i)(1+b)L}\right) p_1 L i \\ & + P\left(\frac{\delta C}{(1+i)(1+b)L} < p_1 \leq \frac{C}{(1+i)(1+b)L}\right) p_1 L (i + b + ib) \\ & + P\left(p_1 > \frac{C}{(1+b)(1+i)L}\right) (C - p_1 L) + \mu(L - \lambda C)\end{aligned}\quad (6)$$

The Kuhn-Tucker conditions are:

$$\frac{\partial \mathcal{L}}{\partial C} = 0 \quad (7)$$

$$\mu(L - \lambda C) = 0 \quad (8)$$

$$\mu \geq 0 \quad (9)$$

$$L \leq \lambda C \quad (10)$$

According to the complementary slackness condition, if  $\mu > 0$ , then  $L = \lambda C$  (the constraint is binding), and if  $\mu = 0$ , the optimal  $C$  is determined solely by the first-order condition. Taking the partial derivative with respect to  $C$  and applying the product and chain rules:

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial C} = & r_o + \frac{\partial}{\partial C} \left[ P\left(p_1 \leq \frac{\delta C}{(1+i)(1+b)L}\right) p_1 L i \right] \\ & + \frac{\partial}{\partial C} \left[ P\left(\frac{\delta C}{(1+i)(1+b)L} < p_1 \leq \frac{C}{(1+i)(1+b)L}\right) p_1 L (i + b + ib) \right] \\ & + \frac{\partial}{\partial C} \left[ P\left(p_1 > \frac{C}{(1+b)(1+i)L}\right) (C - p_1 L) \right] - \mu \lambda\end{aligned}\quad (11)$$

Using the product rule and chain rule for each term:

$$\frac{\partial}{\partial C} \left[ P \left( p_1 \leq \frac{\delta C}{(1+i)(1+b)L} \right) p_1 L i \right] = p_1 L i \cdot f \left( \frac{\delta C}{(1+i)(1+b)L} \right) \cdot \frac{\delta}{(1+i)(1+b)L} \quad (12)$$

$$\begin{aligned} & \frac{\partial}{\partial C} \left[ P \left( \frac{\delta C}{(1+i)(1+b)L} < p_1 \leq \frac{C}{(1+i)(1+b)L} \right) p_1 L (i + b + ib) \right] \\ &= p_1 L (i + b + ib) \cdot \left[ f \left( \frac{C}{(1+i)(1+b)L} \right) \cdot \frac{1}{(1+i)(1+b)L} \right. \\ & \quad \left. - f \left( \frac{\delta C}{(1+i)(1+b)L} \right) \cdot \frac{\delta}{(1+i)(1+b)L} \right] \end{aligned} \quad (13)$$

$$\begin{aligned} & \frac{\partial}{\partial C} \left[ P \left( p_1 > \frac{C}{(1+b)(1+i)L} \right) (C - p_1 L) \right] \\ &= (C - p_1 L) \cdot \left[ -f \left( \frac{C}{(1+b)(1+i)L} \right) \cdot \frac{1}{(1+b)(1+i)L} \right] \\ & \quad + P \left( p_1 > \frac{C}{(1+b)(1+i)L} \right) \end{aligned} \quad (14)$$

Setting  $\frac{\partial \mathcal{L}}{\partial C} = 0$ :

$$\begin{aligned} & r_o + p_1 L i \cdot f \left( \frac{\delta C}{(1+i)(1+b)L} \right) \cdot \frac{\delta}{(1+i)(1+b)L} \\ & + p_1 L (i + b + ib) \cdot \left[ f \left( \frac{C}{(1+i)(1+b)L} \right) \cdot \frac{1}{(1+i)(1+b)L} \right. \\ & \quad \left. - f \left( \frac{\delta C}{(1+i)(1+b)L} \right) \cdot \frac{\delta}{(1+i)(1+b)L} \right] \\ & + (C - p_1 L) \cdot \left[ -f \left( \frac{C}{(1+b)(1+i)L} \right) \cdot \frac{1}{(1+b)(1+i)L} \right] \\ & + P \left( p_1 > \frac{C}{(1+b)(1+i)L} \right) - \mu \lambda = 0 \end{aligned} \quad (15)$$

Grouping the terms:

$$\begin{aligned} & \underbrace{r_o}_{\geq 0} + \underbrace{[p_1 L i - p_1 L (i + b + ib)]}_{< 0} \cdot f \left( \frac{\delta C}{(1+i)L} \right) \cdot \frac{\delta}{(1+i)L} \\ & + \underbrace{[p_1 L (i + b + ib) - (C - p_1 L)]}_{> 0} \cdot f \left( \frac{C}{(1+b)(1+i)L} \right) \cdot \frac{1}{(1+b)(1+i)L} \\ & + \underbrace{P \left( p_1 > \frac{C}{(1+b)(1+i)L} \right)}_{> 0} = 0 \end{aligned}$$

There are several effects at play:

- The first term is positive — a constant marginal cost for providing collateral.
- The second term negative, and represents the lower interest cost due to the increase in the probability of non-liquidation.
- Due to the increment in collateral, there is also an increase probability that the loan will be liquidated before the debt exceeds the value of the collateral. The third term is positive reflecting the increased costs of liquidation in such a scenario.
- Lastly the forth term reflects the higher loss in the event that collateral is completely liquidated.

Given the presence of both marginal costs and benefits in the optimization problem, there exist parameter configurations where the optimal solution  $C^*$  satisfies the first-order condition without binding the constraint  $L \leq \lambda C$ . This interior solution emerges when the marginal benefit of additional collateral (in terms of reduced liquidation risk) exactly offsets its marginal cost (in terms of opportunity cost and potential losses).

## A.2 Proof of Proposition 2: Effect of $\delta$ on Borrower Cost

The liquidation threshold  $\delta$  is a parameter chosen by the protocol DAO. Taking the derivative of the cost function with respect to  $\delta$  reveals how changes in this parameter affect the overall cost:

$$\begin{aligned}
\frac{\partial}{\partial \delta} E[\text{BC}] &= p_1 Li \cdot f\left(\frac{\delta C}{(1+i)(1+b)L}\right) \cdot \frac{C}{(1+i)(1+b)L} \\
&\quad - p_1 L(i+b+ib) \cdot f\left(\frac{\delta C}{(1+i)(1+b)L}\right) \cdot \frac{C}{(1+i)(1+b)L} \\
&= \frac{C}{(1+i)(1+b)L} \cdot f\left(\frac{\delta C}{(1+i)(1+b)L}\right) \cdot [p_1 Li - p_1 L(i+b+ib)] \quad (16) \\
&= \frac{C}{(1+i)(1+b)L} \cdot f\left(\frac{\delta C}{(1+i)(1+b)L}\right) \cdot p_1 L(-b-ib) \\
&= -\frac{C p_1 L(b+ib)}{(1+i)(1+b)L} \cdot f\left(\frac{\delta C}{(1+i)(1+b)L}\right)
\end{aligned}$$

The derivative is negative because:

- All terms in the numerator and denominator are positive
- The negative sign comes from the term  $(-b-ib)$
- The probability density function  $f(\cdot)$  is always non-negative

This confirms that increasing  $\delta$  decreases the cost function, which means that a higher liquidation threshold leads to lower expected costs for the lender.



### A.3 Proof of Proposition 3: Effect of $\delta$ on Collateral Amount

We now show that the optimal response from borrowers is to overcollateralize more when the liquidation threshold is higher.

We use implicit differentiation since we have an equation that implicitly defines  $C$  as a function of  $\delta$ .

Let's start with the first-order condition from the interior solution (where  $\mu = 0$ ):

$$\begin{aligned} & r_o + [p_1 L i - p_1 L(i + b + ib)] \cdot f\left(\frac{\delta C}{(1+i)L}\right) \cdot \frac{\delta}{(1+i)L} \\ & + [p_1 L(i + b + ib) - (C - p_1 L)] \cdot f\left(\frac{C}{(1+b)(1+i)L}\right) \cdot \frac{1}{(1+b)(1+i)L} \\ & + P\left(p_1 > \frac{C}{(1+b)(1+i)L}\right) = 0 \end{aligned}$$

Let's call this equation  $F(C, \delta) = 0$ . To find how  $C$  changes with  $\delta$ , we'll use implicit differentiation:

$$\frac{dC}{d\delta} = -\frac{\partial F / \partial \delta}{\partial F / \partial C}$$

First, let's compute  $\frac{\partial F}{\partial \delta}$ :

$$\frac{\partial F}{\partial \delta} = [p_1 L i - p_1 L(i + b + ib)] \cdot \left[ f'\left(\frac{\delta C}{(1+i)L}\right) \cdot \frac{C}{(1+i)L} \cdot \frac{\delta}{(1+i)L} + f\left(\frac{\delta C}{(1+i)L}\right) \cdot \frac{1}{(1+i)L} \right]$$

In terms of the sign of the denominator ( $\frac{dF}{dC}$ ), this effect is positive since this is a cost minimization problem, and at the minimum point, the second derivative with respect to  $C$  must be positive.

Therefore,  $\frac{dC}{d\delta} = -(-)/(+) = (+)$ , which means that as the liquidation threshold  $\delta$  increases, the optimal collateral amount  $C$  also increases.

This makes economic sense because:

1. A higher liquidation threshold means the position is less likely to be liquidated 2. This reduces the expected cost of liquidation 3. However, this also means the borrower can take on more risk 4. To maintain the same level of risk protection for the protocol, the optimal response is to increase the collateral amount  $C$ .

## A.4 Proof of Proposition 4: Effect of $\lambda$ on Borrower Cost

The borrower's cost minimization problem is:

$$\begin{aligned} \min_C E[\text{BC}] = & r_o C + P \left( p_1 \leq \frac{\delta C}{(1+i)(1+b)L} \right) p_1 L i \\ & + P \left( \frac{\delta C}{(1+i)(1+b)L} < p_1 \leq \frac{C}{(1+i)(1+b)L} \right) p_1 L (i + b + ib) \\ & + P \left( p_1 > \frac{C}{(1+b)(1+i)L} \right) (C - p_1 L) \\ \text{s.t. } & L \leq \lambda C \end{aligned} \quad (17)$$

The Lagrangian for this problem is:

$$\mathcal{L}(C, \mu) = E[\text{BC}] + \mu(L - \lambda C) \quad (18)$$

The first-order condition with respect to  $C$  is:

$$\frac{\partial \mathcal{L}}{\partial C} = \frac{\partial E[\text{BC}]}{\partial C} - \mu \lambda = 0 \quad (19)$$

The complementary slackness condition is:

$$\mu(L - \lambda C) = 0 \quad (20)$$

There are two cases to consider:

1. If the constraint is not binding ( $L < \lambda C$ ), then  $\mu = 0$  and the optimal  $C$  is determined solely by  $\frac{\partial E[\text{BC}]}{\partial C} = 0$ . In this case, changes in  $\lambda$  have no effect on the optimal  $C$  or the expected cost, so  $\frac{\partial E[\text{BC}]}{\partial \lambda} = 0$ .
2. If the constraint is binding ( $L = \lambda C$ ), then  $\frac{\partial E[\text{BC}]}{\partial C} > 0$  at the optimal solution. This is because if  $\frac{\partial E[\text{BC}]}{\partial C} < 0$ , the borrower could reduce their expected cost by increasing  $C$ , which would violate the constraint being binding. Therefore, when  $\lambda$  increases, it relaxes the constraint, allowing the borrower to reduce  $C$  while maintaining the same loan amount, thereby reducing their expected cost. This implies  $\frac{dC}{d\lambda} < 0$  and consequently  $\frac{\partial E[\text{BC}]}{\partial \lambda} < 0$ .

## A.5 Proof of Proposition 5: Effect of Collateral on Liquidity Provider Return

To analyze the effect of  $C$  on  $E[I]$ , we take the derivative with respect to  $C$ . Let  $F(p_1)$  be the cumulative distribution function of  $p_1$ , and  $f(p_1)$  be the probability density function of  $p_1$ . Then:

$$\begin{aligned} \frac{dE[I]}{dC} = & p_1 L i \cdot f \left( \frac{C}{(1+i)(1+b)L} \right) \cdot \frac{1}{(1+i)(1+b)L} + \frac{1}{(1+b)} \cdot \left[ 1 - F \left( \frac{C}{(1+i)(1+b)L} \right) \right] \\ & - \frac{C}{(1+b)} \cdot f \left( \frac{C}{(1+i)(1+b)L} \right) \cdot \frac{1}{(1+i)(1+b)L} \end{aligned}$$

Rearranging terms

$$\begin{aligned} \frac{dE[I]}{dC} = & \underbrace{\left( p_1 Li - \frac{C}{(1+b)} \right)}_{>0} \cdot \underbrace{f \left( \frac{C}{(1+i)(1+b)L} \right)}_{<0} \cdot \frac{1}{(1+i)(1+b)L} \\ & + \underbrace{\frac{1}{(1+b)} \cdot \left[ 1 - F \left( \frac{C}{(1+i)(1+b)L} \right) \right]}_{>0} \end{aligned}$$

The sign of the derivative depends on two effects:

1. A net positive effect of increasing higher interest payments in the case there is repayment or early liquidation.
2. A positive effect of a higher recovery amount in case of liquidation (debt exceeding the collateral value case).

Therefore, increasing collateral values increases the expected outcome for the LP.

## A.6 Proof of Proposition 7: Optimal Liquidation Threshold

From Proposition 2, we know that  $\frac{\partial E[\text{BC}]}{\partial \delta} < 0$ , meaning the borrower's cost decreases with  $\delta$ . From Corollary 5.1, we know that  $\frac{\partial E[\text{I}]}{\partial \delta} > 0$ , meaning the LP's expected return increases with  $\delta$ .

The DAO's optimization problem can be written as:

$$\max_{\lambda, \delta} W(\lambda, \delta) = \alpha(-E[\text{BC}])(\lambda, \delta) + (1 - \alpha)E[\text{I}](\lambda, \delta) \quad (21)$$

subject to:

$$E[\text{BC}](\lambda, \delta) \leq \text{BC}^0 \quad (\text{PC-B})$$

$$E[\text{I}](\lambda, \delta) \geq \text{I}^0 \quad (\text{PC-I})$$

$$0 \leq \delta \leq 1 \quad (\text{BC-}\delta)$$

Since both the borrower's cost decreases and the LP's return increases with  $\delta$ , the participation constraints will never bind for  $\delta < 1$ . This is because:

- For the borrower: if  $E[\text{BC}](\lambda, \delta) \leq \text{BC}^0$  holds for some  $\delta$ , it will also hold for any higher  $\delta$
- For the LP: if  $E[\text{I}](\lambda, \delta) \geq \text{I}^0$  holds for some  $\delta$ , it will also hold for any higher  $\delta$

Therefore, the optimal  $\delta^*$  must be 1, as this maximizes both the borrower's welfare (by minimizing costs) and the LP's welfare (by maximizing returns).

This can be seen from the first-order condition with respect to  $\delta$ :

$$\frac{\partial W}{\partial \delta} = -\alpha \frac{\partial E[\text{BC}]}{\partial \delta} + (1 - \alpha) \frac{\partial E[\text{I}]}{\partial \delta} \quad (22)$$

Since  $\frac{\partial E[\text{BC}]}{\partial \delta} < 0$  and  $\frac{\partial E[\text{I}]}{\partial \delta} > 0$ , we have:

$$\frac{\partial W}{\partial \delta} = \alpha \left| \frac{\partial E[\text{BC}]}{\partial \delta} \right| + (1 - \alpha) \frac{\partial E[\text{I}]}{\partial \delta} > 0 \quad (23)$$

This means the objective function is strictly increasing in  $\delta$  for all  $\delta < 1$ , and therefore the optimal value is  $\delta^* = 1$ .

## A.7 Proof of Proposition 8: Optimal Loan-to-Value Ratio

The DAO's optimization problem with respect to  $\lambda$  is:

$$\max_{\lambda} W(\lambda, \delta) = \alpha(-E[\text{BC}])(\lambda, \delta) + (1 - \alpha)E[\text{I}](\lambda, \delta) \quad (24)$$

subject to:

$$E[\text{BC}](\lambda, \delta) \leq \text{BC}^0 \quad (\text{PC-B})$$

$$E[\text{I}](\lambda, \delta) \geq \text{I}^0 \quad (\text{PC-I})$$

$$0 < \lambda < \delta \quad (\text{BC-}\lambda)$$

The first-order condition with respect to  $\lambda$  is:

$$\frac{\partial W}{\partial \lambda} = -\alpha \frac{\partial E[\text{BC}]}{\partial \lambda} + (1 - \alpha) \frac{\partial E[\text{I}]}{\partial \lambda} \quad (25)$$

From Proposition 4, we know that  $\frac{\partial E[\text{BC}]}{\partial \lambda} < 0$  when the constraint is binding, and from Proposition 6, we know that  $\frac{\partial E[\text{I}]}{\partial \lambda} < 0$  when the constraint is binding.

Therefore, the sign of  $\frac{\partial W}{\partial \lambda}$  depends on the relative weights  $\alpha$  and  $(1 - \alpha)$ :

1. If  $\alpha$  is sufficiently high (borrower-dominated governance), then:

$$-\alpha \frac{\partial E[\text{BC}]}{\partial \lambda} > (1 - \alpha) \left| \frac{\partial E[\text{I}]}{\partial \lambda} \right| \quad (26)$$

This implies  $\frac{\partial W}{\partial \lambda} > 0$ , meaning the objective function is increasing in  $\lambda$ . However, the optimal  $\lambda^*$  may not reach its maximum value of  $\delta$  if the LP's participation constraint (PC-I) becomes binding. Specifically:

- If  $E[\text{I}](1, \delta) \geq \text{I}^0$ , then  $\lambda^*$  could be set arbitrarily close to  $\delta$ .
- If  $E[\text{I}](1, \delta) < \text{I}^0$ , then  $\lambda^*$  will be set to satisfy  $E[\text{I}](\lambda^*, \delta) = \text{I}^0$

2. If  $(1 - \alpha)$  is sufficiently high (LP-dominated governance), then:

$$-\alpha \frac{\partial E[\text{BC}]}{\partial \lambda} < (1 - \alpha) \left| \frac{\partial E[\text{I}]}{\partial \lambda} \right| \quad (27)$$

This implies  $\frac{\partial W}{\partial \lambda} < 0$ , meaning the objective function is decreasing in  $\lambda$ . However, the optimal  $\lambda^*$  may not reach its minimum value if the borrower's participation constraint (PC-B) becomes binding. Specifically:

- If  $E[\text{BC}](0, \delta) \leq \text{BC}^0$ , then  $\lambda^*$  could be set arbitrarily close to 0.
  - If  $E[\text{BC}](0, \delta) > \text{BC}^0$ , then  $\lambda^*$  will be set to satisfy  $E[\text{BC}](\lambda^*, \delta) = \text{BC}^0$
3. For intermediate values of  $\alpha$ , there exists a value  $\lambda^*$  where:

$$-\alpha \frac{\partial E[\text{BC}]}{\partial \lambda} = (1 - \alpha) \left| \frac{\partial E[\text{I}]}{\partial \lambda} \right| \quad (28)$$

Also in this case, participation constraints should be checked to determine if the optimal value of  $\lambda$  is at the boundary or at the interior solution. Specifically:

- If the borrower's participation constraint (PC-B) is binding,  $\lambda^*$  will be set to satisfy  $E[\text{BC}](\lambda^*, \delta) = \text{BC}^0$
- If the LP's participation constraint (PC-I) is binding,  $\lambda^*$  will be set to satisfy  $E[\text{I}](\lambda^*, \delta) = \text{I}^0$

This analysis shows that the optimal loan-to-value ratio depends crucially on the governance structure of the DAO, as captured by the weight  $\alpha$ , and the participation constraints of both borrowers and LPs. The trade-off between borrower costs and LP returns leads to different optimal values of  $\lambda$  depending on which stakeholder group has more influence in the governance process and which participation constraints are binding. The analysis also shows that the values of the participation constraints (i.e. outside financing costs and returns) are important to determine the optimal  $\lambda$ . In that sense the competition between DeFi protocols is also important to determine the optimal  $\lambda$ .