Blockchain Technology in Financial Markets

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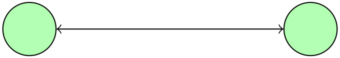
Intermediaries establish trust in financial markets

Trust in (financial) markets is established, e.g., via

- Personal (repeated) interaction
- Clearing-houses
- Broker

Intermediaries establish trust in financial markets



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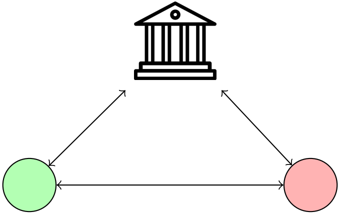

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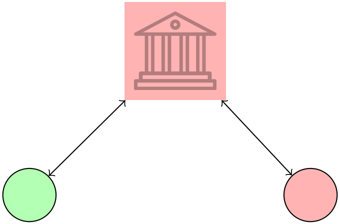

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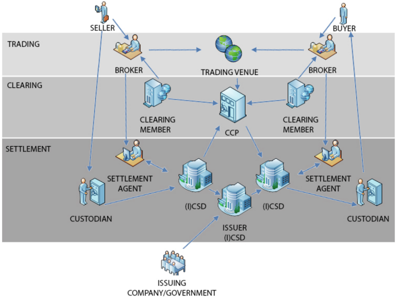
Absence of trust as a market friction

(How) does a Blockchain solve the problem?

"Traditional" Market



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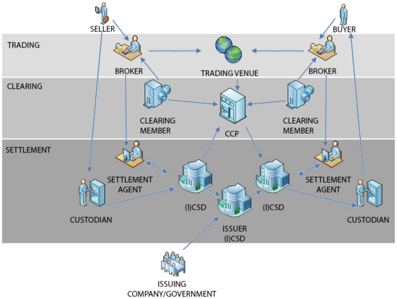
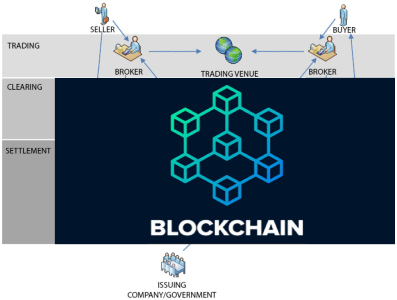


Distributed Ledger



A (public) blockchain is a shared, trusted, ledger that everyone can inspect, but which no single user controls. The participants in a blockchain system collectively keep the ledger up to date: it can be amended only according to strict rules and by general agreement.

Blockchain - Jack of all trades ...

Blockchain-based exchange of assets

- Settlement process much faster ($T + 3d$ vs $T + \varepsilon$)
- "Security" without intermediaries

...master of none?

- Security and reliability concerns
- (Potentially) limited processing capacities
- Transactions are (semi-)transparent
- Regulatory and legal uncertainty (Token financing)

My focus: Implications on market quality

The most famous blockchain

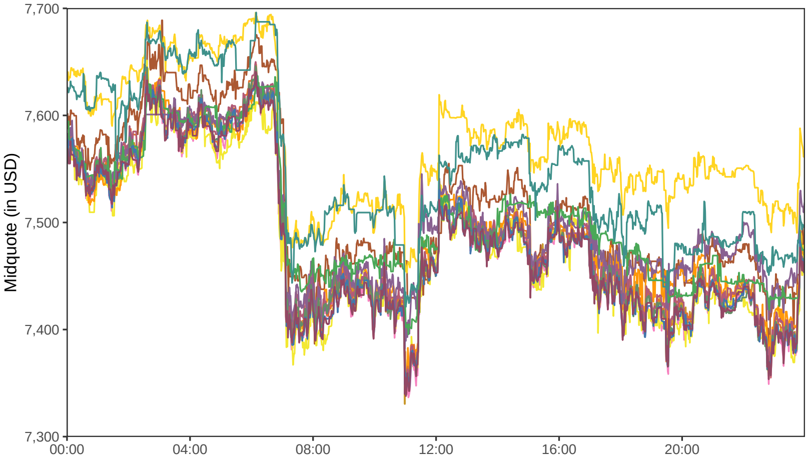
- Bitcoin can be traded on more than 400 exchanges
- Daily spot volume for Bitcoin/Dollar exceeds 2 billion USD (+ futures: 500 mio USD on CBE)

Bitcoin market structure (Hautsch, Scheuch, Voigt, 2020)

- We collect minute-level Bitcoin/Dollar orderbooks from 16 exchanges since January 2018 ($\approx$ 95% of trading volume)

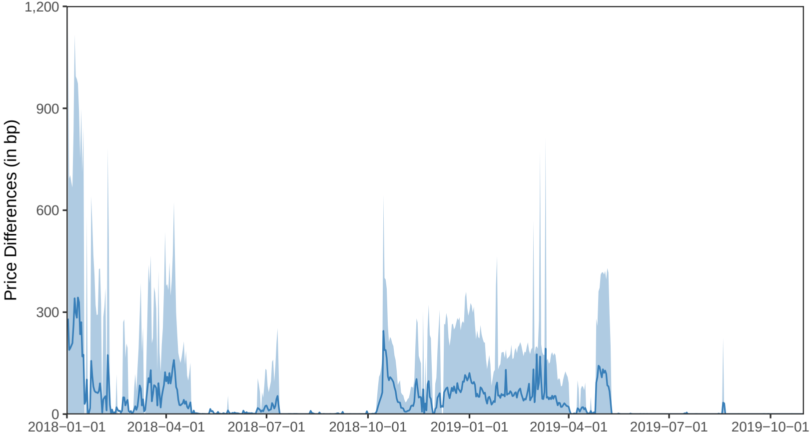
	Orderbooks	Spread (USD)	Spread (bp)	Taker Fee	With. Fee	Conf.	Margin	Business
Binance	941,399	2.61	3.29	0.10	0.00100	2	✓	✗
Bitfinex	938,703	0.62	0.74	0.20	0.00080	3	✓	✓
bitFlyer	919,182	15.13	20.52	0.15	0.00080		✓	✓
Bitstamp	938,483	5.11	6.33	0.25	0.00000	3	✗	✓
Bittrex	940,523	9.07	13.20	0.25	0.00000	2	✗	✓
CEX.IO	936,378	11.73	15.07	0.25	0.00100	3	✓	✓
Gate	907,874	81.24	90.92	0.20	0.00200	2	✗	✗
Gatecoin	560,111	336.52	515.87	0.35	0.00060	6	✗	✓
Coinbase Pro	941,539	0.45	0.54	0.30	0.00000	3	✓	✓
Gemini	912,944	2.57	3.40	1.00	0.00200	3	✗	✓
HitBTC	919,686	2.96	3.68	0.10	0.00085	2	✗	✗
Kraken	936,970	2.63	3.24	0.26	0.00100	6	✓	✓
Liqui	491,516	30.15	45.13	0.25			✓	✗
Lykke	918,768	44.04	57.95	0.00	0.00050	3	✗	✗
Poloniex	916,876	5.38	7.51	0.20		1	✓	✗
xBTCe	887,289	13.34	17.87	0.25	0.00300	3	✓	✗

Arbitrage opportunities in Bitcoin vs. Dollar trading?



Bitcoin-Dollar Mid Quotes on May 25, 2018.
One Bitcoin in US Dollar on a particular day for 17 different exchanges. We gather high-frequency orderbook information of these exchanges by accessing their public application programming interfaces (APIs) on a minute level.

Persistent price differences



This figure shows the daily average of price differences adjusted for transaction costs, across all exchange pairs from January 1, 2018, until October 31, 2019. Price differences are based on minute level transaction cost adjusted bids and asks for each exchange.

How does arbitrage work for Bitcoin?

Market b
Low Price

Market s
High Price

Arbitrageur

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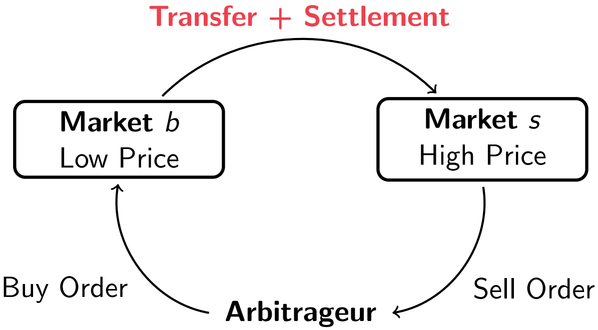

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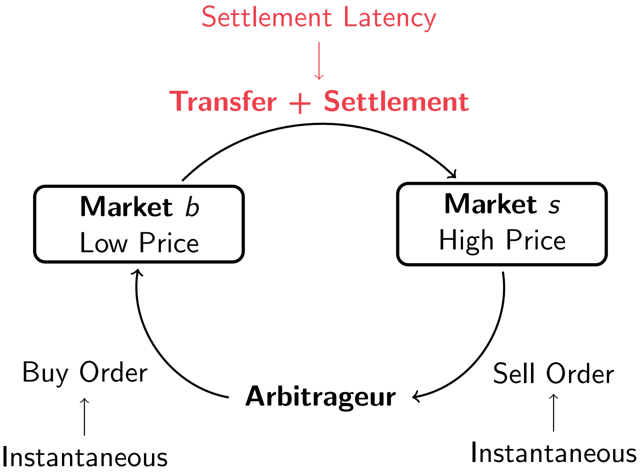


Trust, distributed ledgers and settlement latency

"Traditional" markets

- Settlement through central securities depositories (2-3 days)
- Clearing houses enable trading on non-settled positions
- Trading and settlement disconnected

Distributed ledgers

- Distributed consensus protocols instead of trusted central party
- Settlement is time-consuming & uncertain due to consensus mechanism
- Lack of trust: transfer of assets need to be settled before trading
- Trading connected to settlement

How does settlement on the Bitcoin blockchain work?

Arbitrageur buys Bitcoin on market *b*

Arbitrageur tells market *b* to send asset to market *s*

- Asset is sent to queue of unconfirmed tx (*mempool*) to wait for settlement (*confirmation*)
- Validators (*miners*) solve computationally expensive problem (*consensus protocol*) to add tx to ledger in blocks
- Limited number of tx per block ⇒ stochastic latency until a transaction is included in a block *for the first time*

Market *s* receives Bitcoin

- Risk of revoking confirmed blocks (*double spending attack*)
- Market *s* requires additional block confirmations for security reasons

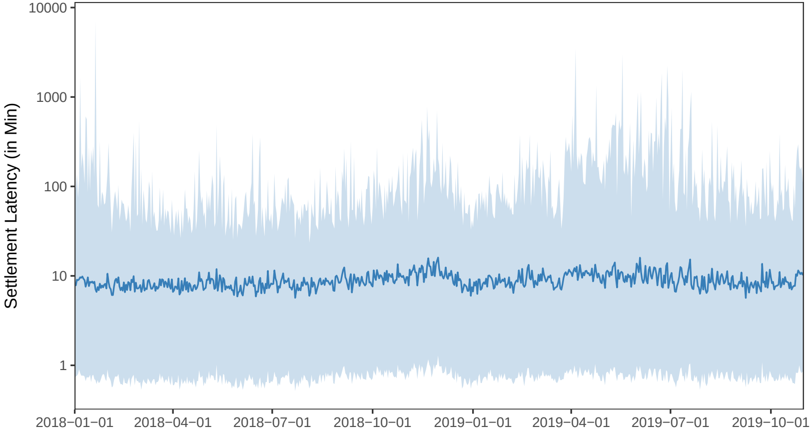
Arbitrageur sells Bitcoin on market *s*

Waiting times in the Bitcoin blockchain

- All confirmed blocks from Jan 2018 until Oct 2019
- 139,704,737 transactions verified in 99,129 blocks

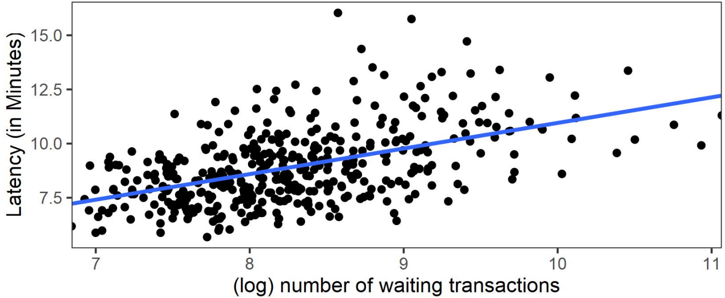
	Mean	SD	5 %	25 %	Median	75 %	95 %
Fee per Byte (in Satoshi)	47.41	183.08	1.21	5.00	14.06	45.52	200.25
Fee per Transaction (in USD)	1.98	24.19	0.02	0.09	0.28	1.12	7.54
Latency (in Min)	41.03	289.26	0.73	3.55	8.82	20.75	109.52
Mempool Size (in Number)	10,018.74	14,876.52	432.00	1,812.00	4,503.50	11,057.50	41,884.50
Transaction Size (in Bytes)	507.28	2174.13	192.00	225.00	248.00	372.00	958.00

Waiting times in the Bitcoin blockchain



Settlement latency is of relevant magnitudes

- Transactions waiting for settlement are broadcast to validators
- Latency: security feature (Hinzen et al., 2019)
- Demand determines latency (Biais et al, 2019; Zimmermann, 2019; Easley et al, 2019)



(Daily) median network activity and settlement latency in the Bitcoin network

Theoretical framework

Market $i \in \{b, s\}$ continuously provides (log) buy quotes (ask) a_t^i and sell quotes (bid) b_t^i

No short selling, margin trading or derivatives

Arbitrageur continuously monitors the quotes on markets b and s

Instantaneous trading: arbitrageur exploits price differences if

$$\delta_t^{b,s} := b_t^s - a_t^b > 0$$

Stochastic latency τ is the random waiting time until a transfer of the asset between markets is settled

(Log) return of the arbitrageur's strategy:

$$r_{(t:t+\tau)}^{b,s} := b_{t+\tau}^s - a_t^b = \underbrace{\delta_t^{b,s}}_{\substack{\text{instantaneous}\\ \text{return}}} + \underbrace{b_{t+\tau}^s - b_t^s}_{\substack{\text{exposure to}\\ \text{price risk}}}$$

Assumptions about price process & latency

Profit of arbitrageur's trading decision is at risk if

$$\mathbb{P}\left(b^s_{t+\tau} \leq a^b_t\right) > 0$$

Assumption 1. Given latency τ, log *price changes* on the sell-side follow Brownian motion with drift:

$$r^{b,s}_{(t:t+\tau)} = \delta^{b,s}_t + \tau\mu^s_t + \int_t^{t+\tau} \sigma^s_t dW^s_k$$

with σ^s_t and μ^s_t locally constant over $[t, t+\tau]$

Assumption 2. *Stochastic latency* $\tau \in \mathbb{R}_+$ is a random variable with probability distribution $\pi_t(\tau)$ with moment-generating function finite on an interval around zero

Constant relative risk aversion (CRRA)

Assumption 3. Arbitrageur has power utility function with $\gamma > 1$

$$U_\gamma(r) := \frac{r^{1-\gamma} - 1}{1-\gamma}$$

Lemma 1. Arbitrage boundary with CRRA utility and $\mu_t^s = 0$

$$d_t^s = \frac{1}{2}\sigma_t^s \sqrt{\gamma \mathbb{E}_t\left(\tau\right) + \sqrt{\gamma^2 \mathbb{E}_t\left(\tau\right)^2 + 2\gamma(\gamma+1)(\gamma+2)\mathbb{E}_t\left(\tau^2\right)}}$$

Limits to arbitrage increase with

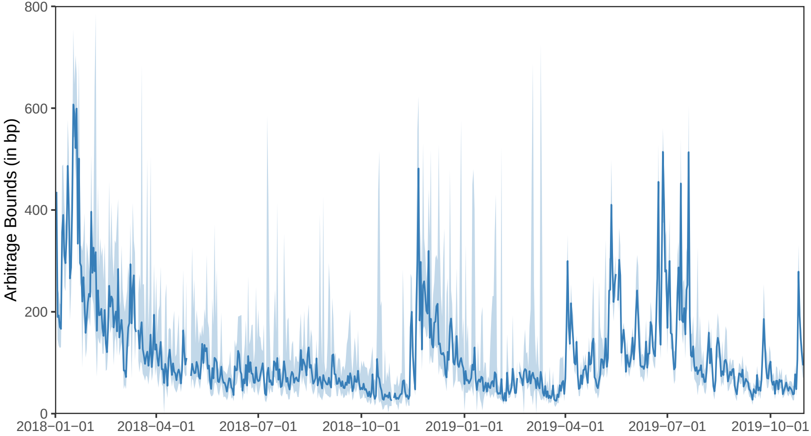
- Sell-side spot volatility $(\sigma_t^s)^2$
- Expected latency $\mathbb{E}_t(\tau)$
- Latency uncertainty $\mathbb{E}_t\left(\tau^2\right)$
- Risk aversion γ

Estimated arbitrage boundaries (in bps, $\gamma = 2$)

- Average boundary about 96bps
- Latency uncertainty accounts for 9% on average

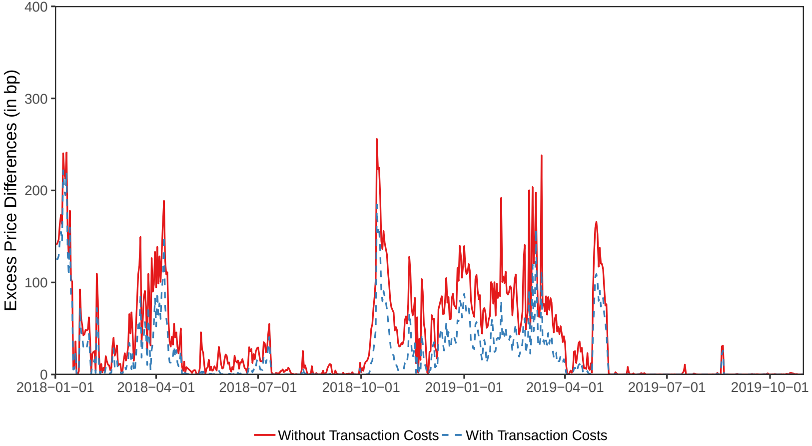
	Mean	SD	5%	25%	Median	75%	95%	Uncertainty
Binance	77.09	62.84	20.41	35.47	56.77	97.75	199.73	9.00
Bitfinex	84.01	69.10	15.38	35.37	62.42	113.17	222.94	8.46
bitFlyer	92.98	65.72	28.72	50.39	73.49	113.91	223.44	8.46
Bitstamp	91.55	69.67	24.35	44.05	69.46	118.17	230.76	8.56
Bittrex	98.30	63.45	28.79	54.26	83.23	124.56	219.35	8.57
CEX.IO	88.90	61.98	25.32	45.58	72.37	112.11	213.13	8.42
Gate	73.45	54.07	19.89	37.20	58.19	92.44	178.68	8.77
Gatecoin	185.74	211.13	2.70	44.90	112.77	253.63	606.39	9.14
Coinbase Pro	78.83	66.43	14.51	32.86	58.54	103.35	213.89	8.56
Gemini	80.81	66.12	17.48	35.99	60.55	103.73	216.48	8.57
HitBTC	66.70	56.45	15.39	30.05	49.73	83.98	175.08	8.84
Kraken	107.08	84.59	21.26	46.79	80.83	143.14	282.51	9.15
Liqui	81.99	48.51	22.02	47.69	73.41	105.93	170.37	8.27
Lykke	92.38	86.87	13.83	35.99	65.35	116.95	265.90	8.53
Poloniex	59.68	51.21	14.21	27.04	43.77	74.66	158.05	13.76
xBTCe	82.70	69.44	15.21	34.73	61.46	110.61	219.68	8.56

Estimated arbitrage boundaries over time ($\gamma = 2$)



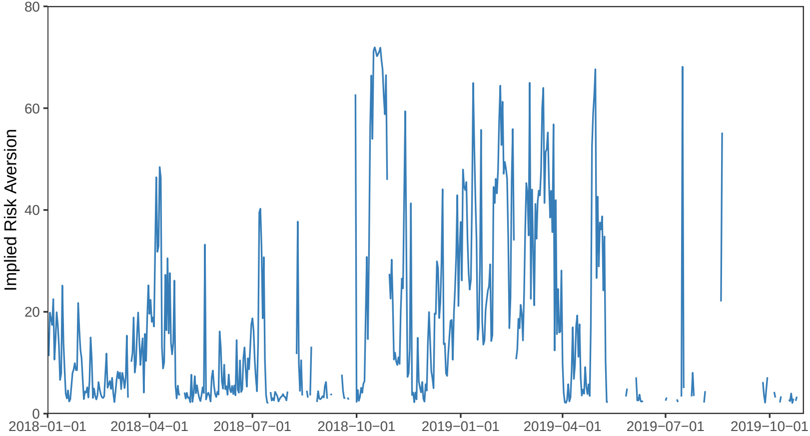
Daily average estimated arbitrage bound based on a CRRA utility function with risk aversion parameter $\gamma = 2$. The solid blue line shows the daily averages (in basis points) across all exchanges.

Price Differences in Excess of Arbitrage Bounds over Time



Daily average minute-level returns in excess of the estimated arbitrage bounds across all exchange pairs from January 1, 2018, until October 31, 2019. The solid red line corresponds to price differences based on the best bid and best ask of the individual exchange pairs.

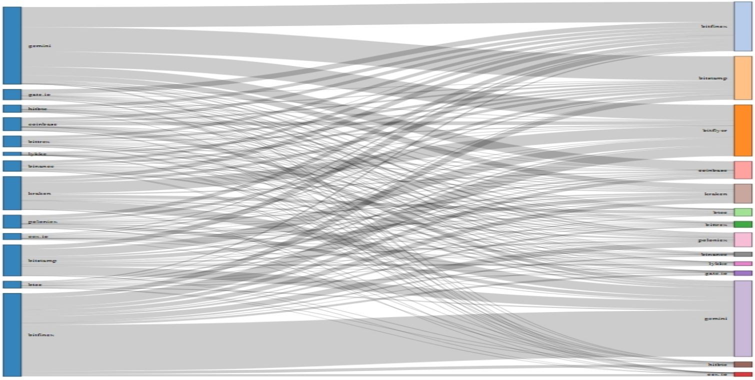
What do we miss?



Daily average implied risk aversion parameter. We compute implied risk aversion as the smallest relative risk aversion such that all observed price differences adjusted for transaction costs fall within the implied limits to arbitrage.

Transparency in cryptocurrency markets

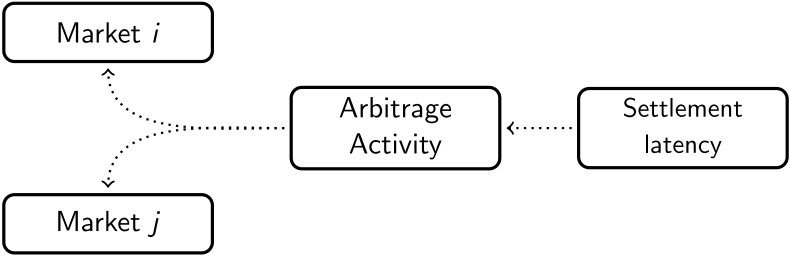
- We identify 62 million wallets associated to 15 exchanges in our sample
- 3.7 million transactions with 54 million USD average daily volume



Settlement latency: major impediment for arbitrage

Dependent Variable:	Price Differences			
	(1)	(2)	(3)	(4)
Arbitrage Bound (in %)	0.307***		0.440***	0.442***
	(15.98)		(18.62)	(12.84)
Spot Volatility (in %)		5.416***		
		(16.99)		
Latency Median (in Min)		0.003***		
		(3.92)		
Latency Variance (Standardized)		0.078***		
		(3.53)		
Arbitrage Bound × Margin Trading			-0.258***	
			(-7.07)	
Arbitrage Bound × Business Accounts				-0.220***
				(-5.38)
Spread (in %)	0.111***	0.075*	0.093**	0.101***
	(2.91)	(1.95)	(2.42)	(2.65)
Exchange Fixed Effects	Yes	Yes	Yes	Yes
Adjusted R^2	0.162	0.163	0.162	0.162
Exchange-Hour Observations	213,984	213,984	213,984	213,984

Market making and settlement latency



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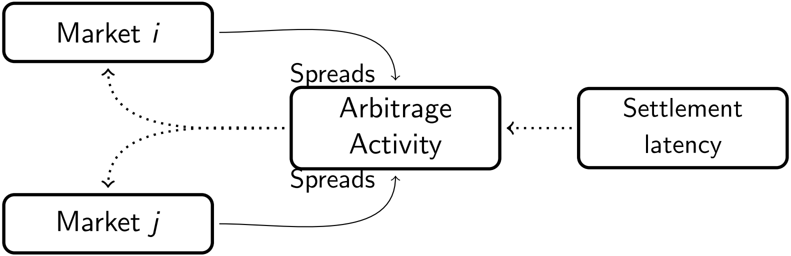


Remember the first slide?

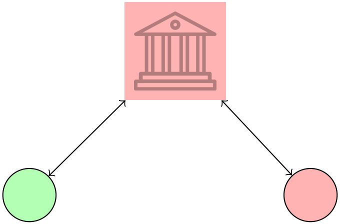
Decentralization paradoxon

- Crypto-exchanges operate as custodian of customer funds
- Orderbooks are maintained off-chain (internal settlement)
- Latency potentially good news for liquidity providers

	S_t^{Bitstamp}	S_t^{Gemini}
γ	-13.593^{***}	-2.683^{***}
	(0.115)	(0.095)
# Transactions	$-\mathbf{0.114}^{***}$	$-\mathbf{0.051}^{***}$
	(0.003)	(0.002)
$S_{t-1}^{\text{Bitstamp}}$	0.455^{***}	0.028^{***}
	(0.001)	(0.001)
S_{t-1}^{Gemini}	0.051^{***}	0.552^{***}
	(0.001)	(0.001)
Controls	Volume, volatility, past price	

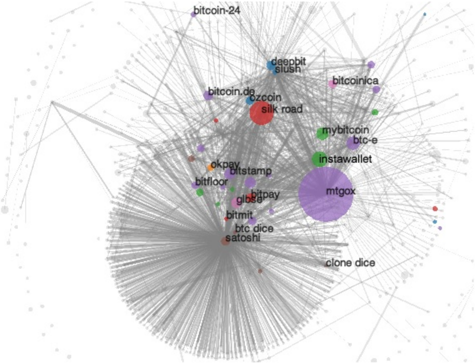
Truly decentralized exchanges

- Blockchain may make intermediaries obsolete **but** decentralization imposes limits to arbitrage
- Cryptomarket evolution: Reinstalling well-known intermediaries (side-chains, centralized exchanges)



- Technological solution allows to circumvent centralized custody of funds
- May impose novel frictions (risks for liquidity providers, regulatory uncertainty)
- Expose market participants to substantial costs
- Currently suffer from low liquidity

Wallet transparency is used by market participants (Meiklejohn et al (2013))



- Bitcoin transaction history is used to trace back drug dealers active on *silk road*
- Network analysis allow (and is used) to resemble asset flows even when *mixing* services are used.