Battle of the Bots: Flash loans, Miner Extractable Value and Efficient Settlement

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Blockchain Settlement

- Settlement Volume in 2021
  - Ethereum $11.6 Trillion
  - Visa $10.4T
  - Bitcoin $4.6T
- 2022 Stablecoin settlement volume on chain $8T
- 2022 Bitcoin $14.8T
- In Sept 2023 Ethereum settles about $2B/day

Blockchain Settlement is different

- Competitive settlers
- Free market for fees
- No strict time priority
  - No central node
  - cannot trust timestamps
- No regulation: frontrunning, settlers can also trade

Decentralized Settlement

- In blockchain settlement systems, users broadcast transactions to a peer to peer network of nodes.
- Transactions get collected in a public mempool
- Miners choose a subset of the submitted transactions to process

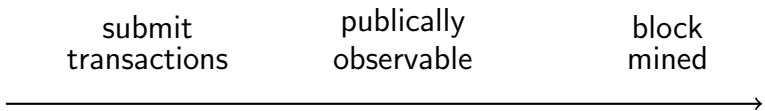


Figure: **Sequence of Events within a block mining period**

- Anyone with a node can observe pending transactions as part of the process

Incentive Problems

- There are profitable trading opportunities - arbitrage - that can be found
- Orders in the mempool can be analyzed or screened and, if they lead to profitable trades, expropriated.
- Order of execution within a block matters
- Screeners can expropriate via front running

- Miners can exploit trades.
- Miners who can also transact leads to a problem of Miner/Maximum Extractable Value

Ethereum's Dark Forest (April 2020)

Our paper

- How does screening/MEV affect arbitrage opportunities
- Screening should be done by the miner
- Alternative mechanism to bypass the mempool - private transactions - can increase welfare and lower fees (for ordinary users)
- More than half the blocks are affected
- Miners collect more than $2.3m per day in side-payments from private transactions

Literature

- MEV term due to Daian, et al (2020), worry about consensus layer
- Qin et al (2021) quantify MEV for specific protocols and selected transaction
  - Estimate a MEV of 540 million USD over 32 months.
  - Lower bound as impossible to quantify all possible profitable transactions at a given time given state of the blockchain.
- Zhou et al (2021) search algorithm to show the computational complexity.
- Capponi Jia and Wong consider Flashbots versus on-chain as dark versus lit.
  - Arbitrageurs front run orders (arbitrageurs are bad)
  - Miners choose which market to participate in
  - Execution risk for arbitrageurs if there are not enough miners.

Our perspective: Arbitrage and Social Value

- Some arbitrage trades are socially efficient
  1. Maintain price efficiency
     - Vital for AMM's
  2. Monitor collateral
     - Reduce risk for lenders
  3. Identify bad code
     - "Arbitrageurs/exploiters" take the place of regulators in TradFi
- Some arbitrage trades are socially inefficient
  - Expropriation / Front running

Model

- Users:
  - $1 - \lambda$ agents have a private value for transactions $v \sim [0, \bar{v}]$.
  - Participate when value exceeds the fee f to settle a transaction
- Arbitrageurs: λ agents are arbitrageurs who trade for profit.
  - Finding arbitrage of size R is requires costly effort e_A.
  - If they do not find an opportunity they submit a private value trade $\bar{v}$
- Screeners: Agents who screen the mempool to find arbitrageur trades.
  - Screening the mempool requires costly effort
  - Screener can expropriate value with probability e_s.
  - Screening can be done my independent agents or by miner
- Miners:
  - Profit maximizing miner
  - Charge a fee f for including a transaction from the mempool.
  - Two transactions are processed per period.

First Best/Social Planner

- ω fraction of arbitrage trades has a positive social value.
- Optimal value of arbitrage activity
- Include all user trades: sets fee to zero
- No screening: just a transfer

Public Mempool

- Arbitrageur's Problem:
  - Set effort level to find a trade
  - Possibility to get screened

$$\max_{e_a} E\pi_a = \lambda\{e_a R(1-e_s) + (1-e_a)\bar{v} - f\} - \frac{ae_a^2}{2}. \quad (1)$$

- Screener's Problem: find trades of arbitrageurs
  - Set effort level to find and expropriate arbitrageur

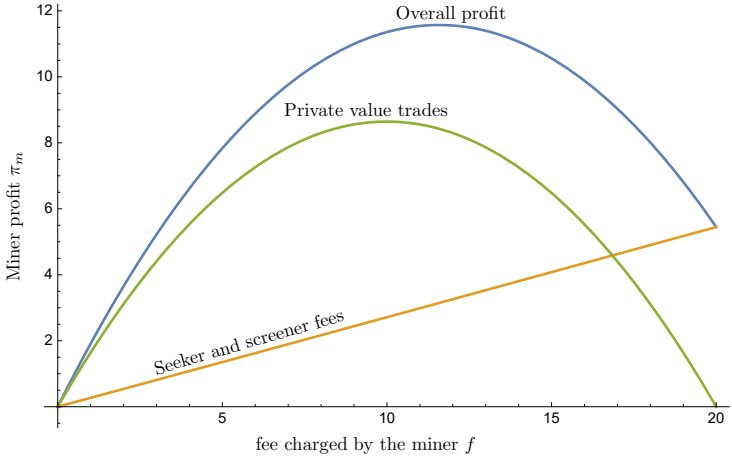
$$\max_{e_s} \pi_s = \lambda e_s e_a (R-f) - \frac{se_s^2}{2}. \quad (2)$$

- Optimal effort of arbitrageur will decrease in screening
- Optimal screening will increase in arbitrage activity

Public Mempool

- Miner's Problem: collect fees
  - Higher fees reduces participation by ordinary users but extracts more from arbitrageurs and screeners
  - Arbitrageurs and screeners are willing to pay very high fees (above)
  - Miner anticipates how fees will affect arbitrage and screening activity
  - Ordinary users will drop out as the miner increases fee
  - Screener can be separate or miner = screener

Miner's profit as function of fee



Nash Equilibrium (Public Market)

- Fees are high
- Many users are excluded from the market
- Screeners puts in too much effort to expropriate (relative to the first best)

- Is is best if the miner is the screener
  - Miner also makes screening profits
  - Fees are lower
  - Welfare from users increases
  - Arbitrage activity decreases

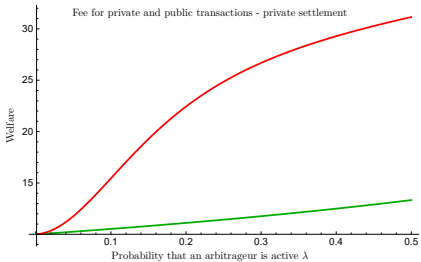
MEV-GETH

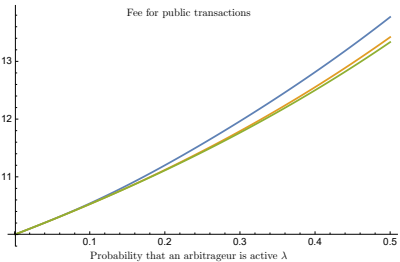
- Nov 23, 2020 Flashbots released MEV-Geth "... to propose a permissionless, transparent, and fair ecosystem for MEV extraction that reinforce the Ethereum ideals."
- Arbitrageurs privately contract with miners to have their transactions included without having to go through the mempool.
- Arbitrageurs pay a negotiated fee but cannot be screened

Private Market: Miner is screener

- Miner screens the mempool enough to deter arbitrageur from using it
- Routing an arbitrage trade through the mempool not attractive
- Separation: users take mempool, arbitrageur uses private market
- Miner can extract some surplus from the arbitrageur
- Good for users as they pay a lower fee
- Miner screens mempool even though there are no arbitrage transactions

Fee f and fraction of arbitrageurs λ





Public - Miner is not a screener (blue)
Public - Miner is screener (orange)
Private - mempool fee (green)
Private - private fee (red)

Private Market: Summary

Miner is screener:

- Lower fees and higher volume from ordinary users
- Higher welfare for ordinary users
- Less congestion on the blockchain (no screeners)

Consistent with goals of Flashbots

Data

Data collection

- Blockchain data from our own archive node
- Flashbots API: all packages that were processed by flashbots
  - From February 11, 2021 to March 17, 2023
  - Includes 8,048,889 bundles

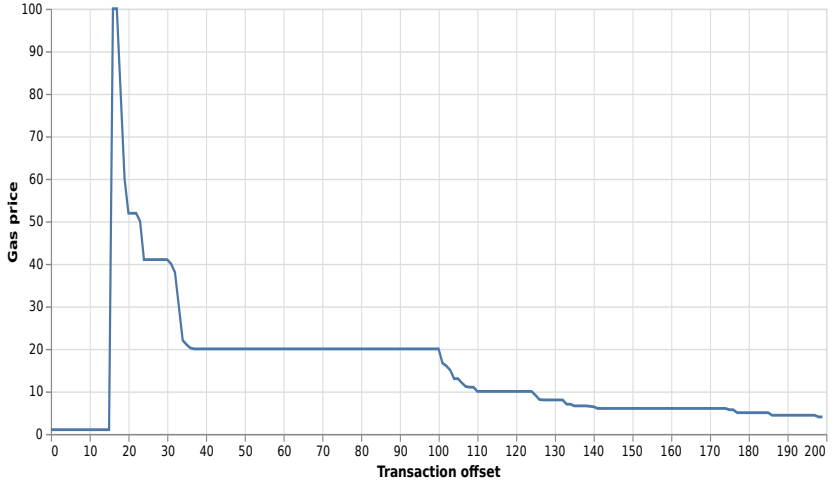
Lower bound on MEV activity:

- Other private markets exist
- Users might contract directly with miners
- Some mempool transactions might be screened

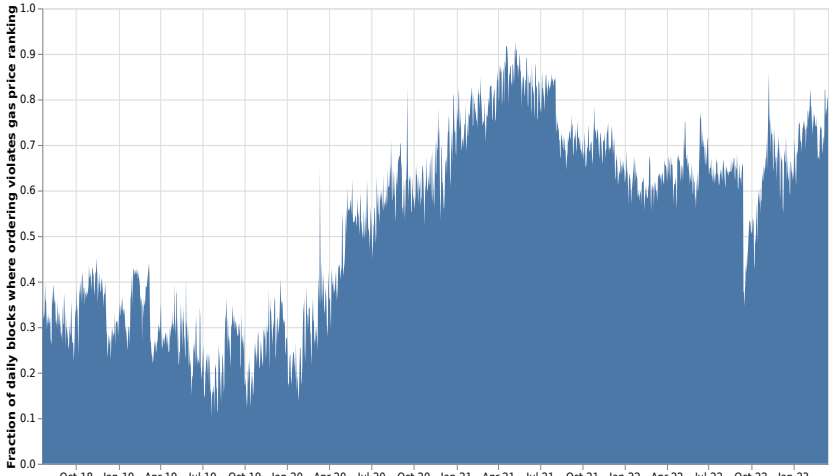
Unusual ordering of transactions

- Users pay gas fees to miners
- Order of execution in a block is important
- Miners should rank transactions with highest fees first

Block 6000003



MEV: Fractions of Blocks with Unconventional Ordering

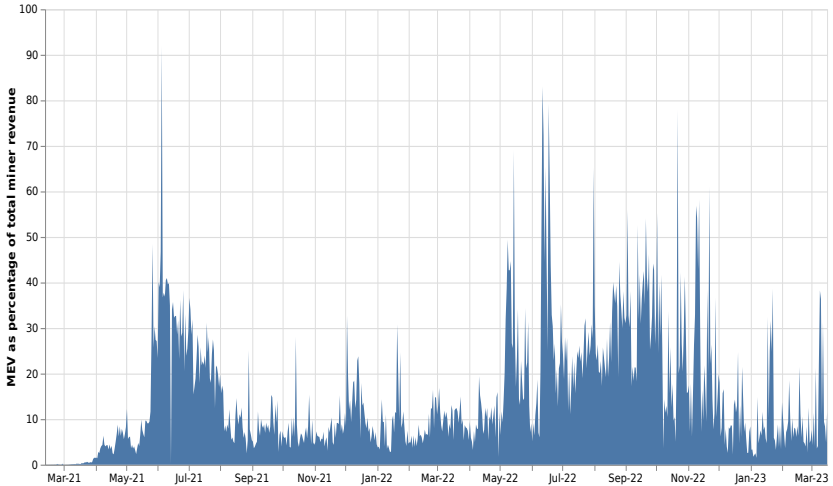


Note Flashbots released MEV-Geth fork on Nov 23, 2020

Private fee payments

- Typically users can attach fees to their transaction
- Fee is a compensation for computing power to verify transaction
- Fee has to be paid even when transaction fails
- Arbitrageurs pay fees as a direct transfer to miners to make fee conditional on execution
- Would show up as zero fee transaction in a block

Fractions miner income from MeV

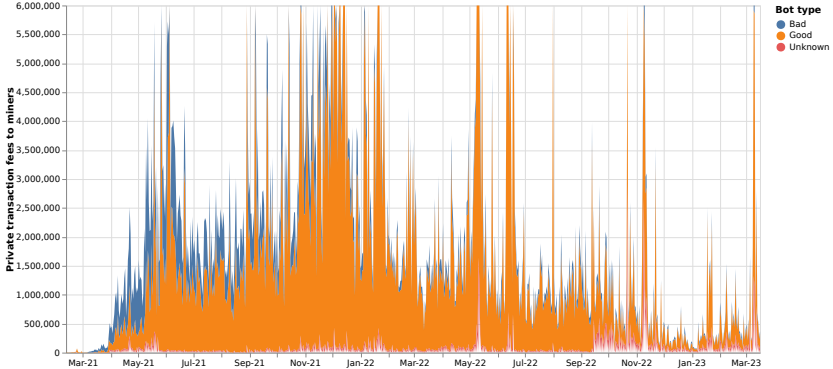


15.3% of miner revenue stems from Flashbot MEV transactions

Good and Bad Bots

- To distinguish good and bad bots we examine typical transaction patterns.
- Bad Bots:
  - example: frontrunning
  - Typically 3 transactions Bot-Victim-Bot
- Good Bots:
  - 1 transaction e.g., liquidations, arbitrage
  - 2 transactions: backrunning, i.e. trade+arbitrage

Daily Private Transaction Fees to Miners



highly variable - figure capped at $ 6 million
On average USD 2,302,641 per day

Proposer Builder Separation

- Post Ethereum's transition to proof of stake
- Miner $\rightarrow$ Validator/Proposer
- MEV more institutionalized
- Competing builders make block proposals
  - Can include bundles from flashbosts or others
  - Arrange transactions to maximize revenue for Validator
  - Take a cut of MeV
- Validator picks most profitable block proposal
- All happens within 15 seconds

Conclusion

- Arbitrageurs can be good or bad.
- Inter-relationship between level of arbitrage activity and MEV
- Private settlement
  - can lower fees for ordinary users
  - increase participation of ordinary users
  - reduce incentives to find arbitrage
  - Positive welfare gains
  - Reduce congestion
- MEV is a big market
- Many bots are active
- Good bot activity seems to dominate bad bot activity