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MEMORANDUM

TO: File No. SR-CboeBZX-2021-039

FROM: Neel Maitra
Senior Special Counsel (Fintech & Crypto Specialist)
Division of Trading and Markets
U.S. Securities and Exchange Commission

DATE: September 8th, 2021

SUBJECT: Meeting with Representatives from Fidelity Digital Assets, et al.

On September 8th, 2021, the following Commission staff:

Valerie Szczepanik, Strategic Hub for Innovation and Financial Technology ("**FinHub"**)
Amy Starr, FinHub
David Shillman, Division of Trading and Markets ("**TM**")
Molly Kim, TM
Thomas K. McGowan, TM
Randall Roy, TM
Raymond Lombardo, TM
Neel Maitra, TM
Abraham Jacob, TM
Timothy Fox, TM
Sarah Schandler, TM
Stacia Sowerby, TM
Jonathan Ingram, Division of Corporation Finance ("**CF**")
Mark Vilardo, CF
Michael Reedich, CF, and
Sumeera Younis, Division of Investment Management

attended a WebEx meeting and presentation with the individuals identified below.

- Tom Jessop, President, Fidelity Digital Assets
- Cynthia Lo Bessette, Head of Asset Management Legal, Fidelity Investments
- Peter Jubber, Managing Director, Fidelity Digital Funds
- Kristy Croushore, Vice President, Fidelity Investments
- Terrence Dempsey, Vice President of Product, Fidelity Digital Assets
- Jason Goggins, Vice President, Federal Government Relations, Fidelity Investments, and
- Kyle Murray, Vice President, Associate General Counsel, CBOE

The presentation concerned, among other things, matters related to File No. SR-CboeBZX-2021-039. In addition, Fidelity representatives provided the attached document entitled "Wise Origin Bitcoin Trust."

Wise Origin Bitcoin Trust

September 8, 2021

Agenda

Since 2014, Fidelity has developed a broad set of bitcoin and digital asset capabilities within the firm and filed for a bitcoin ETP in March 2021

Digital Assets Services and Offerings

Fidelity Digital Assets

*Fidelity Digital Assets (FDAS) provides **infrastructure and market access solutions** for institutions seeking growth and capital efficiency in the digital asset class through its **custody and trading solutions***

Fidelity Digital Funds
(FD Funds Management)

*Fidelity Digital Funds (FDF) creates and manages Fidelity's **digital asset investment products,** including **Wise Origin Funds,** three private investment funds offering exposure to BTC*

Research and Development

Fidelity Center for Applied Technology

FCAT researches various digital assets, blockchain protocols, and emerging blockchain-related topics, as well as **incubating new products and services**

2014
Fidelity conducted initial blockchain and digital asset research

2015
Fidelity's Center for Applied Technology (FCAT) launched blockchain incubator

2015
Fidelity Charitable began accepting bitcoin

2018
Fidelity Digital Assets (FDAS) began offering custody solutions

2019
Fidelity Digital Assets received NY Trust Charter

2020
Fidelity launched its first externally-offered digital asset private fund: Wise Origin Bitcoin Index Fund I, LP

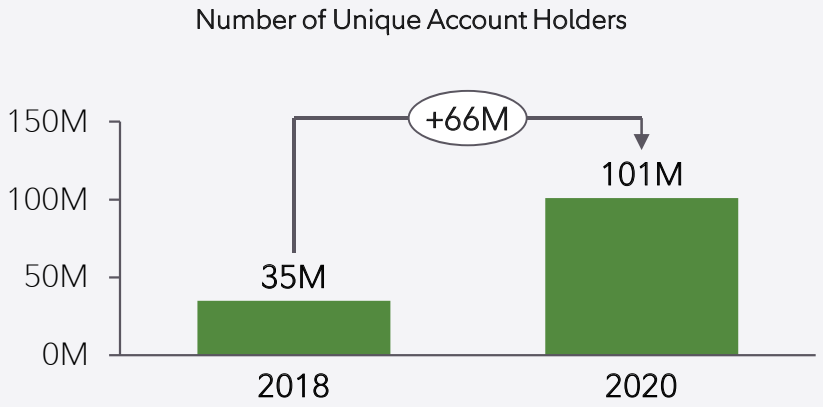
2020
Fidelity launched its first two digital asset private funds, offered only to employees: Wise Origin Fund I & II

2021
Fidelity launched 'Sherlock' a digital assets data and analytics solution for institutional investors

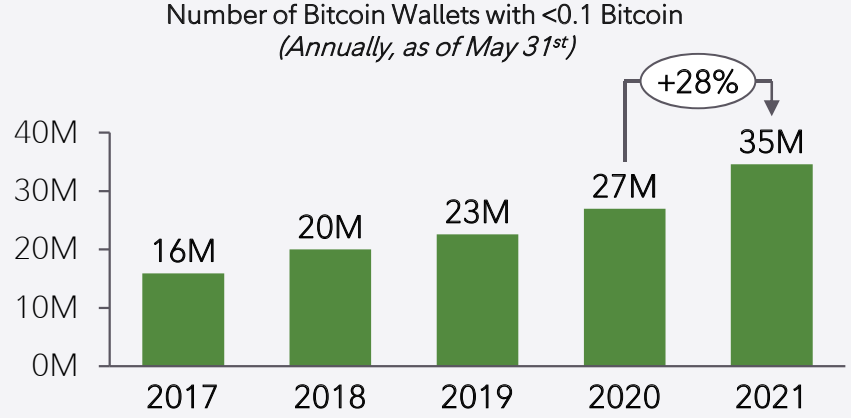
Investor Demand

Bitcoin began as a peer-to-peer network driven by individual interest; today there is broad retail adoption and growing institutional interest in gaining exposure to bitcoin

A University of Cambridge Study[1] found the **number** of **unique crypto asset account holders** grew from **35M in 2018** to over **100M in 2020**



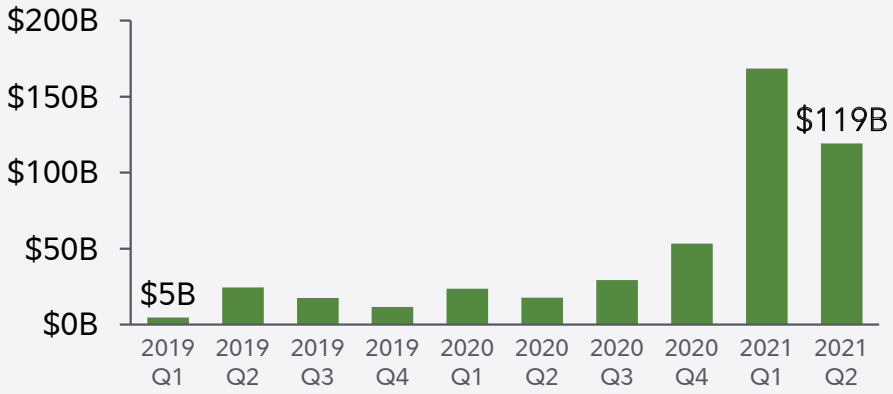
There were **34.6M bitcoin wallets** (90% of 38M total wallets) holding between zero and 0.1 bitcoin as of **May 31st, 2021**[2]



Fidelity's 2021 Digital Asset Survey[3] saw **strong interest** in digital assets from **US institutions**

- **33% of US institutional investors** are **invested in digital assets** today[4]
  - Their **preferred** way to **access** digital assets is through an **investment product**[4]
- **69% of US institutional investors** feel **digital assets** should be part of an **investment portfolio going forward**[5]
- A **bitcoin ETP** is the **most appealing** digital asset investment product, with **38% of US institutional investors** finding it appealing[6]

Between Q1 2019 & Q2 2021, quarterly **CME bitcoin futures volume** grew more than **20x**



Sources / Notes: (1) Third Global Cryptoasset Benchmarking Study; University of Cambridge, Judge Business School; (2) Coin Metrics, Accessed June 2021; (3) See slide 16 for detail on the survey; (4-6) 2021 Phase III Institutional Digital Asset Survey; (7) Coin Metrics, July 2021.

Numerous service providers and methods to gain bitcoin exposure have emerged to meet the demand for exposure to bitcoin

Institutional Service Providers	Methods to Gain Bitcoin Exposure	Investor Protection Challenges
▪ Institutional Custody (e.g., Fidelity, Coinbase) ▪ Retail Custody & Trading (e.g., Coinbase, Gemini) ▪ Payment Services (e.g., Square, PayPal) ▪ Index Services (e.g., S&P, CME, Bloomberg, NASDAQ) ▪ Investment Management (e.g., Fidelity, Grayscale, NYDIG)	▪ Direct holdings of bitcoin ▪ Operating company proxy exposure (e.g., Tesla, MicroStrategy) ▪ OTC-traded, SEC reporting funds (e.g., GBTC) ▪ Bitcoin futures and other derivatives ▪ '40 Act mutual funds holding bitcoin futures and other bitcoin funds	▪ Technically complex ▪ Proxy risk ▪ Limited disclosures ▪ Expensive ▪ Poor performance tracking ▪ Premium / discount to NAV ▪ Indirect and / or leveraged exposures ▪ Trading / roll fees

International Bitcoin ETPs	▪ Global developed market regulators have approved ETPs investing in bitcoin in Canada, Germany, Switzerland, and Sweden

We believe bitcoin futures-based products are not a necessary interim step before a bitcoin ETP; firms should be able to meet investor demand for direct exposure to bitcoin through '33 Act bitcoin ETPs because the bitcoin market has matured and can support them

Bitcoin Market Maturation

Exchange Act Section 6(b)(5) requires that the rules of a national securities exchange be 'designed to prevent fraudulent and manipulative acts and practices'

SEC Standard

- When a spot market is unregulated, a listing exchange can satisfy its obligations under 6(b)(5) to prevent fraudulent and manipulative acts by showing that it "has entered into a surveillance-sharing agreement with a **regulated market of significant size** in derivatives related to the underlying asset"
- because. . . the Commission believes that there is a reasonable likelihood that a person **attempting to manipulate the ETP** by manipulating the underlying spot market **would also have to trade in the derivatives market in order to succeed**, since arbitrage between the derivative and spot markets would tend to counter an attempt to manipulate the spot market alone"*

Definition of *Market of Significant Size*

- A ***market of significant size*** is defined as: *a market or group of markets where:*
  - *(i) there is a reasonable likelihood that a person attempting to manipulate the ETP would have to trade on the market so that a surveillance-sharing agreement would assist in detecting and deterring misconduct*
  - *(ii) it is unlikely that the ETP would be the predominant influence on price in that market*

*Self-Regulatory Organizations; Bats BZX Exchange, Inc.; Order Setting Aside Action by Delegated Authority and Disapproving a Proposed Rule Change, as Modified by Amendments No. 1 and 2, To List and Trade Shares of the Winklevoss Bitcoin trust, 83 Fed. Reg. 37579, 37600 (Aug 1, 2018).

The CME bitcoin futures market is a regulated market of significant size under 6(b)(5) because of its leadership in price discovery across bitcoin trading markets

Fidelity's lead-lag analysis and results show that the CME bitcoin futures market leads price discovery across USD-based trading in bitcoin futures and spot markets.

CME futures market-leading price discovery across USD-based bitcoin trading markets as well as it's aggregate significant trading volume and liquidity make it unlikely that trading in a bitcoin ETP would be the predominant influence on prices in CME bitcoin futures.

Part (i)

There is a reasonable likelihood that a person attempting to manipulate the ETP would have to trade in the CME bitcoin futures market because:

- CME bitcoin futures market leads in bitcoin price discovery across USD-based trading in bitcoin futures and spot markets globally
- Arbitrage between the CME bitcoin futures market and spot markets would tend to counter an attempt to manipulate the spot market alone
- *(Detail on pages 8-9)*

Part (ii)

It is unlikely that trading in a bitcoin ETP would be the predominant influence on CME bitcoin futures market or bitcoin spot prices because:

- CME bitcoin futures market leads in bitcoin price discovery across USD-based trading in bitcoin futures and spot markets globally
- Significant trading volume in USD-based bitcoin futures and spot markets and overall market cap of bitcoin
- Highly liquid bitcoin spot market
- *(Detail on pages 10)*

Fidelity's lead-lag analysis adds to prior bitcoin price discovery research by addressing the disparate and infrequent trading activity of the CME bitcoin futures market

Importance of Price Discovery	▪ Price discovery refers to the act of determining a common price for an asset and is the result of buyers and sellers interacting on a market or across markets ▪ The lead-lag relationships between and among bitcoin futures and spot markets are important to understand the directional influences of markets on price discovery
Prior Price Discovery Research	▪ Prior analyses have shown that some bitcoin futures and spot markets tend to "lead" price discovery over other markets, which tend to "lag" – i.e., the "lagging" market tends to follow the movements of "leading" market with a time delay ▪ However, conclusions are mixed as to which markets "lead" vs. "lag" – e.g., Alexander and Heck (2020) find the CME futures lag the spot markets while Kapar and Olmo (2019) and Fassas et al. (2020) find that CME futures lead the spot markets ▪ This lack of agreement is likely due to the use of classic metrics (e.g., information share) derived from the Vector Error Correction Model (VECM), which likely involves substantial imputation when used with data sets such as CME bitcoin futures trading data – This imputation can produce biased results (Buccheri 2019)
Fidelity's Lead-Lag Analysis	▪ Fidelity's analysis accounts for the characteristics of CME's trading data by applying the Hayashi-Yoshida ("HY") estimator within a lead-lag framework – The use of the HY estimator is more suitable for disparate and infrequent data, as it is free from imputation (Hayashi & Yoshida 2005) – It has also previously proven useful in price discovery research (Huth & Abergel 2012, Dao et al. 2018) including bitcoin spot markets (Schei 2019)

Sources / Notes: Market data sourced from Coin Metrics; See Appendix for methodology details on slides 19 – 25, including citations

This analysis demonstrates that the CME bitcoin futures market has consistently led bitcoin price discovery across global USD bitcoin markets

Context

- Taking the USD & USDT exchanges (including spot, futures, and perpetual futures) reported by Coin Metrics, we have analyzed which markets lead and which lag in bitcoin price discovery by quarter, from Q1 2019 to Q1 2021
- For simplicity, only the leading market for each market category is shown below

Leading Exchange Category - Based on the Leading Exchange within the Category

Leading Category	CME Bitcoin Futures	CME Bitcoin Futures	CME Bitcoin Futures	CME Bitcoin Futures	CME Bitcoin Futures	CME Bitcoin Futures	CME Bitcoin Futures	CME Bitcoin Futures	CME Bitcoin Futures
1st Lagging Category	USD Spot	USD Spot	USD Perpetual Futures	USD Spot	USD Futures	USD Futures	USD Spot	USD Futures	USD Futures
2nd Lagging Category	USDT Spot	USD Perpetual Futures	USD Spot	USDT Spot	USD Spot	USD Spot	USD Futures	USD Spot	USDT Futures
3rd Lagging Category	USD Perpetual Futures	USDT Spot	USDT Spot	USD Futures	USD Perpetual Futures	USDT Perpetual Futures	USDT Perpetual Futures	USD Perpetual Futures	USD Perpetual Futures
4th Lagging Category	USD Futures	USD Futures	USD Futures	USD Perpetual Futures	USDT Spot	USDT Spot	USDT Spot	USDT Perpetual Futures	USDT Perpetual Futures
5th Lagging Category	N/A	N/A	N/A	USDT Perpetual Futures	USDT Perpetual Futures	USD Perpetual Futures	USDT Futures	USDT Spot	USDT Spot
6th Lagging Category	N/A	N/A	N/A	N/A	N/A	USDT Futures	USD Perpetual Futures	USDT Futures	USD Spot
	Q1 2019	Q2 2019	Q3 2019	Q4 2019	Q1 2020	Q2 2020	Q3 2020	Q4 2020	Q1 2021

Legend: CME Bitcoin Futures | USD Spot | USDT Spot | USD Futures *(Excluding CME)* | USDT Futures | USD Perpetual Futures | USDT Perpetual Futures

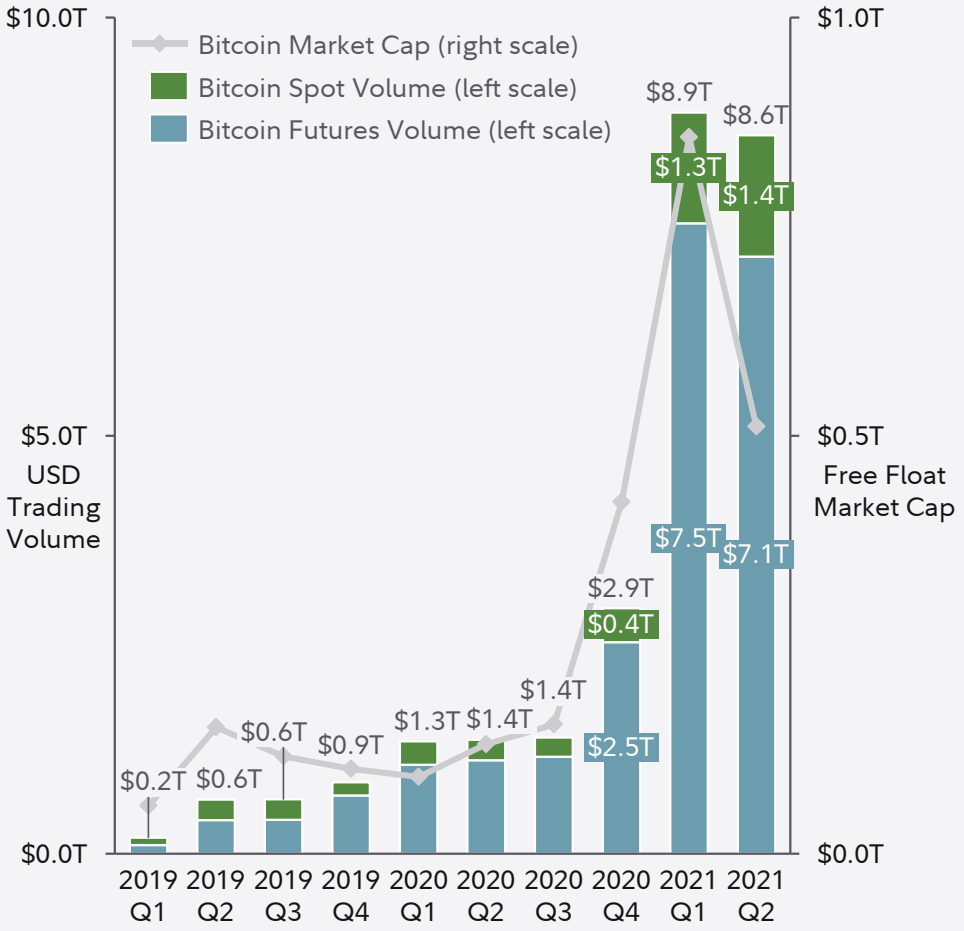
Our study's finding that the CME bitcoin futures market leads bitcoin price discovery across bitcoin futures and spot markets means that an actor trying to manipulate the ETP would be reasonably likely to have to trade in the CME bitcoin futures market

Sources / Notes: Market data sourced from Coin Metrics; See Appendix for methodology details on slides 19-25, including citations

The bitcoin market is significant, as seen by trading volume and deep liquidity

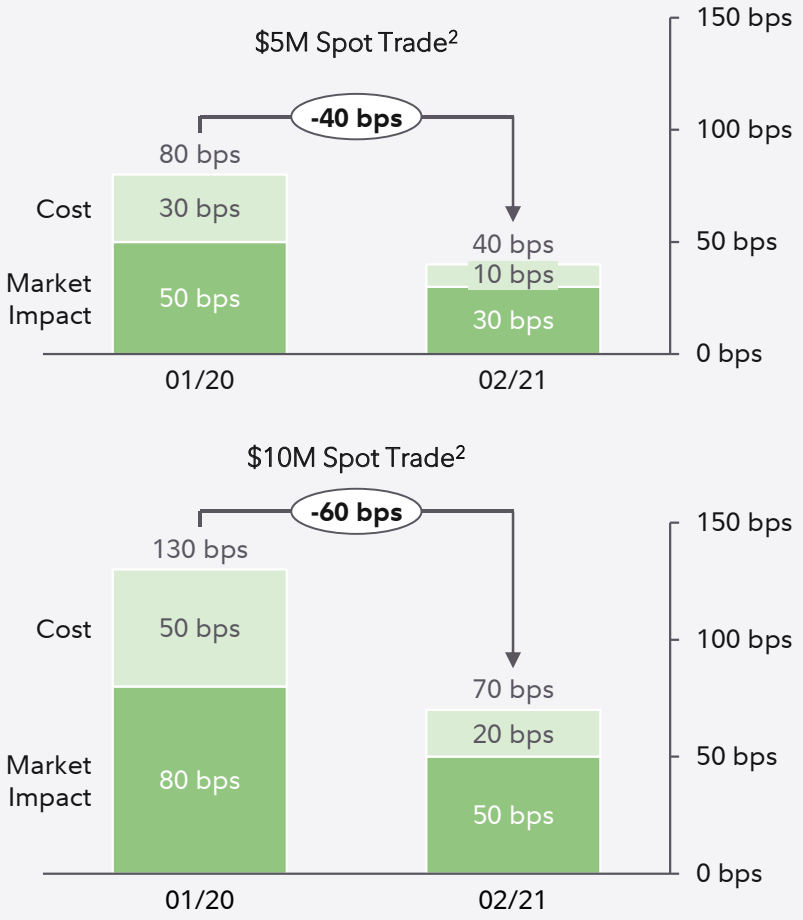
Bitcoin trading volume and market capitalization has continued to grow[1]

(2019 Q1 – 2021 Q2)



Spot trading cost and market impact have decreased over the last year

(January 2020 – February 2021)



Sources / Notes: (1) Market data sourced from Coin Metrics; (2) CoinRoutes, February 2021, as shown in Cboe BZX Exchange, Inc.; Notice of Filing of a Proposed Rule Change to List and Trade Shares of the Wise Origin Bitcoin Trust under BZX Rule 14.11(e)(4);

Why approve a bitcoin ETP now?

- **Investor benefits of exchange-regulated ETP providing direct exposure to bitcoin**
  - Transparency of valuation and pricing of ETP shares
  - Selection and oversight of bitcoin custodian by ETP sponsor
- **Bitcoin market maturity**
  - Bitcoin futures and spot markets are now of significant size and the CME bitcoin futures market is a ***regulated market of significant size*** under Section 6(b)(5)
- **Product innovation**
  - SEC-registered bitcoin futures-based funds are a positive development, with the first fund launched in 2019 and others more recently
  - A bitcoin futures-based ETF is not a necessary interim step before approving an exchange-regulated physical bitcoin ETP
- **Wise Origin Bitcoin Trust**
  - Since 2014, Fidelity has committed resources to the development of a broad set of bitcoin and digital asset capabilities, including custody, mining, and private bitcoin investment funds
  - The Wise Origin Bitcoin Trust is sponsored by Fidelity Digital Funds and is designed to offer investors direct exposure to bitcoin in a familiar vehicle

Appendix

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Wise Origin Bitcoin Trust | Product Overview

Trust	Wise Origin Bitcoin Trust
Sponsor	FD Funds Management LLC
Registration	Securities Act of 1933
Bitcoin Custodian	Fidelity Digital Asset Services, LLC (“FDAS”)
Administrator	Fidelity Service Company, Inc. (“FSC”)
Index Provider	Fidelity Product Services LLC
Index	Fidelity Bitcoin Index PR
Create / Redeem Process	In-Kind
Listing Exchange	Chicago Board Options Exchange (CBOE)

Fidelity Bitcoin Index PR | Index Methodology

The Fidelity Bitcoin Index PR is designed to reflect the performance of bitcoin in U.S. dollars

- **Construction**
  - The index is constructed using bitcoin price feeds from eligible exchanges and the volume weighted median price (VWMP) method, based on rolling 5-minute increments to develop a bitcoin price composite
  - The index is calculated in 15 second increments; 24 hours a day, 365(6) days/year and is published on platforms such as Bloomberg and FactSet
- **Oversight**
  - The Fidelity Index Committee ("Index Committee") is responsible for oversight of this index, along with other Fidelity indices
  - In addition, the Digital Asset Advisory Committee ("Advisory Committee") provides input to the Index Committee on digital asset specific considerations and implications to indices
- **Exchange Selection**
  - All U.S digital asset exchanges and/or regulated digital asset exchanges are eligible, subject to a review by the Fidelity Digital Asset Services Advisory Committee and the Fidelity Index Committee
  - The exchanges are evaluated quarterly and during market disruptions where an exchange review is warranted
  - Current exchanges include: Bitstamp, Coinbase, Gemini, itBit, and Kraken

Fidelity Digital Assets | Custodian

Fidelity Digital Assets is a limited liability trust company organized under New York Banking Law that is authorized to operate a virtual currency business. Fidelity Digital Assets was launched in 2018 to provide custody and execution services to institutions.

- **Custody Overview**
  - Secure custody of private keys in cold storage
  - Robust operational, cyber and physical controls including on chain multi-signature, multi-person access controls and maker/checker approvals
  - User access requires two-factor biometric authentication and user actions are based on a dynamic account entitlements structure
  - Soc 1 Type 2 Report issued by a big four audit firm
  - Maintains insurance against theft, loss, breaches, etc.
  - Supervised and examined by the NY Department of Financial Services (NYDFS) and subject to capital requirements and NYDFS regulations (e.g., transaction monitoring, cybersecurity)
  - Complies with Bank Secrecy Act requirements and associated anti-money laundering regulations

About the Survey

The blind survey was executed in association with Coalition Greenwich on behalf of Fidelity Digital Assets and the Fidelity Center for Applied Technology between December 2, 2020 and April 2, 2021. The survey included 1,100 institutional investors in the U.S. (408), Europe (393) and Asia (299), including high net worth investors, family offices, digital and traditional hedge funds, institutional investors, financial advisors and endowment and foundations.

Questions referenced in the presentation:

1. Q4. On behalf of your portfolio/ your clients' portfolios/ your firm how do you currently buy/invest in Digital Assets? *(2021 US Sample Size: 400)*
    1. 33% of US institutional investors indicated that they currently buy/invest in Digital Assets
    2. 18% of US Institutional investors indicated that they do so via buying an investment product holding digital assets
2. Q9. How do you believe Digital Assets should be part of your portfolio / your clients' portfolios / an institutional portfolio? *(2021 US Sample Size: 373)*
    1. 69% of US Institutional investors indicated that Digital assets should be part of an investment portfolio
3. Q42. How appealing to you are the following crypto/digital asset ideas…? (5-point scale where 5=very appealing and 1=not at all appealing) *(2021 US Sample Size: 408)*
    1. 38% of US institutional investors rated a bitcoin ETP as "appealing," where appealing includes ratings of 4 or 5

Canadian bitcoin ETF/ETPs have launched successfully with high volume and tight spreads

Canadian ETF Market

The Canadian ETF market has 6 bitcoin ETFs totaling $1.8B in assets.

Of the four physically backed ETFs, on average:

- Trading spreads are between $0.04 and $0.24.
- Daily trading volumes are between $0.2m and $60m.
- Daily premium/discounts are between -2% and 0.3%.

Impact on markets and trading at launch

- Daily trading volumes were 19% higher during the 1st 30 days of the ETF's inception compared to YTD averages.
- Generally, spreads have tightened $0.02 - $0.14 since launch

ETF Name	Ticker	Launch Date	AUM (M)	Avg Daily Traded Volume (M)	Average Spread	Average Premium/ Discount (%)
Ninepoint Bitcoin ETF	BITC	1/27/21	$86	$1.9	$0.24	-2.08
Purpose Bitcoin ETF	BTCC	2/18/21	$729	$60.3	$0.10	0.14
Evolve Bitcoin ETF	EBIT	2/19/21	$48	$6.1	$0.10	-0.19
CI Galaxy Bitcoin ETF	BTCX	3/9/21	$189	$7.1	$0.04	0.29
3iQ CoinShares Bitcoin ETF	BTCQ	3/31/21	$707	$20.7	$0.07	0.09
BetaPro Bitcoin ETF[1]	HBIT	4/14/21	$2	$0.2	$0.06	0.10

Note: (1) Futures backed product.
Source: Data from Bloomberg as of 6/30/21. All values are quoted in USD

European bitcoin ETF/ETPs have launched successfully with high volume and tight spreads

European ETF Market

The European ETF market has 7 bitcoin ETFs based in 5 different domiciles, totaling $2.1 billion in assets.

Of the six physically backed ETFs, on average:

- Trading spreads are between $0.02 and $1.50.
- Daily trading volumes are between $0.9 million and $42 million.
- Daily premium/discounts are between -1.22% and 0.33%.

ETF Name	Ticker	Fund Domicile	Launch Date	AUM (M)	Avg Daily Traded Volume (M)	Average Spread	Average Premium/ Discount (%)
CoinShares Bitcoin Tracker One[1]	COINXBT	Sweden	5/18/15	$685	$17.16	$0.31	-0.47
21Shares Bitcoin ETP	ABTC	Switzerland	2/28/19	$212	$3.48	$0.05	0.31
WisdomTree Bitcoin ETC	BTCW	Jersey	11/28/19	$209	$4.74	$1.50	0.19
BTCetc Physical Bitcoin	BTCE	Germany	8/6/20	$592	$42.13	$0.07	0.30
VanEck Vectors Bitcoin ETN	VBTC	Lichtenstein	11/19/20	$147	$8.71	$0.07	0.33
CoinShares Physical Bitcoin	BITC	Jersey	1/19/21	$211	$1.12	$0.19	-0.00
Iconic Funds Physical Bitcoin ETN	XBTI	Germany	4/15/21	$10	$0.09	$0.02	-1.22

Note: (1) Derivative backed product.
Source: Data from Bloomberg as of 6/30/21. All values are quoted in USD

Research Design

Within financial econometrics literature, several methodologies have been used to analyze price movement between two assets' returns/prices. Two more widely accepted metrics utilizing the Vector Error Correction Model (VECM) are the Information Share (IS) proposed by Hasbrouck (1995) and the Component Share (CS) proposed by Gonzalo and Granger (1995). These techniques assume that the prices/returns under consideration are synchronous and so adjustments need to be made for non-synchronous and/or infrequent data. Adjustments such as imputation or synchronous sampling can lead to spurious results for these methods (Buccheri et al. 2019).

Due to the high sparsity of CME futures data, we believe the framework of correlation-based lead-lag analysis using the Hayashi-Yoshida (HY) estimator (Hayashi and Yoshida 2005) is more suitable. This approach is free from any imputation or sampling and has proven useful in price discovery research (Huth and Abergel 2012, Dao et al. 2018) including bitcoin spot markets (Schei 2019). In our study, we focus on exploring the information flow using the HY estimator not only within bitcoin spot markets, but also including futures markets.

Lead-Lag Methodology (2 of 6) | Data Description

Data Description

We obtain tick level trade data for bitcoin spot prices and futures prices from Coin Metrics spanning from January 1st, 2019 to March 31st, 2021. Due to the size of the dataset, we aggregate the tick level trades to the one second floor level using a volume weighted average price (VWAP) approach.

In order to exclude any impacts caused by exchange rate movements, we limit our dataset to BTC-USD and BTC-USDT trades. For futures markets, we include both ordinary futures and perpetuals. Table 1 summarizes our selection by exchange, market type, and quote currency.

Within the ordinary futures market, one exchange, quote, and contract lifespan combination can often have same-day trading on contracts with different expiration dates.

If a bitcoin market has average correlation lower than 0.1 to other bitcoin markets, in any given quarter, it is removed from the analysis.

Table 1: Summary of Reporting Exchanges

	Spot		Ordinary Futures		Perpetual Futures	
Exchange	**USD**	**USDT**	**USD**	**USDT**	**USD**	**USDT**
Binance		✓	✓	✓	✓	✓
Binance.US	✓					
Bitfinex	✓	✓				✓
bitFlyer	✓					
BitMEX			✓		✓	
Bitstamp	✓					
Bittrex	✓					
Bybit					✓	✓
CEX.IO	✓					
CME			✓			
Coinbase	✓					
Deribit			✓		✓	
FTX	✓		✓		✓	
Gemini	✓					
HitBTC		✓				
Huobi		✓	✓		✓	✓
itBit	✓					
Kraken	✓	✓	✓		✓	
LBank		✓				
Liquid	✓					
OKEx		✓	✓	✓	✓	✓
ZB.COM		✓				

Legend: CME Bitcoin Futures | USD Spot | USDT Spot | USD Futures | USDT Futures | USD Perpetual Futures | USDT Perpetual Futures

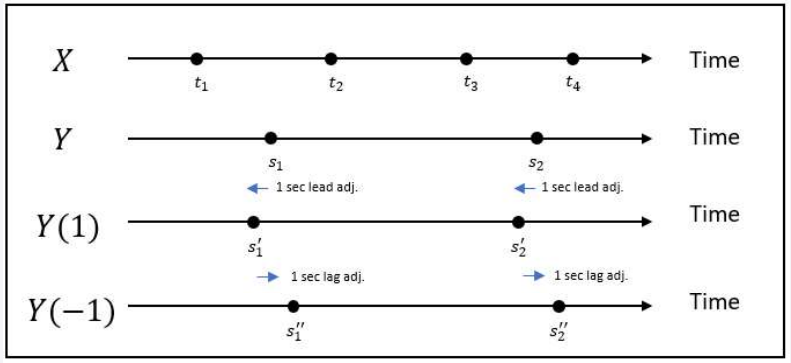
To remove price gaps in this market type, we construct a continuous time-series of prices by choosing the contract with the highest volume per day within an exchange, quote, and contract lifespan combination. For each combination, successive contracts are backwards adjusted using the price difference between the two contracts at the time of rollover.

Analysis

In the lead-lag analysis, we examine the pairwise lead-lag relationship within the spot market and futures market, as well as across them. For each pair, we compute the correlation coefficients using the HY estimator between one price time series and timestamp-adjusted (lead/lag) versions of the other price time series to find the timestamp that maximizes their correlations. For illustration below, we use the pair of CME and Coinbase as an example to describe the steps and denote their price time series as X and Y respectively.

Step 1: Fix the timestamp of CME and adjust the timestamps of Coinbase from N seconds lagging to N seconds leading. Figure 1 shows this process with N equals to 1 for illustration purpose.

Figure 1: Adjustment of Timestamps



Notes: Each dot is a price observation; t_i and s_j are the observation timestamps of X and Y; Y(1) and Y(-1) are timestamp adjusted price time series with 1 second backward shift and 1 second forward shift respectively.

Analysis (Continued)

Step 2: Compute the correlation coefficients between CME price time series and each of timestamp adjusted time series of Coinbase with l_i seconds ($l_i \in$[-N, N]) using HY estimator. The correlation coefficient is defined as (Hayashi & Yoshida 2005): *(at right)*

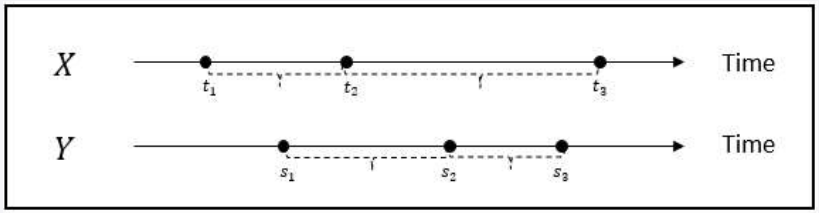
$$\hat{\rho} = \frac{\sum_{i,j} r_X^i r_Y^j \mathbb{I}_{\{O_{ij} \neq \emptyset\}}}{\sqrt{\sum_i \left(r_X^i\right)^2 \sum_j \left(r_Y^j\right)^2}},$$

where

- X and Y are trade prices on two different markets
- $r_X^i = X_{t_i} - X_{t_{i-1}}$ and t_i is the i_{th} observed time of X
- $r_Y^j = Y_{s_j} - Y_{s_{j-1}}$ and s_j is the j_{th} observed time of Y
- The observed times, t_i and s_j for X and Y are independent
- O_{ij} is the overlapping time between interval (t_{i-1}, t_i) and interval (s_{i-1}, s_i)
- $\mathbb{I}$ is defined as an indicator function, $\mathbb{I} = \begin{cases} 1, & O_{ij} \neq \emptyset \\ 0, & O_{ij} = \emptyset \end{cases}$.t

The numerator of $\hat{\rho}$ is the covariance between CME and Coinbase, which equates to the sum of every product of price changes that share a time overlap. Figure 2 shows this process with a simple example.

Figure 2: Data Points Used in HY Estimator



Notes: The interval (t_1, t_2) is overlapped with the interval (s_1, s_2), and the interval (t_2, t_3) is overlapped with both of the intervals (s_1, s_2) and the interval (s_2, s_3). Therefore, the covariance is calculated by summing the products of the following pairs of price changes: $(X_{t_2} - X_{t_1}, Y_{s_2} - Y_{s_1})$, $(X_{t_3} - X_{t_2}, Y_{s_2} - Y_{s_1})$, and $(X_{t_3} - X_{t_2}, Y_{s_3} - Y_{s_2})$.

Lead-Lag Methodology (5 of 6) | Analysis (Continued)

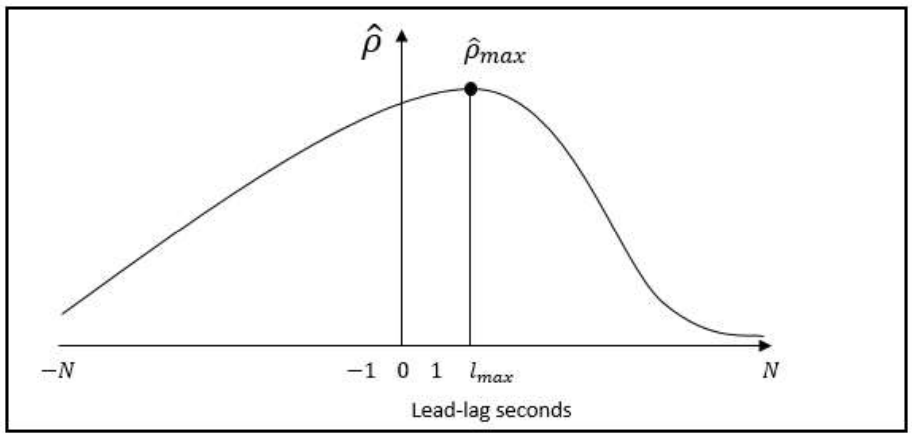
Analysis Continued

Step 3: Collect the correlation coefficients with different lead-lag seconds as a correlation curve and search for the value l_{max} from $-N$ to N that maximizes their correlation. Meanwhile, compute the lead-lag ratio between CME and Coinbase, llr, to measure the strength of the lead-lag relationship (Huth & Abergel 2012). It is defined as

$$llr = \frac{\sum_{i=1}^{N} \hat{\rho}^2(l_i)}{\sum_{i=1}^{N} \hat{\rho}^2(-l_i)}.$$

If $llr \in [0.95, 1.05]$ or l_{max} is zero, we conclude neither market leads. If llr is not in the range $[0.95, 1.05]$ and l_{max} is positive, CME leads Coinbase by l_{max} seconds and vice versa. Figure 3 shows an example of the correlation curve.

Figure 3: Example of the Correlation Curve



We follow these three steps for every pair of markets and aggregate the results by taking the average of the lead-lag seconds across all the markets.

Lead-Lag Methodology (6 of 6) | Citations

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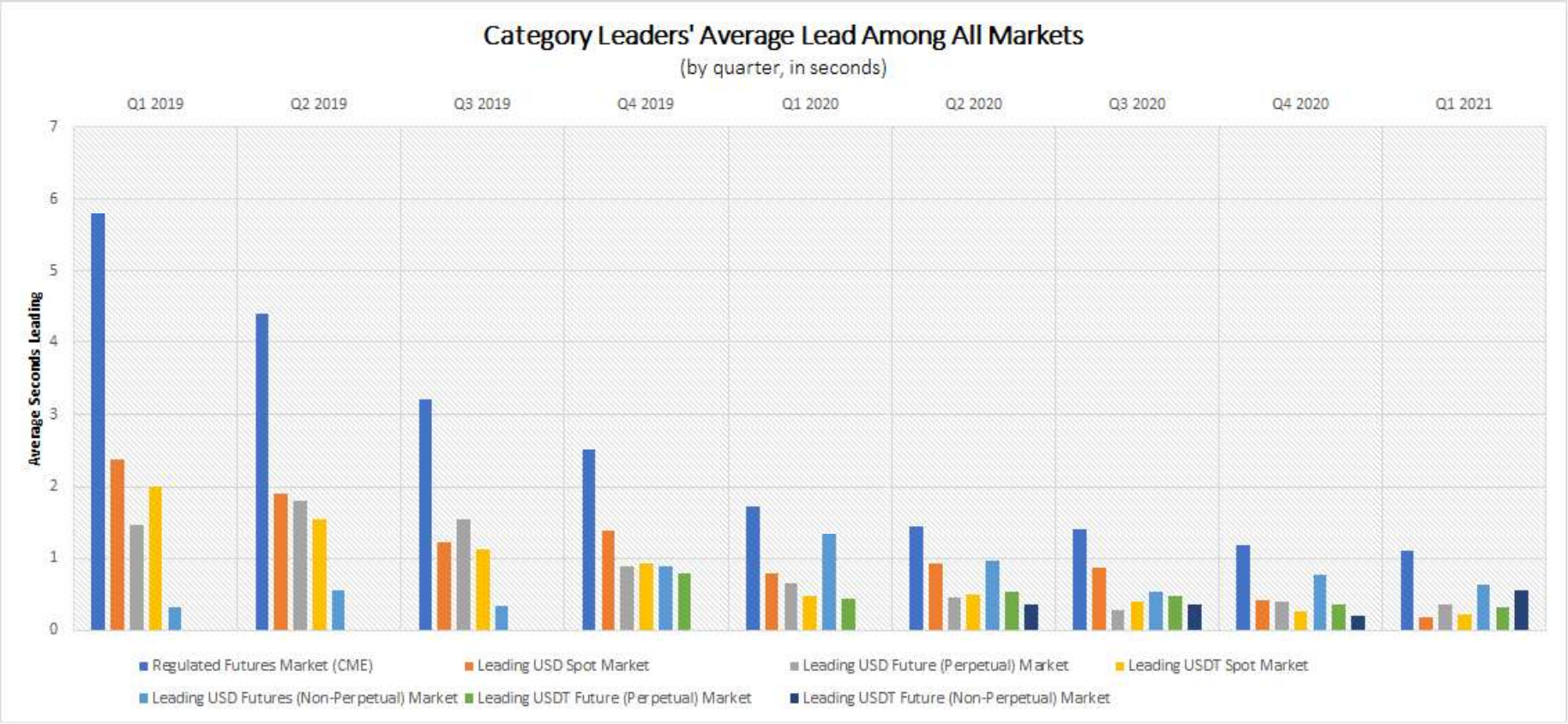
Lead-Lag | Category Leaders Average Lead Among USD Bitcoin Markets

- Taking the USD & USDT exchanges (including spot, futures, and perpetual futures) reported by Coin Metrics, we have analyzed which markets lead and which lag in bitcoin price discovery by quarter, from Q1 2019 to Q1 2021
- For simplicity, only the leading market for each market category is shown below
- The size of the lead has decreased over time, demonstrating continued improvement in market efficiency and reduction of arbitrage opportunities



Sources / Notes: Market data sourced from Coin Metrics;

U.S. Bitcoin ETP Filings | S-1 Filings

Fund	Sponsor	S-1 Filing Date	19b-4 Filing Date	Exchange	Structure	Holdings	Custodian	Creation Unit Type	Index
VanEck Bitcoin Trust	VanEck Digital Assets	12/30/20	3/15/21	CBOE	Delaware statutory trust	Bitcoin	TBD	In-Kind	MVIS CryptoCompare Bitcoin Benchmark Rate
Valkyrie Bitcoin Fund	Valkyrie Digital Assets	1/22/21	4/23/21	NYSE	Delaware statutory trust	Bitcoin	Coinbase Custody Trust Company, LLC	In-Kind & In-Cash	CME CF Bitcoin Reference Rate
NYDIG Bitcoin ETF	NYDIG Asset Management	2/16/21	N/A	NYSE	Delaware statutory trust	Bitcoin	NYDIG Trust Company LLC	In-Kind	N/A
WisdomTree Bitcoin Trust	WisdomTree Digital Commodity Services	3/11/21	4/9/21	CBOE	Delaware statutory trust	Bitcoin	TBD	In-Kind	CF Bitcoin US Settlement Price
First Trust SkyBridge Bitcoin ETF Trust	First Trust Advisors	3/19/21	5/6/21	NYSE	Delaware statutory trust	Bitcoin	NYDIG Trust Company LLC	In-Kind	N/A
Wise Origin Bitcoin Trust	**FD Funds Management**	**3/24/21**	**5/10/21**	**CBOE**	**Delaware statutory trust**	**Bitcoin**	**Fidelity Digital Asset Services, LLC**	**In-Kind**	**Fidelity Bitcoin Index PR**
Kryptoin Bitcoin ETF Trust	Kryptoin Investment Advisors	4/9/21	4/10/21	CBOE	Delaware statutory trust	Bitcoin	Gemini Trust Company, LLC	In-Kind	CF Bitcoin US Settlement Price
Galaxy Bitcoin ETF	Galaxy Digital Funds	4/12/21	N/A	NYSE	Delaware statutory trust	Bitcoin	TBD	In-Kind	Bloomberg Galaxy bitcoin Index
One River Carbon Neutral Bitcoin Trust	One River Digital Asset Management	5/24/21	N/A	NYSE	Delaware statutory trust	Bitcoin, MCO2 Tokens	Coinbase Custody Trust Company, LLC	In-Kind	MVIS One River Carbon Neutral Bitcoin Index
ARK 21Shares Bitcoin ETF	21Shares US	6/28/21	N/A	CBOE	Delaware statutory trust	Bitcoin	Coinbase Custody Trust Company, LLC	In-Kind	S&P Bitcoin Index
Global X Bitcoin Trust	Global X Digital Assets, LLC	7/21/21	8/17/21	CBOE	Delaware statutory trust	Bitcoin	TBD	In-Kind	N/A

U.S. Bitcoin Futures-Based Mutual Funds

Fund	Tickers	Advisor	Date Filed	Effective Date	Structure	Holdings
Stone Ridge Bitcoin Strategy Fund	BTCIX (118 bps), BTCMX (133 bps)	Stone Ridge Asset Management	5/12/21	7/26/21	Mutual fund	▪ Bitcoin futures ▪ Bitcoin funds ▪ Cash and fixed income instruments
Bitcoin Strategy ProFund	BTCFX (115 bps)	ProFund Advisors	5/14/21	7/28/21	Mutual fund	▪ Bitcoin futures ▪ Bitcoin funds ▪ Cash and fixed income instruments
Cboe Vest Bitcoin Target Volatility Strategy Fund	BTCVX (145 bps), BTCLX (170 bps), BTCYX (125 bps)	Cboe Vest Financial	5/17/21	08/04/2021	Mutual fund	▪ Bitcoin futures ▪ Bitcoin funds ▪ Cash and fixed income instruments
First Trust SkyBridge Bitcoin Strategy Fund	TBD	First Trust Advisors	5/26/21	N/A	Mutual fund	▪ Bitcoin futures ▪ Bitcoin funds ▪ Cash and fixed income instruments
Van Eck Bitcoin Strategy Fund ***(Withdrawn on 8/27/2021)***	N/A	Van Eck Absolute Return Advisers Corporation	6/21/21 ***(Withdrawn on 8/27/2021)***	N/A	Mutual fund	▪ Bitcoin futures ▪ Bitcoin funds ▪ Cash and fixed income instruments