The Market Microstructure of Uniswap

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  - ➢ The price is set **algorithmically** according to the the constant formula:

    $$(R_X - O)(R_Y + \gamma I) = R_X R_Y$$

    where R_i is the reserve of token i in the pool and $(1-\gamma)$, the transaction fees .

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- However, the ability of traders to engage in arbitrage may be hindered by inventory holding costs.
  - ➢ Inventory costs influence traders' behavior and price dynamics, as they become exposed to market risks, including price volatility.
  - ➢ This is a well-documented phenomenon in traditional financial market microstructure literature (Smidt (1971), Garman (1976), Stoll (1978), Amihud and Mendelson (1980), Ho and Stoll (1981, 1983), Hasbrouck, J. (1988)).

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Main finding

As the pool increases, resulting in a decrease in price impact, traders tend to mitigate the price discrepancy between Uniswap and centralized exchanges less, as they face greater exposure to inventory risks.

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- To maintain its reputation as **a reliable oracle**.
- To **refine protocol parameters** and enhance the overall efficiency and stability of DeFi platforms.
- To make informed choices and **manage their risk exposure effectively**.

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- Prior to any trade, they all observe the price of the trading pair both on **Uniswap (P_t)** and on the **CEX (P_t^C)**.
- The **CEX price** is the **reference market price**.

Once the trader has observed the Uniswap and the Centralized prices, she submits her trade to Uniswap so as to maximize her utility.

The latter is assumed to be a **linear function of the mean and the variance of the trader's wealth**, subject to **an inventory holding cost** as follows:

$$u(t, W) = E\left[W\right] - \frac{\rho}{2} Var\left[W\right] - \phi(X_{i,t} + Q_t - \bar{X})^2, \qquad (1)$$

where $\rho =$ the coefficient of absolute risk aversion, $\phi =$ the inventory holding cost, $X_{i,t} =$ the trader's asset inventory before the trade, $\overline{X} =$ her desired inventory level, and her wealth is given by:

$$W_{i,t} = (X_{i,t} + Q_t)\tilde{V}_t - P^E(Q_t)Q_t + C_{i,t}$$

where $C_{i,t}$ the cash holding (in ETH) and $P_E\left(Q_t\right)$ the execution price of the trade.

The problem resumes to solve the following optimization problem :

$$\max_{Q_t \in \mathbb{R}} \quad u(t, W_{i,t})$$

After solving the above problem, we find the value of Q_t, which replaced in P_{t+1}, gives the following expression:

$$P_{t+1} - P_t \quad = \quad \beta_{0,t}\bar{X} + \beta_{1,t}\left(P_t^C - P_t\right) + \beta_{2,t}(X_{i,t} - \bar{X}) \qquad (2)$$

The characterization of **price dynamics** in Uniswap given by :

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depends on:

- The price difference between Uniswap and the CEX before that trade, capturing the **arbitrage opportunity**.
- The trader's desired inventory level.
- The deviation from its desired inventory level.

The Arbitrage opportunity effect

In equation (3), the arbitrage opportunity effect is captured by:

$$\beta_{1,t} = 1 - \left(\frac{\rho\sigma_V^2 + 2\phi}{\rho\sigma_V^2 + 2\frac{P_t}{R_{X,t}} + 2\phi} \right)$$

where ρ is the coefficient of absolute risk aversion, ϕ is the inventory holding cost and σ_V^2 is the volatility of Binance price.

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- The higher the inventory cost, the less they will close the gap between the CEX and Uniswap.
- The less risk averse the trader (low ρ) and/or the less volatile the asset (low σ^2), the more they will close the gap between the CEX and Uniswap.

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- The less risk averse the trader (low ρ) and/or the less volatile the asset (low σ^2), the more they will close the gap between the CEX and Uniswap.
- The larger the pool size, the less they will close the gap.

The Inventory effect

In equation (3), the inventory effect is captured by:

$$\beta_{2,t} = -\frac{\frac{P_t}{R_{X,t}}}{\rho\sigma_V^2 + 2\frac{P_t}{R_{X,t}} + 2\phi}\left(\rho\sigma_V^2 + 2\phi\right)$$

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- The inventory effect is negative.
- The magnitude of this inventory effect is amplified with:
  - ➢ higher inventory costs,
  - ➢ higher volatility of the asset,
  - ➢ a greater risk aversion.

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The Centralized market: Binance

- Source: Kaggle.
- Data type: 1-minute price data (incl. open price, close price, lowest price, highest price and total traded volume.).
- Pair: BTC-ETH.
- Period: from May, 2020 to December, 2022.

Uniswap Data

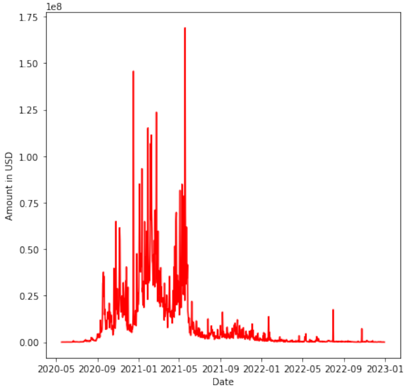
- Source: The Graph, a decentralized API designed to index and query Ethereum data. (https://thegraph.com/hosted-service/subgraph/uniswap/uniswap-v2)
- Data type: Transaction data (i.e. Mint, Burn and Swap events).
- Pair: BTC-ETH.
- Period: from May, 2020 to December, 2022.

➢ Reconstruct the reserves of the two tokens and update them after each event.

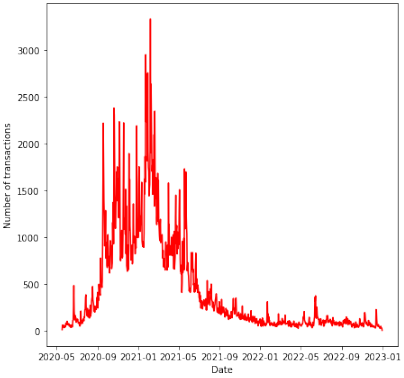
➢ Retrieve the Uniswap transaction price P_t^E for a given swap and update the price P_t after that swap.

➢ Take the 1-minute closing price.

Trading activity on Uniswap

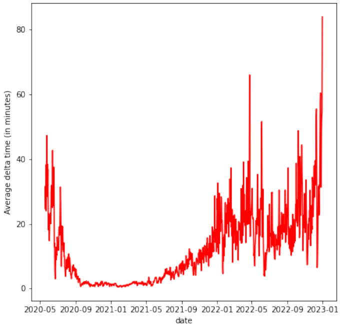


(a) Evolution of volume exchanged in USD

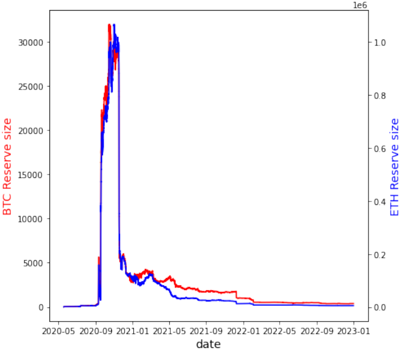


(b) Evolution of the daily number of transactions

Trading activity on Uniswap



(a) Daily average delta time (in minutes) between two transactions in Uniswap



(b) Evolution of ETH and BTC Reserves within the ETH-BTC Pool on Uniswap

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$$\Delta P_{t+1} = \widetilde{\beta}_{0,t} + \beta_{1,t}(P_t^C - P_t) + \epsilon_t \qquad (4)$$

where $\widetilde{\beta}_{0,t} = \beta_{0,t}\overline{X}$, $\epsilon_t = u_t + \beta_{2,t}(X_{i,t} - \overline{X})$, with u_t the disturbance term.

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- Model (4) is estimated using OLS with Newey-West robust estimation of the variance-covariance matrix.

Estimating the arbitrage opportunity effect

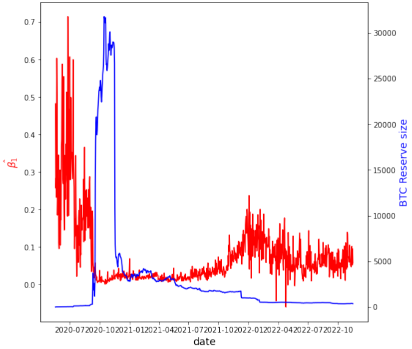
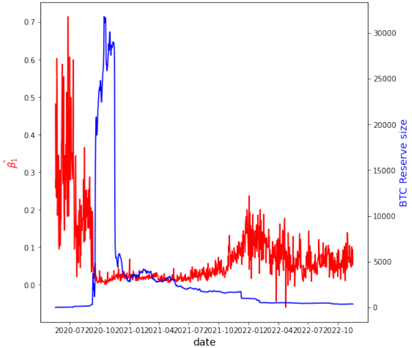


Figure: Daily estimation of arbitrage opportunity effect β_1

Estimating the arbitrage opportunity effect



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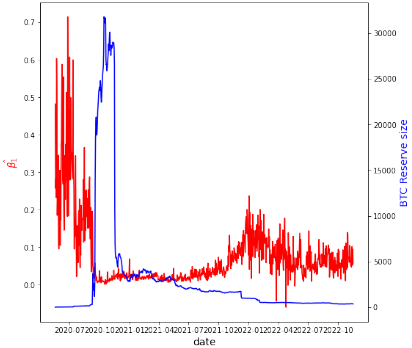

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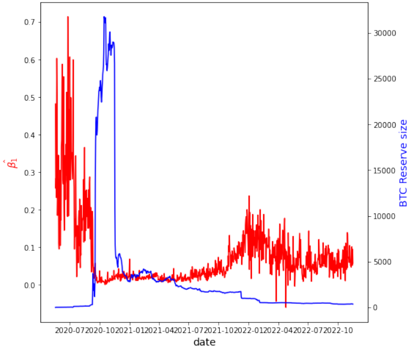

Figure: Daily estimation of arbitrage opportunity effect β_1

- As expected, β_1 is statistically lower than 1.
- Traders react less to price difference over time.
- As the pool increases, trades need to be larger to close the gap, which implies a higher amount of inventory that traders do not want to bear.

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Conclusion

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What's next?

- Estimate the inventory cost ϕ.
- Other possible explanation to explore: **MEV**. Traders may not close the gap at once to avoid front-running.
- Add other market microstructure elements that might impact Uniswap price through trades: private information and transaction costs.

Thank your for your attention!

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- DeFi Pulse, https://www.defipulse.com/

Appendix A

Ljung-Box test and Granger causality tests

Test	Null hypothesis	Stat	p-value
Ljung-Box test	Residuals are independently distributed	18588.225853	0.0
Granger causality test May	The Binance price doesn't granger causes the Uniswap price	41.4845	0.0000
Granger causality test June	The Binance price doesn't granger causes the Uniswap price	41.4845	0.0000
Granger causality test July	The Binance price doesn't granger causes the Uniswap price	29.7635	0.0000
Granger causality test Aug.	The Binance price doesn't granger causes the Uniswap price	197.7922	0.0000
Granger causality test Sept.	The Binance price doesn't granger causes the Uniswap price	301.7219	0.0000
Granger causality test Oct.	The Binance price doesn't granger causes the Uniswap price	330.6377	0.0000
Granger causality test Nov.	The Binance price doesn't granger causes the Uniswap price	157.3262	0.0000
Granger causality test May	The Uniswap price doesn't granger causes the Binance price	0.3678	0.7762
Granger causality test June	The Uniswap price doesn't granger causes the Binance price	0.4186	0.7396
Granger causality test July	The Uniswap price doesn't granger causes the Binance price	0.3218	0.8097
Granger causality test Aug.	The Uniswap price doesn't granger causes the Binance price	0.4715	0.7022
Granger causality test Sept.	The Uniswap price doesn't granger causes the Binance price	1.3849	0.2453
Granger causality test Oct.	The Uniswap price doesn't granger causes the Binance price	1.0251	0.3802
Granger causality test Nov.	The Uniswap price doesn't granger causes the Binance price	5.3800	0.0011