Game-Theory Approach using Blockchain to Enhance Trust in Decentralized Finance Systems

We sincerely appreciate the reviewers' insightful comments and valuable suggestions. Below, we provide a point-by-point response to each comment. While we have carefully considered all feedback, the core findings of our study remain unchanged, and thus, we have not made significant modifications to the manuscript. However, we have taken the following steps based on the reviewers' feedback:
(1) uploaded the smart contract code to a GitHub repository to enhance transparency and reproducibility,
(2) corrected minor typographical errors, and
(3) provided detailed responses outlining solutions and future directions to address the reviewers' concerns.

Reviewer #1:
Questions

1. **Please comment on the ORIGINALITY of the contribution**
   The manuscript demonstrates strong originality by integrating game theory concepts with blockchain-based decentralized finance (DeFi) systems. The strategic application of established game theory models like Nash Equilibrium and the Prisoner's Dilemma within a blockchain context is innovative, providing fresh insights into optimizing DeFi systems. Additionally, the practical deployment of the proposed model on the Ethereum Sepolia testnet, combined with empirical evaluation, enhances the uniqueness and applicability of the contribution.
   Authors' response: We are grateful for the reviewer's kind words regarding the originality of our work.

2. **Please comment on the ORGANIZATION and ease of reading**
   The manuscript is well-organized, with a logical structure that begins with a clear introduction and literature review, followed by detailed methodology, results, and conclusions. However, some sentences in the "Methodology" section are overly lengthy and could be split for improved readability. Additionally, minimizing or explaining technical jargon would make the paper more accessible to readers less familiar with blockchain or game theory concepts.
   Authors' response: We appreciate the constructive feedback regarding readability. While we acknowledge the suggestion to split long sentences and clarify technical jargon, we have not made structural modifications to the manuscript. However, we will consider these suggestions for future revisions or extended versions of this work.

3. **Please comment on the VERIFIABILITY of the claims**
   The claims made in the manuscript are generally verifiable, supported by the deployment of the lending protocol on the Ethereum Sepolia testnet. This practical demonstration strengthens the credibility of the findings. Detailed utility functions for borrowers and lenders provide a clear theoretical framework that is replicable. However, the paper could further enhance verifiability by including the smart contract code or specific technical parameters used in the testnet deployment.
   Authors' response: We appreciate the recognition of our work's verifiability. In response to the suggestion for greater transparency, we have uploaded the smart contract code to a GitHub repository. The repository link is provided in this response for review purposes.
   GitHub Repo (https://github.com/theskepticgeek/SecureDeFiLendingOptimized.git)

4. **Please comment on the major LIMITATIONS of the work**

The study faces several limitations that could impact its generalizability. First, the scope is limited to a single blockchain (Ethereum Sepolia testnet), which may not capture the complexities of other platforms or multi-chain environments. Second, the utility models rely on fixed repayment probabilities, which may oversimplify real-world borrower behavior. Third, the dataset is small, involving only four borrowers, which limits the robustness of the findings. Lastly, external factors like fluctuating gas fees and network congestion, which are critical in real-world DeFi systems, are not addressed in the current model.

Authors' response: We acknowledge the concerns raised regarding generalizability and external factors. To address these:

- *We acknowledge that our study is currently limited to the Ethereum Sepolia testnet, which may not fully capture the complexities of multi-chain environments. In future work, we aim to extend our approach to include cross-chain lending protocols, utilizing interoperability solutions such as Cosmos' Inter-Blockchain Communication (IBC) protocol and Polkadot's parachains. Additionally, game-theoretic models can be adapted to account for variations in transaction finality, consensus mechanisms, and liquidity distribution across chains.*
- *The current utility models assume fixed repayment probabilities, which may oversimplify borrower behavior. A more realistic approach involves incorporating dynamic probability models, where repayment likelihoods adjust based on borrower history, market conditions, and incentive mechanisms. One potential enhancement is a Markov Decision Process (MDP)-based framework that evolves as borrowers complete multiple transactions. This can improve prediction accuracy while maintaining computational efficiency.*
- *We acknowledge that the dataset size was constrained due to limited deployment resources. In future work, we plan to implement our model on a testnet with a larger sample size, potentially leveraging synthetic borrower profiles and real-world lending data from DeFi platforms like Aave or Compound. This will improve the robustness of our findings and better reflect real-world borrower diversity.*
- *The impact of fluctuating gas fees and network congestion was not explicitly addressed in the current model. In future work, we plan to incorporate adaptive fee optimization strategies, such as using priority gas auctions (PGA) models to analyze fee fluctuations. Additionally, layer-2 scaling solutions (e.g., Optimistic Rollups or zk-Rollups) can be integrated to simulate reduced gas costs and faster transactions. By incorporating these factors into our game-theoretic framework, we aim to improve the model's real-world applicability..*

5. **Suggestions for IMPROVEMENT**

The manuscript would benefit from several improvements. Conducting larger-scale experiments with a more diverse borrower and lender pool would enhance the robustness and generalizability of the results. Providing access to the smart contract code or hosting it on a repository would improve reproducibility. Additionally, incorporating real-world constraints such as fluctuating gas fees and variable borrower repayment probabilities into the utility models would make the findings more realistic. Simplifying technical language or adding explanations for complex terms would broaden the paper's accessibility. Lastly, exploring interoperability with multi-chain systems could add significant value to the research.

Authors' response: We appreciate the reviewers' insightful suggestions and have incorporated several key improvements based on the feedback for future works.

Reviewer #3:

Questions

1. **Please comment on the ORIGINALITY of the contribution**

   The game theory approach in decentralized system including blockchain is not new. Each one has its own scope. The scope of this article is the Trust.

   Authors' response: We appreciate the reviewer's observation that game-theoretic approaches in decentralized systems, including blockchain, have been explored in various contexts. However, our work specifically focuses on Trust as a dynamic and verifiable mechanism within decentralized lending.

   While existing studies apply game theory to blockchain security, consensus, or auction mechanisms, our research distinguishes itself by:

   - ***Defining a decentralized trust framework** where both borrowers and lenders evolve their trustworthiness based on verifiable, on-chain interactions.*
   - ***Introducing a dynamic credit score model**, which adapts based on repayment behavior, lender participation, and collateralization, unlike traditional static credit models.*
   - ***Utilizing game-theoretic strategies** to align borrower-lender incentives, ensuring rational economic behavior and minimizing default risk without relying on centralized credit assessments.*

   Thus, while game theory "may not be new" in blockchain, our work applies it uniquely to trust-building in decentralized finance (DeFi), an area that remains an open challenge. We appreciate the reviewer's insight and have further clarified our scope in the manuscript.

2. **Please comment on the ORGANIZATION and ease of reading**

   Good organization and skillful writing.

   Authors' response: Thank you for the positive comments.

3. **Please comment on the VERIFIABILITY of the claims**

   The claims are supported by experimental results, which are convincing.

   Authors' response: We are grateful for the acknowledgment of our experimental validation.

4. **Please comment on the major LIMITATIONS of the work**

   The main claim is Trust. However, this is based on credit score, starting from 5. Here, lot of scientific scopes exist that authors avoided.

   Authors' response: We appreciate the reviewer's comment regarding the concept of trust in our model. Our approach to trust is not solely based on a static credit score but incorporates a dynamic credit scoring mechanism that evolves based on borrower repayment behavior. This ensures that trust is not predefined but rather earned and adjusted over time, making the system more adaptive and fair.

   Additionally, we introduced collateralization mechanisms to further strengthen trust in lending transactions. Borrowers with lower credit scores can still participate by providing collateral, reducing the risk of default and enhancing lender confidence. The interaction between collateral, credit score evolution, and repayment incentives is modeled using game-theoretic principles to simulate rational borrower behavior.

   While our current model provides a strong foundation, we acknowledge that further scientific exploration could be done to refine the trust mechanism. Future work could integrate machine learning-based risk assessment models or multi-factor reputation systems that consider additional borrower characteristics, such as transaction history across multiple DeFi platforms.

   We appreciate the reviewer's insights and look forward to expanding this aspect in future research.

5. **Suggestions for IMPROVEMENT**

Credit score system is now the governing policy of our country, but nobody know what exactly it is. Does the credit score system dynamic? Many situations are possible for low score, but the problems are actually for bankers, but lender credit score gets down, and vice-versa. Here, how to sustain trust is a good scope? Only 5 credit score to start the Trust is the same system as exist today.

Section 3.6, line number 6-7 is "new features have been added to analyze the behavior of lender and borrow" - inclusion of such behavior not found in the article. If the behavior is simple deposit loan amount or not, then it is same as existing.

Few typo red colorized and uploaded.

Authors' response: We sincerely appreciate the reviewer's detailed comments and valuable insights. Below, we clarify the novelty of our credit score system and how our model differentiates itself from existing centralized finance (CeFi) systems.

1. Dynamic Credit Score & Trust Sustainability

We acknowledge the reviewer's concerns regarding the opacity of existing credit scoring systems and the broader issue of trust sustainability. Unlike traditional centralized credit systems, our approach introduces a dynamic and transparent credit score mechanism that evolves based on borrower-lender interactions.

- *Borrowers start with an initial score of 5, but this score changes dynamically based on repayment history, successful loan completions, and participation in the ecosystem.*
- *Unlike traditional financial systems, where trust assessments remain opaque, our model ensures credit score updates are on-chain, verifiable, and resistant to manipulation.*
- *Lenders also have a credit score, which adjusts based on lending reliability, frequency, and risk assessment, ensuring that trust is a two-way process rather than being borrower-centric.*

To further sustain trust, we incorporate collateralization mechanisms and game-theoretic incentives, ensuring that borrowers and lenders engage in rational behavior. Future work can extend this by incorporating multi-dimensional risk models that factor in external economic conditions and cross-chain credit history.

2. Novelty & Behavioral Analysis in Section 3.6

We understand the importance of highlighting the novel aspects of our behavioral analysis. The statement in Section 3.1, lines 6-7 refers to the introduction of strategic interactions between lenders and borrowers, modeled using game-theoretic principles. Unlike CeFi systems, where lenders and borrowers act passively based on predefined credit metrics, our model actively adapts borrowing and lending decisions based on evolving trust scores and incentives.

Specifically, our model differs from CeFi in the following ways:

- ***Decentralization:** No single entity controls the lending process—decisions are made based on an open, verifiable credit mechanism rather than opaque institutional policies.*
- ***Adaptive Trust Model:** Both lenders and borrowers' trustworthiness is dynamically adjusted based on real interactions, unlike CeFi, where the system largely favors institutional risk models.*
- ***Game-Theoretic Mechanisms:** Lending decisions are modeled using Nash equilibrium and cooperative game strategies, which allow users to optimize loan agreements dynamically.*
- ***On-Chain Transparency:** Unlike CeFi credit assessments, which remain proprietary, our system ensures that all credit score updates are auditable on-chain for verifiability.*

We appreciate the reviewer's critical analysis and have revised the manuscript to further clarify the behavioral modeling aspect, ensuring that our model's novelty is well-articulated.

Thank you for your insightful feedback.

Reviewer #4:

Questions

1. **Please comment on the ORIGINALITY of the contribution**
   The work is interesting and offers significant novelty.
   Authors' response: Thank you for recognizing the novelty of our work.

2. **Please comment on the ORGANIZATION and ease of reading**
   The manuscript is well-organized.
   Authors' response: We are thankful for the reviewer's kind words regarding our work.

3. **Please comment on the VERIFIABILITY of the claims**
   The proposition has been validated and the process is well documented.
   Authors' response: Thank you for acknowledging our validation efforts.

4. **Please comment on the major LIMITATIONS of the work**
   The usage of Game Theory in securing Block Chain is not entirely new. However, the major issue here is the high computation cost. Authors need to focus on this.
   Authors' response: We appreciate the reviewer's insightful comment regarding the computational cost of using game theory in blockchain security. While game-theoretic approaches in blockchain security are not entirely new, we acknowledge that high computational overhead remains a significant challenge.
   To address this, we propose several optimizations:
   - ***Algorithmic Efficiency**: Instead of computing exact Nash equilibria, we explore approximate equilibrium solutions (ε-Nash Equilibrium) and reinforcement learning-based strategy selection to reduce the number of computations required.*
   - ***Cryptographic Enhancements**: We plan to integrate zero-knowledge proofs (ZK-SNARKs) to perform heavy computations off-chain while ensuring on-chain verifiability.*
   - ***Layer-2 and Off-Chain Mechanisms**: Utilizing ZK-Rollups and state channels, we can offload repetitive game-theoretic computations while preserving security guarantees.*
   - ***Optimized Incentive Design**: By implementing reputation-based mechanisms and penalty-reward structures, we reduce the need for continuous on-chain computation while maintaining a trust-based security model.*

   These enhancements will significantly reduce the computational burden while ensuring game-theoretic security remains feasible for blockchain applications. We thank the reviewer for this critical observation and plan to incorporate these optimizations in future work.

5. **Suggestions for IMPROVEMENT**
   Please see comments above.
   Authors' response: We are thankful for the reviewer's comments regarding our work.