The End of the Crypto-Diversification Myth

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October 28th, 2022

Cryptos are everywhere

FINANCIAL TIMES

Cryptocurrencies + Add to myFT

Crypto has 'no inherent worth' but is good to trade, says Man Group chief

Gary Silverman in New York JULY 26 2021

The New York Times

Fidelity's New 401(k) Offering Will Invest in Bitcoin

The employer that oversees the retirement savings plan would have to decide to include the digital assets account.

By Tara Siegel Bernard

April 26, 2022

REUTERS®

Future of Money

2 minute read · January 5, 2022 5:43 PM GMT · Last Updated 9 months ago

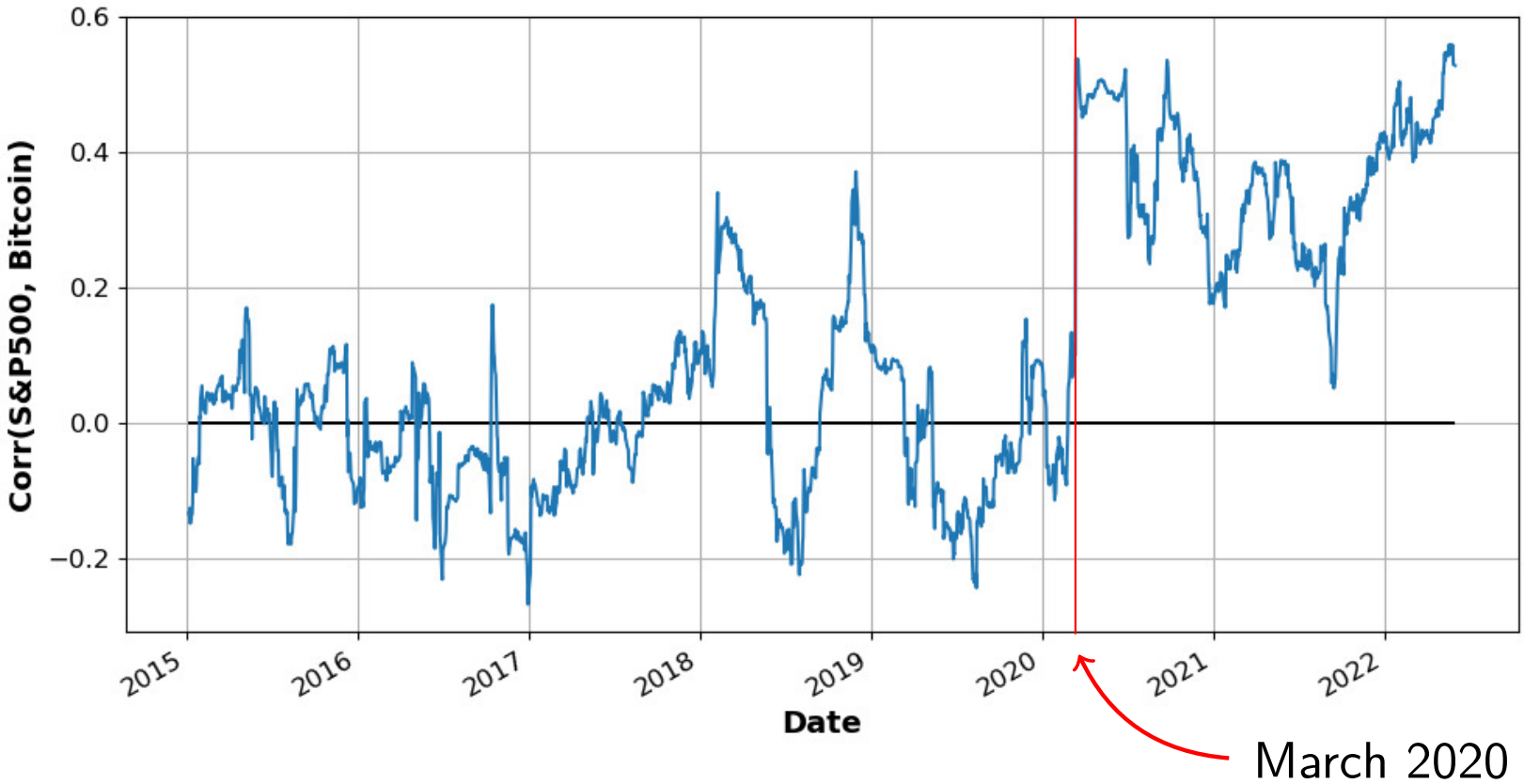
Goldman Sachs says bitcoin will compete with gold as "store of value"

What do we know?

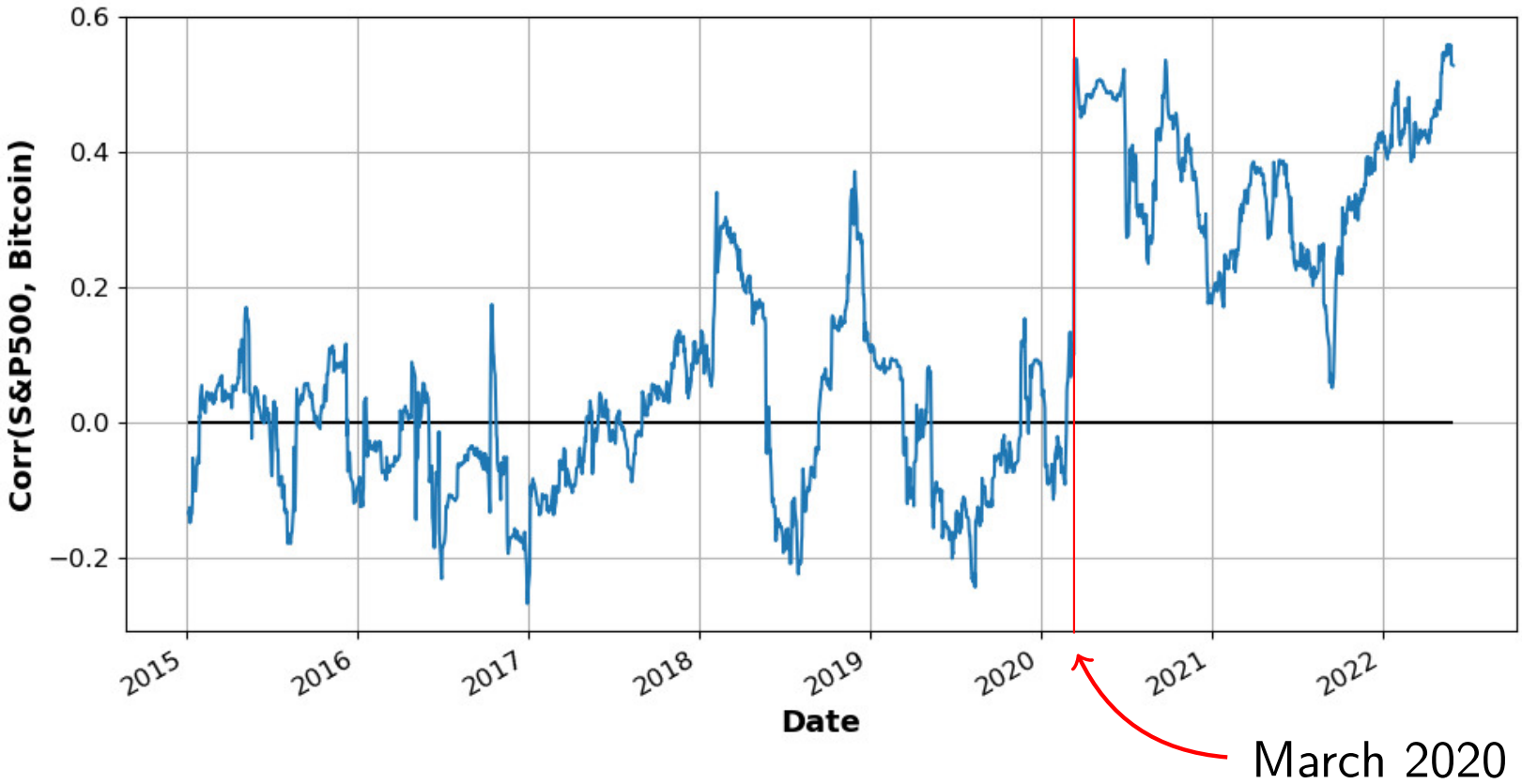
- ✔ **Theory**: transactional value is the fundamental (e.g., Foley, Karlsen, and Putniņš, 2019; Schilling and Uhlig, 2019; Biais, Bisiere, Bouvard, Casamatta, and Menkveld, 2020).
- ✔ **Empirics**: network effects, speculative asset (e.g., Liu and Tsyvinski, 2021; Hackethal, Hanspal, Lammer, and Rink, 2022).

- ✘ Why does Bitcoin move together with the market?

Is Bitcoin a diversification tool?



Is Bitcoin a diversification tool?



What drives the crypto-equity correlation?

(Why has Bitcoin started behaving like a tech stock?)

Key takeaway: Retail investors drive the correlation

We theoretically show:

- Without a fundamental driver, uninformed investors trading flows can generate a correlation.

We empirically show:

- Retail investors trade cryptos and equities at the same time and in the same direction.
- This behavior started in March 2020, at the same time as the crypto-equity correlation.
- Periods with higher correlation correspond to retail crypto traders being more active. Their favourite stocks are the most correlated with Bitcoin.

The paper in a nutshell

1. We formalize the argument with a toy model.
2. We present a novel dataset of retail investors trading cryptocurrencies and equities.
3. We find empirical evidence for the model's implications at the micro level.
4. We show pattern in global markets consistent with the proposed mechanism.

Crash course on Kyle (1985)

- Risky asset with fundamental value $v \sim \mathcal{N}(\mu, \sigma^2)$
- Agents:
  - *Informed*: know v and submits an order x
  - *Uninformed*: submit an order $u \sim \mathcal{N}(0, \sigma_u^2)$
  - *Market maker*: observes the total order flow $(x + u)$ and competitively sets the price p for the risky asset

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- Sequential equilibrium:
  - Insiders's market order $x(v)$ s.t.

$$x(v) = \arg\max_x \mathbb{E}\Big[[v - p(x+u)]x \mid v\Big] = \underbrace{\frac{\sigma_u}{\sigma}}_{\beta}\Big[v - \mu\Big]$$

  - Market maker's price function $p(x+u)$ s.t.

$$p(x+u) = \mathbb{E}\Big[v \mid x+u\Big] = \mu + \underbrace{\frac{\sigma}{2\sigma_u}}_{\lambda}\Big[x+u\Big]$$

Crypto-Kyle: assumptions

1. 2 risky assets: stocks and cryptocurrencies

   The fundamental values are uncorrelated. (A1)

2. 2 market makers

   Market making in crypto and stock markets is segmented. (A2)

3. Uninformed investors trade both asset classes

   Trading flows of uninformed investors are correlated because they engage in cross-asset trading. (A3)

Crypto-Kyle: set-up

- 2 risky assets with fundamental values not correlated

$$V = \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \sim \mathcal{N}\left(\begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix}, \begin{bmatrix} \sigma_1^2 & 0 \\ 0 & \sigma_2^2 \end{bmatrix} \right) \quad \text{A1}$$

- Agents:
  - *Informed*: know V and submits an order

$$X = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} \beta_{11} & 0 \\ 0 & \beta_{22} \end{bmatrix} \left(\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} - \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix} \right) = \begin{bmatrix} \beta_{11} (v_1 - \mu_1) \\ \beta_{22} (v_2 - \mu_2) \end{bmatrix}$$

  - *Uninformed*: submit correlated order flows A3

$$U = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \sim \mathcal{N}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \sigma_u^2 \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix} \right)$$

  - *Market makers*: observe the total order flow $(x_i + u_i)$ and competitively sets the price p_i for the risky asset i A2

Crypto-Kyle: sequential equilibrium

- Insiders's market order $X(V) = \begin{bmatrix} x_1(v_1) \\ x_2(v_2) \end{bmatrix}$ s.t.

$$x_1(v_1) = \arg\max_{x_1} \mathbb{E}\Big[\big[v_1 - p_1(x_1 + u_1)\big]x_1 \mid v_1\Big] = \frac{\sigma_u}{\sigma_1}\Big[v_1 - \mu_1\Big]$$

$$x_2(v_2) = \arg\max_{x_2} \mathbb{E}\Big[\big[v_2 - p_2(x_2 + u_2)\big]x_2 \mid v_2\Big] = \frac{\sigma_u}{\sigma_2}\Big[v_2 - \mu_2\Big]$$

- Market maker's price function $P(X + U) = \begin{bmatrix} p_1(x_1 + u_1) \\ p_2(x_2 + u_2) \end{bmatrix}$ s.t.

$$p_1(x_1 + u_1) = \mathbb{E}\Big[v_1 \mid x_1 + u_1\Big] = \mu_1 + \frac{\sigma_1}{2\sigma_u}\Big[x_1 + u_1\Big]$$

$$p_2(x_2 + u_2) = \mathbb{E}\Big[v_2 \mid x_2 + u_2\Big] = \mu_2 + \frac{\sigma_2}{2\sigma_u}\Big[x_2 + u_2\Big]$$

Model predictions

1. The price covariance is positive iff the correlation of the uninformed investors' trading is positive:

$$Cov(p_1, p_2) = \rho \frac{\sigma_1 \sigma_2}{4} > 0 \quad \Longleftrightarrow \quad \rho > 0$$

2. Simultaneous change in the cross-asset retail investors' trading habits and in the price correlation (March 2020).

3. We observe a stronger price correlation when crypto-retail investors are more active.

4. There is a stronger correlation between Bitcoin and stocks favored by crypto-retail investors.

Swissquote data

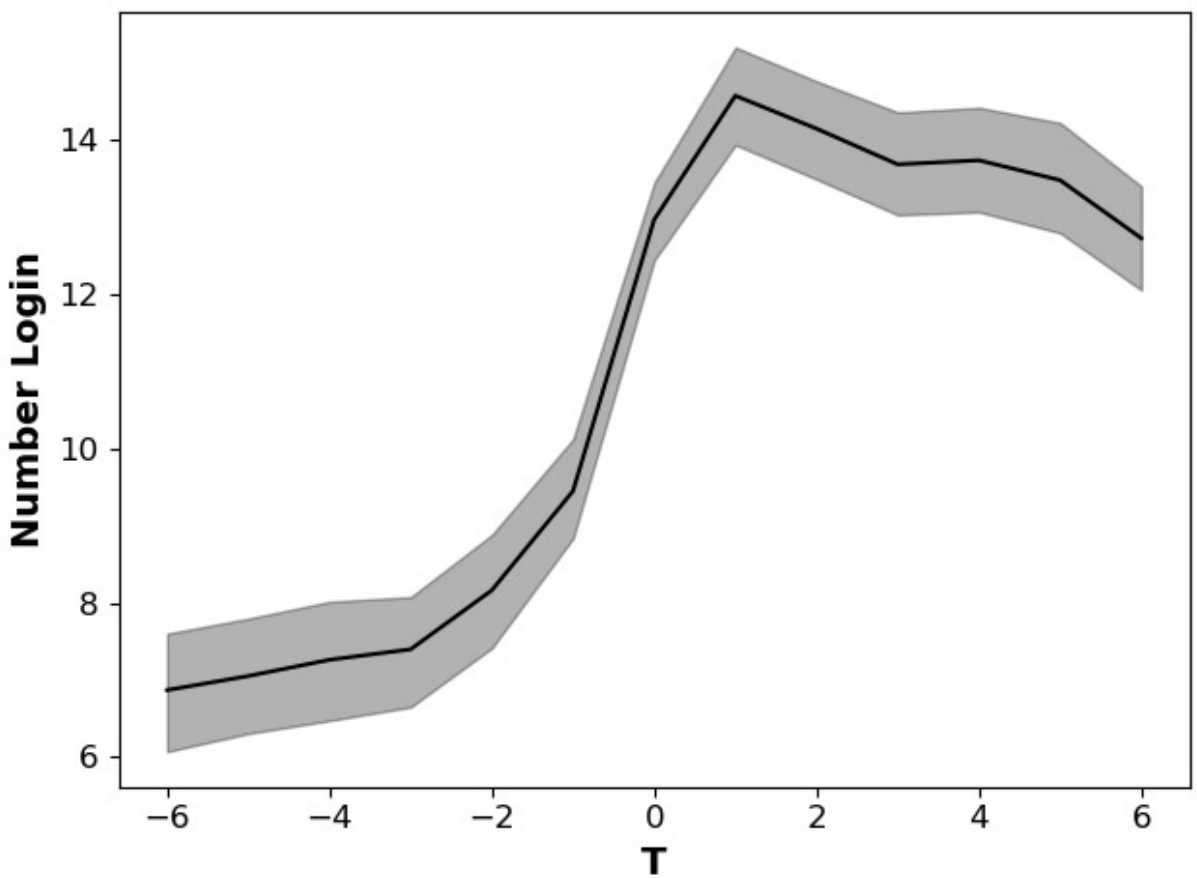
- Swiss bank
- Well-established and listed on SIX stock exchange since 1999
- It offers both brokerage services and cryptocurrency wallets
- 28 cryptocurrencies available for trading
- Customers exchange real tokens (no indirect trading)

Summary statistics

- 77,364 clients with gender, age, and number of daily logins
- Daily holdings and transactions between 2017 and 2020
- We identify as *crypto-oriented investors* those customers with a pre-existing securities trading account that opened a crypto wallet and kept at least 1% of cryptocurrencies

	Securities only	Crypto-oriented
# clients	60,881	16,483
Investor assets (CHF) - median	34,951	17,228
Investor assets (CHF) - mean	181,680	115,425
% daily-traded wealth	0.8%	2.0%
Age - mean	54	47
% female	18.0%	8.8%
Portfolio return - mean	6.7%	11.2%
Portfolio return - std	17.4%	30.6%

Crypto-investors monthly logins



$T = 0$: traders introduce crypto in their portfolio for the first time

Cross-asset trading

Regression

Dep.: Stock_Turnover	(1)	(2)	(3)	(4)	(5)	(6)
Crypto_User	0.1129***	-0.0092***			0.0088***	-0.0772***
	(0.0033)	(0.0035)			(0.0028)	(0.0035)
Crypto_Turnover			0.2657***	0.1337***	0.2621***	0.1499***
			(0.0037)	(0.0023)	(0.0036)	(0.0023)
Bank_Assets	0.0588***	0.1189***	0.0564***	0.1150***	0.0566***	0.1144***
	(0.0007)	(0.0014)	(0.0006)	(0.0013)	(0.0006)	(0.0013)
Intercept	-0.3615***		-0.3383***		-0.3411***	
	(0.0066)		(0.0064)		(0.0065)	
FE investor	NO	YES	NO	YES	NO	YES
FE time	NO	YES	NO	YES	NO	YES
# Obs	2,695,478	2,695,478	2,695,478	2,695,478	2,695,478	2,695,478
Adj-R^2	0.0366	0.3685	0.0495	0.3715	0.0495	0.3720

- Trading in cryptos and equities is correlated.
- Opening a cryptocurrency wallet is associated with a reduction in stock trading.
- Is there substitution?

Portfolio performance (excluding crypto)

Retail investors are subject to (many) biases. Hence, more trading activity is associated with lower returns (Barber and Odean, 2013).

	Dep.: Return		Dep.: Sharpe	
	(1)	(2)	(3)	(4)
Crypto_User	0.1190***	0.0829***	-0.1732***	0.1583***
	(0.0021)	(0.0031)	(0.0080)	(0.0120)
Bank_Assets	0.0105***	0.0365***	0.1611***	0.1548***
	(0.0003)	(0.0010)	(0.0014)	(0.0038)
Intercept	0.0958***		-0.3489***	
	(0.0033)		(0.0154)	
FE investor	NO	YES	NO	YES
FE time	NO	YES	NO	YES
#Obs	2,695,478	2,695,478	2,695,478	2,695,478
Adj R^2	0.0026	0.2690	0.0074	0.3757

Regression

- Trading in cryptos is associated with a higher Sharpe ratio on the non-crypto portfolio.

Equities and cryptos are substitutes

- Retail investors substitute part of their equities with cryptos in their trading activity.

- Trading in the two asset classes is correlated.

$\Longrightarrow$ **Assumption 3 is validated:**
retail investors engage in correlated cross-asset trading

- In which direction does the correlation go?
  Rebalancing/wealth effects vs. sentiment/liquidity.

Positively correlated trading

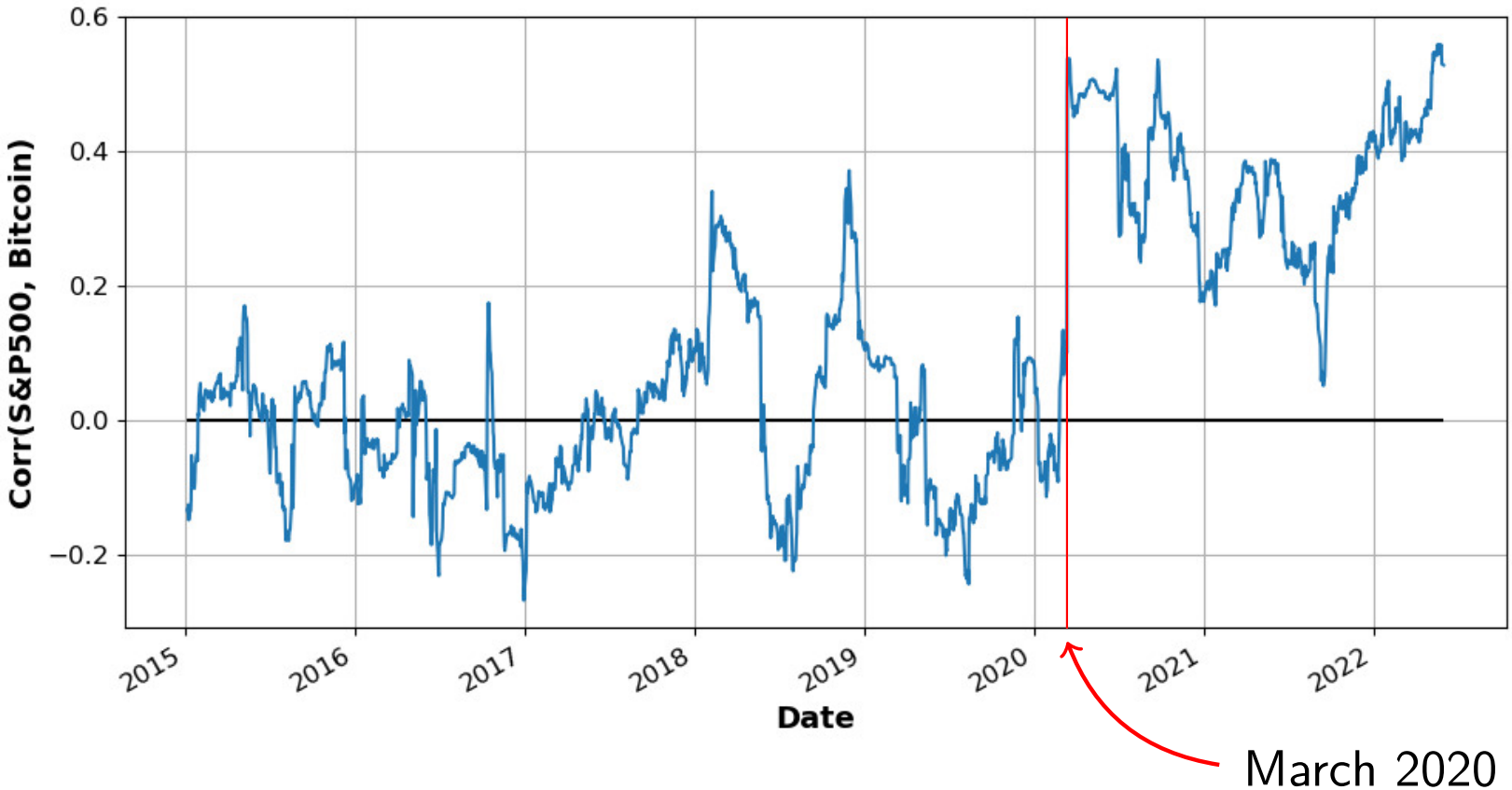
⏩ Regression

Dep.: Net_Stock	(1)	(2)	(3)	(4)	(5)	(6)
Crypto_Pos	0.0182***	0.0200***	0.0223***			
	(0.0031)	(0.0033)	(0.0033)			
Crypto_Neg	-0.0274***	-0.0331***	-0.0265***			
	(0.0029)	(0.0030)	(0.0031)			
Net_Crypto				0.0237***	0.0277***	0.0246***
				(0.0027)	(0.0028)	(0.0028)
Bank_Assets	0.0048***	0.0129***	0.0137***	0.0044***	0.0113***	0.0133***
	(0.0006)	(0.0020)	(0.0020)	(0.0005)	(0.0020)	(0.0020)
Intercept	-0.0060***			-0.0046***		
	(0.0050)			(0.0050)		
FE investor	NO	YES	YES	NO	YES	YES
FE time	NO	NO	YES	NO	NO	YES
# Obs	250,752	250,752	250,752	250,752	250,752	250,752
Adj-R^2	0.0010	0.0459	0.0526	0.0009	0.0458	0.0526

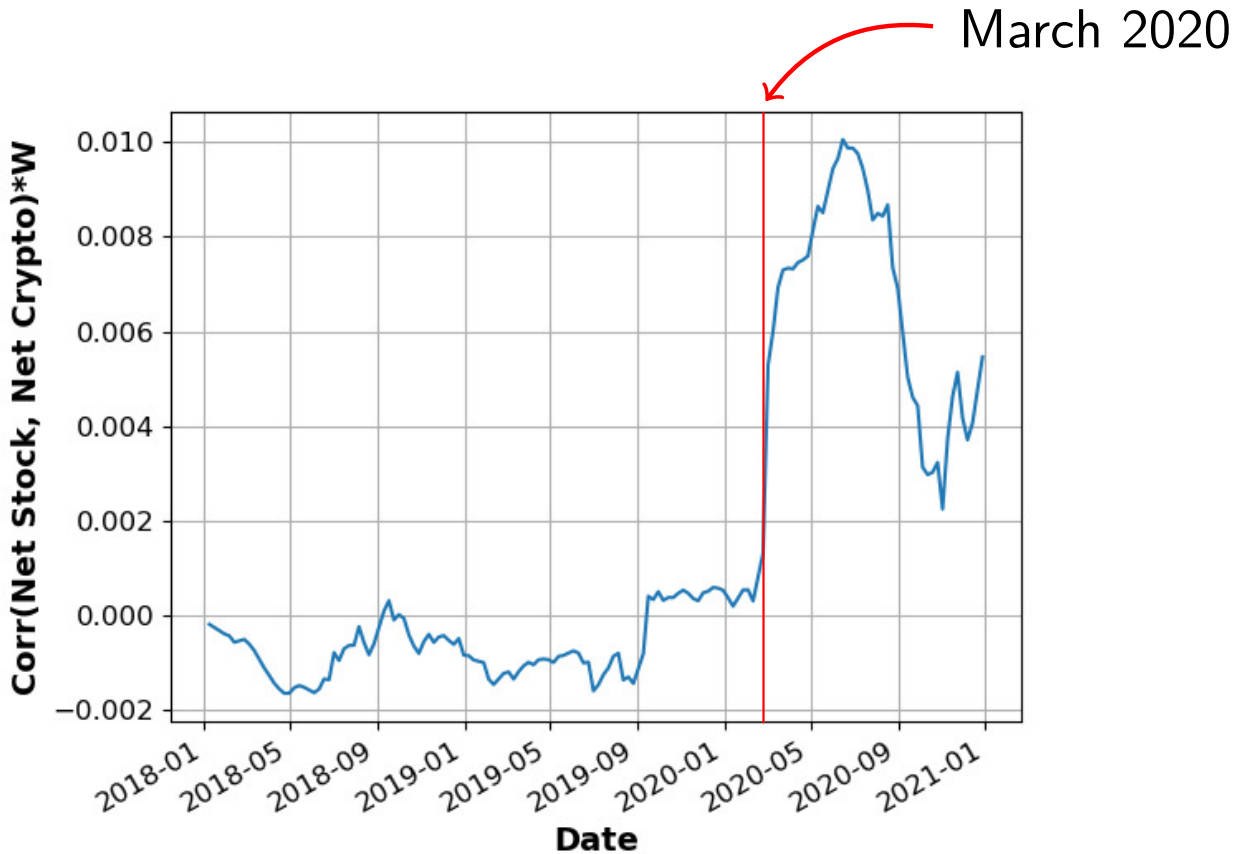
- The correlation of the uninformed traders is positive ($\rho > 0$)

$\Longrightarrow$ **Consistent with Prediction 1.**

Reminder: price correlation spikes in March 2020



Cross-asset trading also spikes in March 2020



- Boom in retail trading (up to 23% of total trading volume)
- Correlation between daily net flows in equities and cryptos in the *Swissquote* dataset jumps.

$\Longrightarrow$ **Consistent with Prediction 2.**

Why March 2020?

- Liquidity and attention shock:
  - Greenwood, Laarits, and Wurgler (2022)
  - Divakaruni and Zimmerman (2021)
- Booming retail volumes, with price impact (Van der Beck and Jaunin, 2021).
- Retail investors looked for new investment opportunities.

Global markets

$\Longrightarrow$ Is our sample representative of global retail investors?
Do we observe similar patterns at the global level?

- Select the 3000 most traded US stocks throughout the sample.
- Rank the stocks depending on the relative weight of trading by crypto-oriented *Swissquote* investors.
- Group stocks in quintiles. **The first quintile contains the least favorites and the fifth quintile the most favorites.**

Crypto traders prefer tech and growth stocks

	Q1	Q2	Q3	Q4	Q5
Industries (%):					
Technology	9.4	12.8	17.0	13.5	18.2
Health Care	16.4	24.0	27.2	29.2	28.4
Consumer Discretionary	11.9	16.1	12.6	18.8	17.2
Basic Materials	5.4	3.1	4.2	3.2	5.4
Telecommunications	2.9	2.8	3.7	3.7	2.9
Consumer Staples	4.7	5.1	2.9	4.4	3.9
Industrials	12.7	12.2	11.2	11.9	9.4
Energy	9.2	7.6	6.0	5.8	6.1
Financials	14.5	8.9	8.9	5.4	5.5
Real Estate	8.7	4.7	3.9	2.3	2.5
Utilities	4.2	2.5	2.4	1.9	0.5
Av. market cap (M USD)	3 256	3 698	4 728	5 930	7 570
Av. price-to-book ratio	3.03	3.13	3.48	3.51	3.70

Volumes and price correlation, global markets

Regression

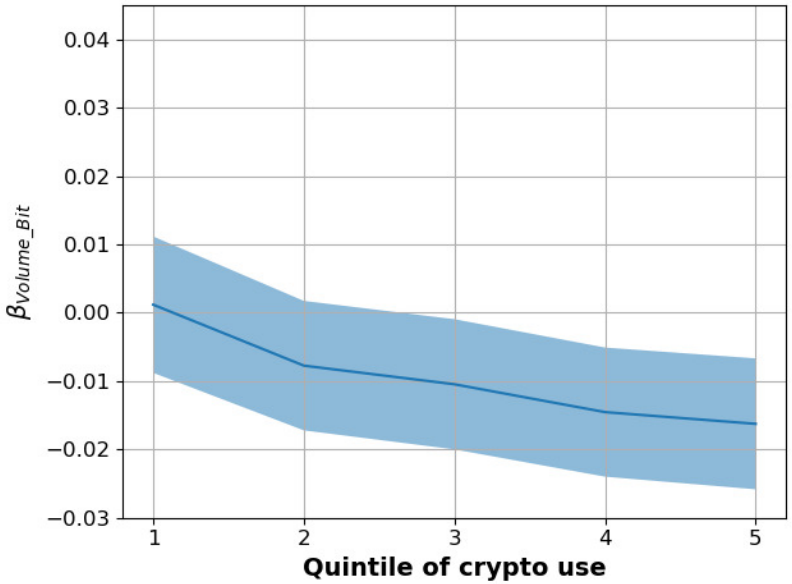
Dep.: Price_Corr	Q1	Q2	Q3	Q4	Q5
Volume_Bit	0.0070***	0.0122***	0.0109***	0.0126***	0.0145***
	(0.0018)	(0.0017)	(0.0017)	(0.0018)	(0.0018)
Vix	0.0197***	0.0223***	0.0228***	0.0228***	0.0207***
	(0.0016)	(0.0015)	(0.0014)	(0.0014)	(0.0015)
Mom	0.3836*	0.6365**	1.0788***	0.2068	0.3361***
	(0.2173)	(0.2570)	(0.3067)	(0.1830)	(0.1252)
Ret	-0.3378*	-0.6216***	-0.0191***	-0.4013***	-0.3322***
	(0.2050)	(0.1607)	(0.0009)	(0.1272)	(0.1254)
Volume	0.0209***	0.0230***	0.0243***	0.0276***	0.0319***
	(0.0037)	(0.0036)	(0.0036)	(0.0034)	(0.0035)
FE firm	YES	YES	YES	YES	YES
# Obs	23,112	24,581	24,385	24,947	23,504
Adj-R^2	0.0332	0.0331	0.0359	0.038	0.0398

Volumes and price correlation, retail investors

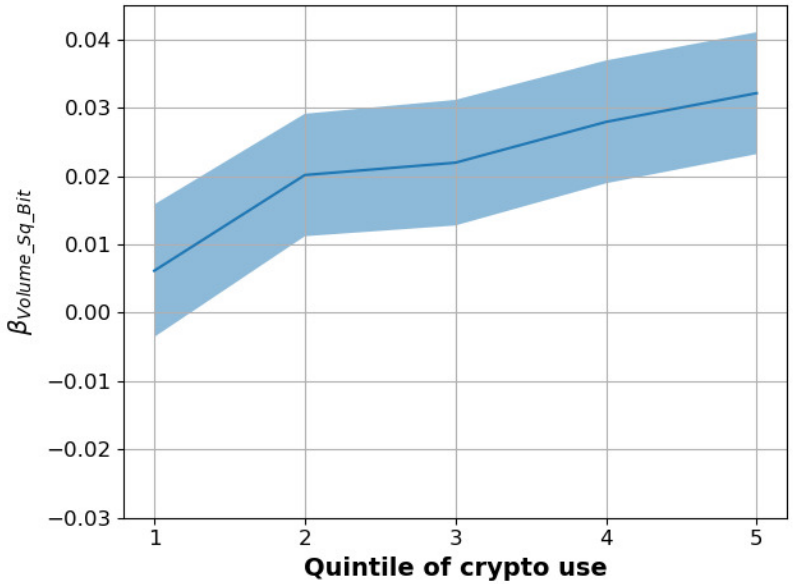
Regression

Dep.: Price_Corr	Q1	Q2	Q3	Q4	Q5
Volume_Bit	0.0007	-0.0066	-0.0088*	-0.0142***	-0.0166***
	(0.0051)	(0.0047)	(0.0048)	(0.0048)	(0.0049)
Volume_Sq_Bit	0.0065	0.0195***	0.0205***	0.0279***	0.0324***
	(0.0049)	(0.0045)	(0.0046)	(0.0046)	(0.0046)
Vix	0.0202***	0.0238***	0.0244***	0.0249***	0.0232***
	(0.0016)	(0.0016)	(0.0015)	(0.0014)	(0.0015)
Mom	0.3858*	0.6400**	1.0939***	0.2110	0.3406***
	(0.2179)	(0.2580)	(0.3109)	(0.1859)	(0.1254)
Ret	-0.3399*	-0.6224***	-0.0193***	-0.3995***	-0.3359***
	(0.2056)	(0.1612)	(0.0009)	(0.1272)	(0.1255)
Volume	0.0210***	0.0233***	0.0246***	0.0283***	0.0327***
	(0.0038)	(0.0036)	(0.0036)	(0.0034)	(0.0036)
FE firm	YES	YES	YES	YES	YES
# Obs	23,112	24,581	24,385	24,947	23,504
Adj-R^2	0.0332	0.0336	0.0364	0.0389	0.0411

Volume and price correlation relationship across quintiles



(a) Total



(b) Retail

- Retail trading volumes are associated with higher crypto-equity correlation.
- Stocks preferred by crypto-oriented retail investors are the ones exhibiting the highest correlation.

$\Longrightarrow$ **Consistent with Prediction 3 and 4.**

Summary

- Cryptocurrencies capture the attention of retail investors and drive it away from equities.
- Retail investors trade the two asset classes at the same time and in the same direction.
- We observe a change in behaviour in March 2020, when the price correlation jumped.
- The effect is stronger when crypto-oriented retail investors are more active and for stocks preferred by them.

What if we integrate crypto and stock markets?

We relax the assumption on market making:

Market making in crypto and stock markets is integrated.

- The market maker observes both order flows $(X + U)$ and competitively set the price P for both the risky assets
- Each sequential equilibrium price depends on both the order flows of the risky assets

The price covariance is *negative* iff the correlation of the uninformed investors' trading is positive:

$$Cov(p_1, p_2) = -\rho \underbrace{\frac{\sqrt{1-\rho^2}}{1-\rho^2+\sqrt{1-\rho^2}}}_{>0} \frac{\sigma_1 \sigma_2}{2} < 0 \quad \Longleftrightarrow \quad \rho > 0$$

More

Takeaways

- Retail investors drive the crypto-equity correlation. If people think of Bitcoin as a tech stock, it will behave as such.
- At the moment, cryptocurrencies are a bad diversification tool for investors' portfolios. During market turmoil, one should expect correlation to go up. This could change with market integration.
- Retail investors act as transmission channel between the two markets (relevant for policymakers).

Thank you!

Download the paper

Website

Selected literature (1)

Barber, Brad M, and Terrance Odean, 2013, The behavior of individual investors, in *Handbook of the Economics of Finance*, volume 2, 1533–1570 (Elsevier).

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Divakaruni, Anantha, and Peter Zimmerman, 2021, Uncovering retail trading in bitcoin: The impact of covid-19 stimulus checks, Technical report, Federal Reserve Bank of Cleveland.

Selected literature (2)

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Greenwood, Robin, Toomas Laarits, and Jeffrey Wurgler, 2022, Stock market stimulus, Technical report, National Bureau of Economic Research.

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Hackethal, Andreas, Tobin Hanspal, Dominique M Lammer, and Kevin Rink, 2022, The characteristics and portfolio behavior of bitcoin investors: Evidence from indirect cryptocurrency investments, *Review of Finance* 26, 855–898.

Selected literature (3)

Liu, Yukun, and Aleh Tsyvinski, 2021, Risks and returns of cryptocurrency, *The Review of Financial Studies* 34, 2689–2727.

Schilling, Linda, and Harald Uhlig, 2019, Some simple bitcoin economics, *Journal of Monetary Economics* 106, 16–26.

Van der Beck, Philippe, and Coralie Jaunin, 2021, The equity market implications of the retail investment boom, *Swiss Finance Institute Research Paper* .

Cross-asset trading: regression

$$\begin{aligned} \textit{Stock\_Turnover}_{i,t} = \beta_0 + \beta_1\, \textit{Crypto\_User}_{i,t} + \beta_2\, \textit{Crypto\_Turnover}_{i,t} \\ + \beta_3\, \textit{Bank\_Assets}_{i,t} + \alpha_i + \gamma_t + \epsilon_{i,t} \end{aligned}$$

where:

- i: investor, t: time (month)
- $\textit{Stock\_Turnover}_{i,t}$: turnover of stock portfolio, trading volume in stocks over average stock holdings
- $\textit{Crypto\_User}_{i,t}$: dummy equal to 1 if investor holds cryptos
- $\textit{Crypto\_Turnover}_{i,t}$: turnover of crypto wallet, trading volume in crypto over average crypto holdings
- $\textit{Bank\_Assets}_{i,t}$: total amount of assets held with Swissquote
- α_i: investor fixed effects
- γ_t: time fixed effects

Back

Short-term trading: regression

$$\%Short\_Term_{i,t} = \beta_0 + \beta_1\, Crypto\_User_{i,t} + \beta_2\, Crypto\_Turnover_{i,t} + \beta_3\, Bank\_Assets_{i,t} + \alpha_i + \gamma_t + \epsilon_{i,t}$$

where:

- i: investor, t: time (month)
- $Short\_Term_{i,t}$: percentage of short-term trades in stocks
- $Crypto\_User_{i,t}$: dummy equal to 1 if investor holds cryptos
- $Crypto\_Turnover_{i,t}$: turnover of crypto wallet, trading volume in crypto over average crypto holdings
- $Bank\_Assets_{i,t}$: total amount of assets held with Swissquote
- α_i: investor fixed effects
- γ_t: time fixed effects

Back

Portfolio performance (excluding crypto): regression

$$Performance_{i,t} = \beta_0 + \beta_1\, Crypto\_User_{i,t} + \beta_2\, Bank\_Assets_{i,t} + \alpha_i + \gamma_t + \epsilon_{i,t}$$

where:

- i: investor, t: time (month)
- $Performance_{i,t}$: portfolio performance in terms of annualized monthly returns or Sharpe ratio
- $Crypto\_User_{i,t}$: dummy equal to 1 if investor holds cryptos
- $Bank\_Assets_{i,t}$: total amount of assets held with Swissquote
- α_i: investor fixed effects
- γ_t: time fixed effects

Back

Positively correlated trading: regression

$$\begin{aligned} \textit{Net\_Stock}_{i,t} = \beta_0 &+ \beta_1 \, \textit{Crypto\_Pos}_{i,t} + \beta_2 \, \textit{Crypto\_Neg}_{i,t} \\ &+ \beta_3 \, \textit{Net\_Crypto} + \beta_4 \, \textit{Bank\_Assets}_{i,t} \\ &+ \alpha_i + \gamma_t + \epsilon_{i,t} \end{aligned}$$

where:

- i: investor, t: time (month)
- $\textit{Net\_Stock}_{i,t}$: net trades in stocks over total stock holdings
- $\textit{Crypto\_Pos}_{i,t}$: ratio of buy orders to crypto holdings
- $\textit{Crypto\_Neg}_{i,t}$: ratio of sell orders to crypto holdings
- $\textit{Net\_Crypto}_{i,t}$: ratio of net orders flows to crypto holdings
- $\textit{Bank\_Assets}_{i,t}$: total amount of assets held with Swissquote
- α_i: investor fixed effects
- γ_t: time fixed effects

Back

Volumes and price correlation, global markets: regression

$$Corr_{i,t} = \beta_0 + \beta_1\, Volume\_Bit_t + \beta_2\, Vix_t + \beta_3\, Mom_{i,t} + \beta_4\, Ret_{i,t} + \beta_5\, Volume_{i,t} + \gamma_i + \epsilon_{i,t}$$

where:

- i: stock, t: time (month)
- $Corr_{i,t}$: correlation between the daily returns of stock i and Bitcoin during month t
- $Volume\_Bit_t$: monthly trading volume of Bitcoin in global markets
- Vix_t: VIX index
- $Mom_{i,t}$: momentum, lagged monthly return of the stock i
- $Ret_{i,t}$: monthly return of stock i
- $Volume_{i,t}$: monthly trading volume of stock i in global markets
- γ_i: stock fixed effects

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Volumes and price correlation, retail investors: regression

$$Corr_{i,t} = \beta_0 + \beta_1 \, Volume\_Bit_t + \beta_2 \, Volume\_Sq\_Bit_t + \beta_3 \, Vix_t + \beta_4 \, Mom_{i,t} + \beta_5 \, Ret_{i,t} + \beta_6 \, Volume_{i,t} + \gamma_i + \epsilon_{i,t}$$

where:

- i: stock, t: time (month)
- $Corr_{i,t}$: correlation between the daily returns of stock i and Bitcoin during month t
- $Volume\_Bit_t$: monthly trading volume of Bitcoin in global markets
- $Volume\_Sq\_Bit_t$: monthly trading volume in Bitcoin on the Swissquote platform
- Vix_t: VIX index
- $Mom_{i,t}$: momentum, lagged monthly return of the stock i
- $Ret_{i,t}$: monthly return of stock i
- $Volume_{i,t}$: monthly trading volume of stock i in global markets
- γ_i: stock fixed effects

Crypto-Kyle with market integration: seq. equilibrium

- Insiders's market order $X(V) = \begin{bmatrix} x_1(v_1) \\ x_2(v_2) \end{bmatrix}$ s.t.

$$x_1(v_1) =_{x_1} \mathbb{E}\Big[[v_1 - p_1(X+U)]x_1 \mid v_1\Big] = \sqrt[4]{1-\rho^2}\frac{\sigma_u}{\sigma_1}\Big[v_1 - \mu_1\Big]$$

$$x_2(v_2) =_{x_2} \mathbb{E}\Big[[v_2 - p_2(X+U)]x_2 \mid v_2\Big] = \sqrt[4]{1-\rho^2}\frac{\sigma_u}{\sigma_2}\Big[v_2 - \mu_2\Big]$$

- Market maker's price function $P(X+U) = \begin{bmatrix} p_1(X+U) \\ p_2(X+U) \end{bmatrix}$ s.t.

$$P(X+U) = \mathbb{E}\Big[V \mid X+U\Big] = \mathbb{E}\Big[V \mid x_1+u_1, x_2+u_2\Big]$$
$$= \mu + \Lambda[X+U] = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix} + \begin{bmatrix} \lambda_{11} & \lambda_{12} \\ \lambda_{21} & \lambda_{22} \end{bmatrix} \begin{bmatrix} x_1+u_1 \\ x_2+u_2 \end{bmatrix}$$

Crypto-Kyle with market integration: price function

- Matrix Λ coefficients:

$$\lambda_{11} = \frac{\sqrt[4]{1-\rho^2}}{1-\rho^2+\sqrt[4]{1-\rho^2}}(1+\sqrt{1-\rho^2})\frac{\sigma_1}{2\sigma_u} \qquad \lambda_{12} = -\rho\frac{\sqrt[4]{1-\rho^2}}{1-\rho^2+\sqrt[4]{1-\rho^2}}\frac{\sigma_1}{2\sigma_u}$$

$$\lambda_{21} = -\rho\frac{\sqrt[4]{1-\rho^2}}{1-\rho^2+\sqrt[4]{1-\rho^2}}\frac{\sigma_2}{2\sigma_u} \qquad \lambda_{22} = \frac{\sqrt[4]{1-\rho^2}}{1-\rho^2+\sqrt[4]{1-\rho^2}}(1+\sqrt{1-\rho^2})\frac{\sigma_2}{2\sigma_u}$$

- Market maker's price function $P(X+U)$:

$$P(X+U) = \begin{bmatrix}\mu_1\\ \mu_2\end{bmatrix} + \underbrace{\gamma\begin{bmatrix}\delta\frac{\sigma_1}{2\sigma_u} & -\rho\frac{\sigma_1}{2\sigma_u}\\ -\rho\frac{\sigma_2}{2\sigma_u} & \delta\frac{\sigma_2}{2\sigma_u}\end{bmatrix}}_{\Lambda}\begin{bmatrix}x_1+u_1\\ x_2+u_2\end{bmatrix}$$

$$\delta = 1+\sqrt{1-\rho^2} > 0 \qquad \gamma = \frac{\sqrt[4]{1-\rho^2}}{1-\rho^2+\sqrt[4]{1-\rho^2}}$$

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