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Impermanent Loss Conditions: An Analysis of Decentralized Exchange Platforms: Open Review

Matthias Hafner,[†] Helmut Dietl[‡]

Reviewers: Reviewer A, Reviewer B

Abstract. The final version of the paper "Impermanent Loss Conditions: An Analysis of Decentralized Exchange Platforms" can be found in Ledger Vol. 11 (2026) 7-30, DOI 10.5195/LEDGER.2026.384. There were two reviewers involved in the review process, neither of whom has requested to waive their anonymity at present, and are thus listed as Reviewers A and B. After initial review by Reviewers A and B, the submission was returned to the authors with feedback for revision (1A). The author resubmitted their work and responded to reviewer comments (1B). The paper was returned to the reviewers who recommended the paper be accepted, thus ending the peer review process. Author responses have been bulleted for reader clarity.

1A. Review

Reviewer A

Thank you for the opportunity to review "Impermanent Loss Conditions: An Analysis of Decentralized Exchange Platforms." The paper's main contribution is an agent-based model of automated market makers (AMMs). The authors show that liquidity providers at AMMs would earn losses from price changes in the underlying assets, if fees paid by arbitrageurs and other traders are not included. While the paper has some issues, you may wish to consider a revision if the authors are willing to make some necessary changes.

I have two main concerns with the paper. The first is that I am unsure of the novelty of the paper's main result. In many traditional financial markets, market makers would earn losses if fees they earned were not included in the calculation. That this is also the case for popular AMM protocols is not especially surprising. If the opposite were true, traders would likely gravitate to a more efficient protocol where they incurred lower costs. In my opinion, whether you choose to move forward on this paper should depend on your feelings about this issue. Second, the paper lacks some necessary detail, even for a shorter

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letterstype paper. I do believe that the authors can improve on this and I've provided several concrete suggestions in my report to increase clarity. If the authors are willing to correct this, I don't see it as a barrier to publication.

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?

Yes, incremental contribution(s)

Please briefly explain why you think the paper makes or does not make a novel contribution.

The result in this paper, that market makers only earn profits if fees are considered, would be very well known in traditional finance (ex: Colliard and Foucault, 2012). This paper extends that concept to distributed finance in the form of an agent-based model of rational arbitrage. I am not familiar with anyone else having taken this approach before.

Is the research framed within its scholarly context and does the paper cite appropriate prior works?

Yes

Please assess the article's level of academic rigor.

Good (not excellent but a long way from poor)

Please assess the article's quality of presentation.

Excellent (the motivation for the work is clear, the prose is fluid and correct grammar is used, the main ideas are communicated concisely, and highly-technical details are relegated to appendixes).

How does the quality of this paper compare to other papers in this field?

This is a good or average paper.

Please provide your free-form review for the author in this section.

This paper discusses automated market makers (AMMs) and the concept of impermanent loss. Roughly speaking, impermanent loss is the idea that the value of assets at the liquidity pool of an AMM may fall below the value that liquidity providers would have had, if they had simply held onto the original assets themselves. The authors construct an agent-based model (ABM) and show that, given the presence of both arbitrageurs and other traders, impermanent losses are to be expected in an AMM when fees are not included. When including fees, AMMs earn net-profits for liquidity providers, except when underlying assets incur extreme losses.

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Generally, the paper is easy to follow, the message is simple to understand and the primary result makes sense. I have two major comments, along with a number of smaller comments and suggestions. I want to be clear that appreciate the paper's current length and don't think it requires a meaningful increase in length.

Major Comments

1. My main question about this paper is about the novelty of the paper's main contribution.

It is not surprising to me that a popular AMM protocol earns losses for liquidity providers if fees are not included. Arbitrageurs only trade if it is profitable and in practice, all liquidity-taking traders have an incentive to use low-cost AMMs. If liquidity providers earned excess profits, liquidity takers would naturally gravitate elsewhere. Similar results to this one are well-known in traditional finance.

I think it would helpful for the authors to highlight part of the paper where their model may deviate from common economic intuition or provide nuance. Figure 6, and its discussion are a good example, since it is surprising that profits are higher if arbitrageurs have a greater incentive to trade (zero transaction cost). If there are other areas where results are surprising, it would add to the paper.

2. There are a few places in the paper where the ABM setup is unclear. These should be clarified for readers:

The arbitrageur (p.6): It is my understanding that the arbitrageur has two opportunities to trade each cycle, before and after the trader arrives. It is also my understanding that the arbitrageur makes a single trade (or no trade) at each opportunity. Regardless of whether this is correct, it could benefit from some clarification.

The trader (p.7): The trader is described as making a trade "based on the historical trading amount of Uniswap's WETH/USDC pool." I believe that more detail is required here.

No fee experiment (p.8): In the "no fee" experiment, you indicate that you assume "all fees and other transaction costs" to be zero. Does this include the arbitrageurs' transaction cost (p.6) which serves as a barrier to them trading? If so, the "no fee" experiment would seem to have fewer arbitrageurs for both fee and transaction cost reasons and I am not sure if this is entirely representative of the role of fees. Figure 6 (p.10) suggests that these other transaction costs are important to the analysis.

Minor Comments and Suggestions

1. The language in the paper could be tightened up to improve readability.

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2. The analysis focuses around a pair which includes a stablecoin (USDC). Is this a deliberate choice or is it simply because this is a highly-traded pair. A quick justification would be helpful.

3. It's unclear how Equation (8) from Angeris et al. (2021) leads to Equation (9) on p.5.

4. Figure 3 (p.6) is an unclear description of the timing of the model. What I believe the timing is that 1) the arbitrageur may trade, 2) a trader may trade, 3) the arbitrageur may trade again. At each stage they interact with the AMM, which updates its price. I understand that you're trying to show all the interactions and conserve space, but a simpler version of the figure would likely be helpful.

5. Standard results (p.8): You indicate that "we first test whether we can replicate standard results from the previous literature." It would be good to have some more detail on the replication. A simple table or a couple figures in the appendix would suffice.

Reviewer B

The paper asks a good question and has a decently well developed approach to address the question. The main shortcomings are the lack of a in depth analysis and poor writing for some parts of the paper. I think the shortcomings can be addressed in a revision and I therefore recommend a revise and resubmit the paper.

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?

Yes, incremental contribution(s)

Please briefly explain why you think the paper makes or does not make a novel contribution.

see report

[Editor's Note: Report's contents included below]

Is the research framed within its scholarly context and does the paper cite appropriate prior works?

Yes

Please assess the article's level of academic rigor.

Good (not excellent but a long way from poor)

Please assess the article's quality of presentation.

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Good (not excellent but a long way from poor)

How does the quality of this paper compare to other papers in this field?

This is a good or average paper.

Please provide your free-form review for the author in this section.

see report

[Editor's Note: Report contents included here]

Report on: Impermanent Loss Conditions: An Analysis of Decentralized Exchange Platforms Around the World.

Summary

The authors focus on fees as an offset for impermanent loss. They simulate trades based on a one year history from Uniswap and show that fees offset impermanent loss for liquidity providers (LPs). The most interesting finding is that higher outside transaction costs for arbitrageurs make LPs worse off.

Discussion

The paper has to main problems: first the authors address an interesting question, however we get very few answers. The paper provides a few figures but lacks insights and a more rigorous analysis. The effort went into programming the analysis and not into thinking about interesting questions. Second, the paper is poorly written so that it is hard to follow at times. The assumptions of the simulation are not clear, the sample is not described, and the analysis and the figures are poorly explained.

Comments

1. p4: the paper discusses the case without fees. This is fine but should be mentioned in the text

2. p6: there should be some summary statistics of the sample

3. p6: The simulation loop is for one trading period. Is this a day, a block, an hour?

4. In Fig 3 The leftmost box and the rightmost box look very similar. Can the figure be simplified? Furthermore there is a path where the arbitrageur trades after an arbitrageur. How is this possible. The first Arbitrageur will trade until the price of the pool is equal to the fundamental value. Then no more arbitrage opportunities exist.

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5. How do the authors identify MEV transactions that are considered as arbitrage? This approach is problematic for several reasons: first I doubt that the authors can identify all MEV transactions. Some data providers flag transactions as MEV, however it is far from certain that this really comprises all MEV transactions. Second, some MEV transactions might not be arbitrage. Consider, for example, a loan liquidation on a platform like AAVE, in which the liquidator sells the collateral on a DEX. This transaction creates order flow for the DEX, like a noise trader, and is certainly not an arbitrage. Yet most liquidations are done through interfaces such as Flashbots and flagged as MEV. Finally, not all arbitrage transactions have to me MEV transactions.

6. It should be explained very clearly how trades from the sample are identified and used in the simulation. For example, is a trader assumed to trade the same amount, the same relative change in price, or for the same absolute change in price?

7. p6: how exactly are gas fees considered in the simulation?

8. In the simulation the authors assume that pool size is exogenous, which is clearly not true as LPs balance fee revenue with adverse selection loss. This should at least made clear in the paper.

9. p7: The authors claim that the analyze arbitrage competition. How is competition modelled? I did not find any analysis on competition.

10. p7: It should be made clear that the benchmark for LPs is a buy and hold strategy

11. The analysis section is very short and superficial. I think the most interesting insight is that higher outside transaction costs for arbitrageurs reduce fee revenue for LPs. This is interesting. What are the implications for price efficiency? Does this mean that DEX prices deviate more from the fundamental value? The authors could break down fee revenue into trading and arbitrage fees. Do we see fewer, larger arbitrage trades and if so why does this decrease fee revenue?

12. Each figure should be self contained. Take a look at an article in a top finance journal and copy the style.

13. Why are all the references in footnotes? Use BibTeX

1B. Author Response

Reviewer A

<u>Major</u>

1.1 It is not surprising to me that a popular AMM protocol earns losses for liquidity providers if fees are not included. Arbitrageurs only trade if it is profitable and in practice,

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all liquidity-taking traders have an incentive to use low-cost AMMs. If liquidity providers earned excess profits, liquidity takers would naturally gravitate elsewhere. Similar results to this one are well-known in traditional finance

- Thank you for your comment! We realize now that we could have been clearer with our research question.

- We added a section to better explain how our research compares to traditional finance, including the following key points:

    - AMMs are a novel approach to liquidity provision, distinct from traditional liquidity provision due to features such as deterministic pricing and increased transparency. As a result of their design, they cannot discriminate between offered prices/spreads (= fees) over time or between different trade types (e.g., informed vs. uninformed trades). However, AMMs allow retail users to provide passive liquidity.

    - Our analysis builds on the existing literature seeking to understand AMMs with deterministic pricing. AMM's liquidity providers' profits depend on fees from traders, portfolio rebalancing, and previously underestimated fees from arbitrageurs.

    - Importantly, early literature has not yet incorporated arbitrageur fees into its models and therefore overlooked them.

    - The traditional market microstructure literature shows that informed traders (arbitrageurs) can negatively affect liquidity providers' profits. Consequently, market makers typically react to informed trading by widening spreads (see, e.g., Adverse selection and the presence of informed trading - ScienceDirect; based on Glosten and Milgrom, 1985). Interestingly, and consistent with our findings, this literature also suggests that a fixed fee imposed by a government (such as a tax) would slow the process of market-maker learning.

    - In the simple AMM models we analyze, liquidity providers cannot adjust spreads because the trading fee is fixed. Furthermore, AMMs automatically adjust market prices and cannot distinguish between informed and uninformed traders. Due to these structural differences, the results may differ from traditional markets.

1.2 I think it would helpful for the authors to highlight part of the paper where their model may deviate from common economic intuition or provide nuance. Figure 6, and its discussion are a good example, since it is surprising that profits are higher if arbitrageurs have a greater incentive to trade (zero transaction cost). If there are other areas where results are surprising, it would add to the paper.

- Thank you, this improves the paper. The surprising results are presented in Section 4.3. We have emphasized these findings more strongly in the revised manuscript.

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2.1 The arbitrageur (p.6): It is my understanding that the arbitrageur has two opportunities to trade each cycle, before and after the trader arrives. It is also my understanding that the arbitrageur makes a single trade (or no trade) at each opportunity. Regardless of whether this is correct, it could benefit from some clarification.

- Thank you very much for that thoughtful comment. We clarified in the paper that that arbitrageurs check for opportunities after each state update and after every trade, with the algorithm allowing iterative execution as a precaution to ensure all arbitrage opportunities are captured. We explained the arbitrageur decision process in greater detail in the revised manuscript.

2.2 The trader (p.7): The trader is described as making a trade "based on the historical trading amount of Uniswap's WETH/USDC pool." I believe that more detail is required here.

- We have clarified the simulation setup.

2.3 No fee experiment (p.8): In the "no fee" experiment, you indicate that you assume "all fees and other transaction costs" to be zero. Does this include the arbitrageurs' transaction cost (p.6) which serves as a barrier to them trading? If so, the "no fee" experiment would seem to have fewer arbitrageurs for both fee and transaction cost reasons and I am not sure if this is entirely representative of the role of fees. Figure 6 (p.10) suggests that these other transaction costs are important to the analysis.

- The no-fee experiment excludes transaction costs for arbitrageurs, consistent with the theoretical static models that serve as a baseline for our research. A simulation including transaction costs yields qualitatively similar results. we have performed additional sensitivity analysis for the arbitrageur simulation.

<u>Minor</u>

1. The language in the paper could be tightened up to improve readability.

- Thank you; the manuscript has been thoroughly revised.

2. The analysis focuses around a pair which includes a stablecoin (USDC). Is this a deliberate choice or is it simply because this is a highly-traded pair. A quick justification would be helpful.

- This choice is motivated by two factors: a) the asset is highly traded (high liquidity), and b) interpretation is simplified when one crypto asset is stable against the US Dollar. We have included this explanation in the revised manuscript.

3. It's unclear how Equation (8) from Angeris et al. (2021) leads to Equation (9) on p.5.

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- We explained the calculations better.

4. Figure 3 (p.6) is an unclear description of the timing of the model. What I believe the timing is that 1) the arbitrageur may trade, 2) a trader may trade, 3) the arbitrageur may trade again. At each stage they interact with the AMM, which updates its price. I understand that you're trying to show all the interactions and conserve space, but a simpler version of the figure would likely be helpful.

- This is correct. We adjusted the figure and the text for better readability.

5. Standard results (p.8): You indicate that "we first test whether we can replicate standard results from the previous literature." It would be good to have some more detail on the replication. A simple table or a couple figures in the appendix would suffice.

- We have included the figures resulting from these simulations in an appendix.

Reviewer B

Discussion

First the authors address an interesting question, however we get very few answers. The paper provides a few figures but lacks insights and a more rigorous analysis. The effort went into programming the analysis and not into thinking about interesting questions.

- Thank you very much for this important observation.
    - We agree that further research on transaction costs is valuable and added more analysis in this area.
    - Please also note that the paper is brief due to strict page limits. The results presented are a summary of the research, and not all analyses have been included.

Second, the paper is poorly written so that it is hard to follow at times. The assumptions of the simulation are not clear, the sample is not described, and the analysis and the figures are poorly explained.

- Given page limits, we have moved these details to the Appendix. We have also clarified the writing and added further statistics.

Comments

1. p4: the paper discusses the case without fees. This is fine but should be mentioned in the text

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- The paper discusses the no-fee case as a baseline for comparison with the fee-inclusive analysis.

2. p6: there should be some summary statistics of the sample

- Summary statistics are provided in Appendix A. We have added a supplementary table to improve the understanding of the data.

3. p6: The simulation loop is for one trading period. Is this a day, a block, an hour?

- We clarified that the loop applies to a single trade rather than a fixed time span. We simulate on a trade-by-trade basis and add arbitrageur trades to the sequence.

4. In Fig 3 The leftmost box and the rightmost box look very similar. Can the figure be simplified? Furthermore there is a path where the arbitrageur trades after an arbitrageur. How is this possible. The first Arbitrageur will trade until the price of the pool is equal to the fundamental value. Then no more arbitrage opportunities exist.

- We simplified the figure.

- Additionally, as a precautionary measure, we allowed the arbitrageur to trade twice to ensure all arbitrage opportunities were eliminated (in case the initial trading amount formula was not entirely accurate). In practice, however, the arbitrageurs traded only once.

5. How do the authors identify MEV transactions that are considered as arbitrage? This approach is problematic for several reasons: first I doubt that the authors can identify all MEV transactions. Some data providers flag transactions as MEV, however it is far from certain that this really comprises all MEV transactions. Second, some MEV transactions might not be arbitrage. Consider, for example, a loan liquidation on a platform like AAVE, in which the liquidator sells the collateral on a DEX. This transaction creates order flow for the DEX, like a noise trader, and is certainly not an arbitrage. Yet most liquidations are done through interfaces such as Flashbots and flagged as MEV. Finally, not all arbitrage transactions have to me MEV transactions.

- We identify MEV using labels from Etherscan and Dune. Since MEV identification is not the main focus of the analysis, we rely on third-party labeling. We also tested whether results change significantly when including only a subset of MEV-labeled data; the results remain consistent. Thus, relying on MEV labels is sufficient in our view.

6. It should be explained very clearly how trades from the sample are identified and used in the simulation. For example, is a trader assumed to trade the same amount, the same relative change in price, or for the same absolute change in price?

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- We added more details to the trading behavior. The simulation uses the *actual* trading amounts provided to the AMM in the data sample; prices are calculated endogenously according to the AMM's pricing formula.

7. p6: how exactly are gas fees considered in the simulation?

- We have added a paragraph explaining the treatment of transaction costs; they are explicitly modeled as costs incurred by traders and arbitrageurs. Please note that we assume gas fees to be constant, as dynamic network fees are outside the scope of this paper.

8. In the simulation the authors assume that pool size is exogenous, which is clearly not true as LPs balance fee revenue with adverse selection loss. This should at least made clear in the paper.

- Indeed, this is clearly not the case. Without holding an LP balance, it would be difficult to assess profitability, as it is endogenously defined. We have clarified this in the paper.

9. p7: The authors claim that the analyze arbitrage competition. How is competition modelled? I did not find any analysis on competition.

- We explained our assumptions better and provided supporting literature:

- The level of competition is included in the transaction cost consideration:

    - Arbitrageurs trade when marginal cost (MC) equals marginal revenue (MR).

    - MR depends on time, specifically the deviation from the market price. Under competition, MR is determined by the lowest MC among all arbitrageurs, meaning all

    - arbitrageurs trade whenever possible without incurring a loss, resulting in zero profits.

    - In a monopoly, waiting can lead to positive profits, so MR is higher, and arbitrageurs

    - trade less actively. Consequently, "costs" are higher in a monopoly than in a competitive market, implying higher transaction costs.

10. p7: It should be made clear that the benchmark for LPs is a buy and hold strategy

- We clarified in the paper:

    - Our approach is based on previous literature.

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- Other benchmarks used in AMM literature are not useful for individual decision-making.

11. The analysis section is very short and superficial. I think the most interesting insight is that higher outside transaction costs for arbitrageurs reduce fee revenue for LPs. This is interesting. What are the implications for price efficiency?

Does this mean that DEX prices deviate more from the fundamental value? The authors could break down fee revenue into trading and arbitrage fees.

Do we see fewer, larger arbitrage trades and if so why does this decrease fee revenue?

- Thank you for pointing this out. We fully agree and have expanded our analysis on this topic. Specifically, we have included two additional pages of analysis in the main text and added a sensitivity analysis in the appendix.

12. Each figure should be self contained. Take a look at an article in a top finance journal and copy the style.

- We adjusted the figures where possible.

13. Why are all the references in footnotes? Use BibTeX

- We would be happy to use BibTeX; however, we followed the guidelines from Ledger.

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