Illiquid Bitcoin Options

July 15, 2022

Abstract

This paper conducts a first look into the regulated Bitcoin options market in the United States. Compared to stock options, bitcoin options tend to be ten times more illiquid as measured by bid-ask spreads. The illiquidity significantly affects bitcoin options pricing: Given that investors are on average net sellers of bitcoin options, heightened illiquidity is associated with a significant premium in subsequent delta-hedged returns, which also strengthens under more imbalanced investor orders. To support the reasonings behind our findings, we further exploit a policy change which allows retail participation and significantly influences order imbalances in the Bitcoin options market.

In 2017, the Commodity Futures Trading Commission (CFTC) approved the first Bitcoin options contract in the United States. After five years of operation, we now have enough evidence to conduct a serious study of this new market. This paper looks into the US-based regulatory-compliant Bitcoin options market and uncovers several facts about this new product that could of interest to academics, investors, and regulators as well.

There are many reasons why it is timely to focus on the Bitcoin options market. First, although there is a growing literature studying the market of financial derivatives with Bitcoin as the underlying asset, much focus has been given to futures contracts only.[1] Given that options are more complicated products than futures, and that retail investors do participate in the Bitcoin options market (as our later evidence will suggest), it is important to inform the public of how the market performs and its key features. Second, similar to Bitcoin futures, most Bitcoin options trading activities occur in overseas markets that neither comply with US regulations nor give access to US residents.[2] Therefore, conclusions drawn from these exchanges, although useful, may not be directly relevant to US investors or regulators. Given ample evidence of

[1] Bitcoin futures or similar products have been in existence outside of the United States for years, such as the popular perpetual swap contract initiated by the Seychelles-based exchange BitMEX. In late 2017, the CFTC approved Bitcoin futures in the United States by CBOE and CME.

[2] For example, Deribit, the largest Bitcoin options exchange by reported volume, bars access to US residents. Similar restrictions are also imposed on smaller peers such as Bit.com and OKX.

market manipulations in unregulated exchanges from the spot market for cryptocurrency, one may also expect less confounded results for crypto derivatives from a regulated exchange. Finally, lessons learned from Bitcoin options may also provide additional evidence to help us better understand options in traditional markets.

The CFTC-approved Bitcoin options contracts are traded on the LedgerX exchange (which is recently acquired by the FTX.US exchange) as a "dealers-driven" market – that is, designated liquidity providers simultaneously post bid and ask prices waiting for prospective investors. We gather transaction data from the exchange and present several findings of this CFTC-approved options market.

Our first major finding is that bitcoin options tend to feature extremely high bid-ask spreads. Compared to stock options that typically have an average bid-ask spread of 7% - 8% of the mid-quote price (Christoffersen, Goyenko, Jacobs, and Karoui (2018)), Average Bitcoin options spreads are almost ten times by magnitude. Therefore, the Bitcoin options market in the United States so far is highly illiquid.

The high illiquidity indicates that transaction costs should be one of the first-order considerations in the Bitcoin options market beyond the traditional Black-Scholes framework. The rest of the paper then quantifies how such illiquidity influences bitcoin options pricing, as measured by subsequent delta-hedged returns following the literature convention.

It is *ex ante* unclear whether increased illiquidity should be associated with higher or lower subsequent delta-hedged returns, despite convention wisdom from the stock market associating illiquidity and premiums in expected returns. The nuance comes from the following fact: as assets with positive supplies, stocks typically feature marginal investors who are longing the stocks. Hence, heightened illiquidity renders a stock less attractive, lowering its current price and increasing its subsequent returns. Options, on the other hand, are assets of zero net supplies. Therefore, the relationship between illiquidity and subsequent delta-hedged return depends on whether the price-setting marginal investor, or in our options market, designated liquidity providers who constantly set bid and ask prices, are longing or shorting the options. In case they designated liquidity providers are on the shorting side, they may require a higher selling price to short the less-attractive options due to heightened illiquidity, rendering a *discounted* subsequent delta-hedged return. In short, for a zero-net supply asset like Bitcoin options, the effect of illiquidity may very well flip signs depending on the signs of designated liquidity providers' inventories.

To carry forward our analysis, we further probe whether designated liquidity providers are on average buying or selling Bitcoin options. Toward this end, we classify each trade into either a buy-initiated or sell-initiated one and calculates the order imbalance in the options market. While we find significant intertemporal variations in order imbalances, on average there are significantly more sell-initiated trades than buy-initiated ones, indicating more selling pressure from liquidity takers. To the extent that client investors take liquidity by initiating trades in response to designated liquidity providers' quotes, the finding suggests that designated liquidity providers on average long bitcoin options. Therefore, we expect heightened options illiquidity to be associated with premia in subsequent delta-hedged returns. Consistently, we find that a 0.1 increase in relative bid-ask spread is associated with a 0.34% increase in subsequent delta-hedged return. Regarding the intertemporal variations in order imbalance, we expect the positive association between illiquidity and subsequent delta-hedged return to strengthen (attenuate) as selling (buying) pressure increases. Consistently, we find that a 0.1 increase in imbalance is associated with a 0.1% decrease in the regression coefficient of subsequent delta-hedged return on illiquidity.

In sum, we find that the illiquidity characterizing Bitcoin options has significant impact on the market. Specifically, options illiquidity is associated with higher returns, which strengthens when designated liquidity providers are more tilted toward the buying side.

To support the above findings and reasoning, we further supplement our regression results with a natural experiment that exogenously shifts the overall order imbalance in the market. In August 2019, upon regulatory approval, LedgerX implemented a policy change so that small retailer investors in the United States are given access to the Bitcoin options market. Such a policy change brought significant shifts in the composition of market participants and witnessed significantly more buying pressure from liquidity-taking client investors. Indeed, order imbalance on average shifted from significantly sell-initiated before the policy change to a much more balanced market after the change. Therefore, based on this observation and our reasonings earlier, we expect a stronger illiquidity-return premium association before the policy change, and a significant sensitivity of such an association to order imbalances after the change. We find results consistent with our expectations as we replicate our tests for the before and after subsamples.

Our findings give a first look at the regulated Bitcoin options market in the United States and offers a fact-check of this new market over the last five years of operation. The high bid-ask spread of bitcoin options suggests that illiquidity should be given more attention to all investors and regulators, especially given that retail investors have access to and also participate in this market. Our findings also contribute to the literature on options in general, demonstrating how existing theories on options could be applied and should be adapted to the practice of options on the new asset class of Bitcoins.

Related literature

Our paper contributes to an emerging literature on crypto derivatives. Most of the existing papers focus on futures contracts. Augustin, Rubtsov, and Shin (2020) study the impact of the introduction of Bitcoin futures contracts by CBOE and CME in December 2017 on the Bitcoin cash market. Ferko, Moin, Onur, and Penick (2021) use regulatory data internal from the CFTC and analyze the composition of Bitcoin futures traders. On Bitcoin options, Alexander, Deng, Feng, and Wan (2021) study the impact of order imbalance on Bitcoin options pricing. Their analysis is based on Deribit, the largest unregulated Bitcoin options exchange that does not allow US investors, while our analysis is based on LedgerX, a CFTC-approved Bitcoin options exchange which for a large portion of our sample the only Bitcoin options exchange in the United States.

Our paper also contributes to the now vast literature on cryptocurrency trading in the spot market. On cryptocurrency pricing across exchanges, Makarov and Schoar (2020) as well as Yu and Zhang (2021) document extensive arbitrage opportunities across spot cryptocurrency exchanges; Choi, Lehar, and Stauffer (2018) and Hautsch, Scheuch, and Voigt (2018) relate such arbitrage opportunities to congestions in Bitcoin's transaction inclusions into blocks. On the demand for cryptocurrencies on secondary markets, Shams (2020) relate cryptocurrency returns to common investor bases across spot exchanges; Benetton and Compiani (2021) study the demand for cryptocurrencies in secondary market trading; Divakaruni and Zimmerman (2021) analyze how the Covid-19 stimulus checks feed into bitcoin demand. Relatedly, Li, Luo, Wang, Wei (2022) analyze potential conflicts of interest in exchanges' cryptocurrency listing decisions, while Li and Yi (2019), Liu, Tsyvinski, and Wu (2022), and Cong, Karolyi, Tang, and Zhao (2022) explore risk factor structures of cryptoassets. Finally, on various manipulations on spot cryptocurrency exchanges, Li, Shin, and Wang (2021) document pump-and-dump schemes in cryptocurrency spot markets; Gandal, Hamrick, Moore, and Oberman (2018) document price manipulations on the unregulated Mt. Gox exchange; Griffin and Shams (2020) document potential Bitcoin spot price manipulation by entities controlled by the issuer of the stablecoin Tether; Aloosh and Jiasun (2020), Amiram, Lyandres, and Rabetti

(2020), and Cong, Li, Tang, and Yang (2020) also document direct and indirect evidence of unregulated cryptocurrency spot exchanges faking trading volumes by conducting or encouraging "wash trading". Because our sample focuses on the CFTC-regulated Bitcoin options market, our findings are less prone to such confounding factors.

Outside of the blockchain literature, our paper also contributes to the options literature in general. While studies on options are too numerous to adequately summarize here, the most related ones are ones that focus on the relationship between options liquidity and pricing, with potential considerations of order imbalance. Deuskara, Guptab, and Subrahmanyam (2011) take imbalance as constant over time and study the interaction between options pricing and illiquidity measured by the relative bid-ask spread. Christoffersen, Goyenko, Jacobs, and Karoui (2017) present a set of regressions that further relate illiquidity, imbalance, and options pricing.[3] More broadly, our paper also contributes to the literature on the relationship between illiquidity, imbalance, and returns for more general assets. In the stock market. Hasbrouck and Seppi (2001) and Chordia, Roll, and Subrahmanyam (2002) give statistical characterizations and regression tests of the interactions among the three

[3] Some papers solely study the relationship between option pricing and imbalances, see e.g. Bollen and Whaley (2004) and Garleanu, Pedersen, and Poteshman (2009).

variables (PCA or correlations), respectively. The theory of Acharya Pedersen (2005) and evidence from the CDS market in Bongaerts, De Jong, and Driessen (2011) further study the effect of liquidity risk.

Finally, since we study bitcoin options on a centralized exchange, our results complement the literature on decentralized exchanges, including Lehar and Parlour (2021), Capponi and Jia (2021), Aoyagi and Ito (2021), as well as Han, Huang, and Zhong (2021).

The rest of the paper is organized as follows. Section 1 provides a brief introduction to the institutional background of bitcoin options. Section 2 discusses the data used for our analysis. Section 3 constructs illiquidity measures and presents evidence of Bitcoin options' illiquidity. Section 4 investigates how illiquidity affects Bitcoin options returns. Section 5 presents additional results from a policy change that shocks the composition of market participants. Section 6 then concludes.

1. Institutional background

A bitcoin options contract is conceptually similar to an options contract on other assets. A call option gives its holder the right, but not the obligation to purchase a certain number of underlying assets at a pre-determined strike price either at a particular future time (European options) or any time before a particular future time (American options). Similarly, a put option gives its holder the right, but not the obligation to sell a certain number of underlying assets.

As bitcoin rise to become a major asset class, various entities began to offer venues for trading options on bitcoin. Most such bitcoin options exchanges do not have approval from the CFTC or regulators from other major economies to clear derivatives, so they do not allow US residents from participating on such platforms.[4]

Major overseas Bitcoin options exchanges include Deribit (founded in 2016), OKX (founded in 2017), and Bit.com (founded in 2019), of which the Netherland-based Deribit is the largest one by reported open interests, accounting for a bit shy of 90% of open interests. However, Deribit is unavailable to citizens or residents of the United States, as well as Cuba, Ontario (Canada), Guam, Iran, Iraq, Japan, North Korea, Panama, Puerto Rico, Samoa, Sudan, Syrian, and U.S. Virgin Islands, and partially restricted to a few other jurisdictions. Similarly, the Seychelles-based OKX is not available in the U.S. The newcomer Bit.com is also based in Seychelles. According to its support article (https://support.bit.com/hc/en-us/articles/360051112014), its

[4] Other derivatives products like Bitcoin futures also feature similar regulatory landscapes. US regulators are active in punishing any attempts or negligence by non-regulated derivative exchanges to allow US residents from accessing their products. For example, BitMEX, the Seychelles-based popular crypto derivatives exchange has all of its co-founders indicted in the US court and plead guilty with fines and probation sentences.

access and its services are not available for individuals or corporations located, incorporated, established in, or a citizen or resident of any of the following regions: China Mainland, Hong Kong, North Korea, Japan, Iran, Singapore, Syria, American Samoa, Canada, Cuba, Guam, Puerto Rico, Northern Mariana Islands, United States, Crimea, and Sevastopol.

Before late 2017, US residents do not have access to options trading on bitcoins. After months of lobbying, on September 2, 2017, the CFTC announced the approval of LedgerX, a digital currency platform, for clearing derivatives.[5] In addition to being the first approved bitcoin options exchange in the United States, LedgerX was also the only regulatory-compliant bitcoin options exchange in the United States for many years, until the Chicago Mercantile Exchange (CME) launched options on Bitcoin futures in January 2020.[6] In Oct 25, 2021, LedgerX was acquired by FTX.US to be rebranded as FTX US Derivatives. The acquisition had no material impact on LedgerX's operations as it continued to provide its current offerings to existing

[5] See https://www.cftc.gov/PressRoom/PressReleases/8230-20. LedgerX had previously announced in May 2017 that it had raised $11.4 million via its parent company, Ledger Holdings, in the hope that the CFTC would rule in its favor—which the agency did (https://www.reuters.com/article/us-ledgerx-exchange-funding/bitcoin-options-exchange-raises-11-4-million-in-funding-idUSKBN18I0B9).

[6] CME's futures offerings include both a "full-size" Bitcoin contract for which the underlying is 5 Bitcoin and a "micro" contract for 0.1 Bitcoin. Both are quoted in terms of the price one coin. Options are only available in European style on the full-size contracts.

customers, and we will continue to refer to the exchange as LedgerX throughout the paper.

LedgerX operates as a "dealer-driven" market in which designated liquidity providers simultaneously submit bid and ask quotes. According to LedgerX's rule book (Chapter 4 Liquidity Providers), interested party may complete a Liquidity Provider Agreement and be appointed by the exchange as a Liquidity Provider for certain series of contracts. Liquidity providers receive reduced trading fees or other incentives, while are obliged to "make good-faith efforts to enter on the Platform current binding bid and offer quotes, with a bid/offer spread as specified in the applicable Liquidity Provider Agreement, as necessary to ensure liquidity."

The flagship product by LedgerX is the European style Bitcoin Mini Options (Calls & Puts), which are physically settled monthly or weekly options on bitcoin. Their contract sizes are of 0.01 bitcoin[7], the minimum price fluctuation is $1.00, prices are quoted in U.S. dollars per bitcoin, and trading hours are 24 x 7. Trading fees are the lower of $0.15 per contract or 20% of the options premium per contract, and the minimum block is 100 contracts (1 BTC). The strike intervals are the following: For each new expiration month, LedgerX lists at least five strikes in $1,000 strike intervals.

[7] The contract sizes are 1 bitcoin before December 3rd , 2019.

The exchange will add additional strikes as the expiration month approaches additional strikes in accordance with the underlying price movement using 1000, 2500, or 5000 strike increments. In the first half of every current month, the exchange may list additional contracts for the current month. In the second half of the current month, FTX US Derivatives may list additional contracts for the current month and the following month. For weekly contracts, the exchange will introduce a strike at the At-The-Money (ATM) level, and at minimum two strikes above and two strikes below the ATM level in $1,000 strike intervals. The exchange will add additional strikes in accordance with the underlying price movement using 1000, 2000, 4000 strike increments. Weekly strikes may be listed up to 20% above the ATM strike level and down to 20% below the ATM strike level, in accordance with BTC price volatility.

2. Data

We obtain all options trade data on LedgerX (from February 2018 to January 2022) using the exchanges' API. The trades data contain the contract, transaction size, price, and timestamp for each transaction. We will use the high-frequency data to construct daily variables of interest. The API does not provide high-frequency quote updates, but we are able to obtain quotes at the daily frequency from LedgerX website, which indicates the last prevailing quotes of each trading day. We also obtain Bitcoin spot price and volume from CoinMarketCap, a popular data aggregator for the cryptocurrency market. For the appropriate risk-free rate in the Bitcoin market, we follow industry wisdom in Radovan and Matus (2020) and use 3.69%, although our conclusions are not sensitive to the choice of risk-free rates.[8]

Following the literature convention (e.g. Christoffersen et al. (2018) and Choy & Wei (2020)), we filter out the following contract-day samples: (1) samples with maturity below 10 days or above 360 days; (2) samples with zero open interest; (3) samples with missing last bid or last ask, or samples whose last bid is higher to equal to the last ask; (4) samples that violate options price boundaries and yield arbitrage opportunities. Overall, the filtering process reduces the sample size from 52,517 to 31,334, mostly due to contracts that have super long maturities.[9] Finally, since LedgerX changed the contract size in December 2019, we adjust the sample before and after the change so that each contract corresponds to the same underlying asset of one bitcoin.

[8] Radovan and Matus (2020) proposed deriving the risk-free interest rate of US$-denominated Bitcoin from combining the price difference of CME Bitcoin futures contracts with different maturities and U.S. Treasury bill rates. Using data from January 2018 to December 2019, it calculates an average risk-free rate for US$-denominated Bitcoin of 3.69% (compounded annually). Alternatively, Wesner (2015) proposed deriving the risk-free interest rate of US$-denominated Bitcoin from macroeconomic theories such as uncovered interest rate parity and Fisher effect, and calculates an average annualized compound interest of 5%, ranging between about 4%-6%.

[9] Per interviews with LedgerX insiders, super-long maturity options are popular among Bitcoin miners who tend to be option sellers to hedge market risks they in face in their operations.

Insert Figure 1 here

Figure 1 presents the time-series of bitcoin prices, bitcoin trading volume, bitcoin volatility, and bitcoin options trading volume on LedgerX. Overall, the bitcoin price goes up over time despite significant volatility. Bitcoin option volume on LedgerX also tends to increase over time, indicating increasing interest from investors into this new market.

Insert Table 1 here

Table 1 provides summary statistics of all the listed options. Among the 31,334 contracts in total, there are 21,287 calls and 10,047 puts. The average maturity is about 99 days, while strikes range from $2,000 to $400,000, averaging at about $40,000.

3. Options Illiquidity

This section investigates the liquidity (or illiquidity) of bitcoin options. Following Christoffersen, Peter, Goyenko, Jacobs, and Karoui (2018), we measure options illiquidity by relative spread, as defined below:

Relative Spread (RS): for a given contract n and day t, its relative spread RS_{nt} is defined as

$$RS_{nt} = \frac{last\ ask_{nt} - last\ bid_{nt}}{\left(\frac{last\ ask_{nt} + last\ bid_{nt}}{2}\right)},$$

where $last\ ask_{nt}$ and $last\ bid_{nt}$ denotes the last ask and bid for contract n on day t. That is, the relative spread is the ratio between the quoted bid-ask spread and the mid-quote price.

Insert Table 2 here

Table 2A provides summary statistics of relative spreads for calls and puts across different moneyness categories. A salient feature of the bitcoin options market is its illiquidity. Average relative spread can be as high as 74.9% for calls and 83.4% for puts. In comparison, relative spreads for stock options are typically 7% for calls and 8% for puts according to Christoffersen, Goyenko, Jacobs, and Karoui (2018). Puts tend to have larger relative spreads than calls. Consistent with options in other markets, out-of-the-money (OTM) options have the highest spreads for both calls and puts while in-the-money options have the lowest relative spreads. To avoid concerns over the high average spread being driven by inactive outliers, Table 2A also reports volume-weighted averages. Results paint a similar picture: the volume-weighted average of spreads is as high as 80% for calls and 73.3% for puts.

While relative spread is our main interested variable to measure option illiquidity, for robustness, we also alternatively adopt the Amihud (2002) liquidity measure, as defined below:

Amihud liquidity measure (Amihud): for a given contract n and day t, the Amihud liquidity measure $Amihud_{nt}$ is defined as

$$\text{Amihud}_{\text{t}} = \frac{|return_t|}{volume_t},$$

that is, the Amihud liquidity measure calculates the ratio between the absolute value of daily return over daily trading volume. Table 2B provides summary statistics of Amihud for calls and puts across different moneyness categories.

Insert Figure 2 here

Figure 2 plots the time series of the daily relative spread for Bitcoin options over time (Panel A), as well as similar measures for Bitcoin spot for comparison (Panel B). After smoothing, we find both series to have similar trends across time (both tend to increase over time), indicating that illiquidity of options contracts is highly correlated with that of the underlying assets (the correlation is 0.52). Relative spreads of options are also much more volatile before a policy change (indicated by the green line) in August 2019 to be described in detail in Section 5. Similarly, we compare the Amihud measure for options (Panel C) and that for Bitcoin spot (Panel D). while Amihud measures for Bitcoin options also tend to increase over time, those for Bitcoin spot tend to first decrease then increase (a U-shape). The pattern indicates that relative spreads and Amihud measures tend to capture different aspects of Bitcoin options and spot illiquidity.

4. Impact of Illiquidity on Options Returns

Having documented the illiquid nature of bitcoin options, it is natural to ask how such friction affects the bitcoin options pricing and return. Following the literature, we focus on the delta-hedged return of bitcoin options, as defined below:[10]

Delta-hedged return (DHR): For a specific options contract n on a specific day t, we have

$$\tilde{R}^{o}_{t+1,n} = R^{o}_{t+1,n}\text{-}R^{S}_{t+1}S_t\frac{\Delta_{t,n}}{O_{t,n}},$$

where $\tilde{R}^{o}_{t+1,n}$ denotes the daily delta-hedged options return, $R^{o}_{t+1,n}$ denotes the (raw) daily options return, R^{S}_{t+1} denotes the daily Bitcoin spot return, S_t denotes the spot

[10] Our results will be robust to alternative measures, such as changes in implied volatility as used in Deuskara, Guptab, and Subrahmanyam (2011).

market price of Bitcoin, $O_{t,n}$ denotes the options price, and $\Delta_{t,n}$ denotes the options delta based on the Black Scholes formula. Figure 3 presents the average daily delta-hedged options returns, separating between calls and puts as well as at-the-money (ATM) and all options.

Insert Figure 3 here

Table 3 reports summary statistics for daily delta-hedged options returns. We first compute respective statistics for each options class and report the average across options classes. We also report the average number of options series per options class for each moneyness category. The delta-hedged return averages are small and positive and exhibit positive skewness and excess kurtosis in all categories. The returns of options also display rapid mean-reversion as evidenced by the negative first-order autocorrelation. These reversals are suggestive of the importance of liquidity provision in this market. Volatility persistence, as measured by the absolute return autocorrelation, is much higher for call returns than for put returns. Table 3 also reports sample statistics for bitcoin returns in panel C. Not surprisingly, volatility and skewness are both much lower for bitcoin returns than for options returns, while kurtosis is quite high for bitcoin returns.

Insert Table 3 here

We test whether illiquidity influences subsequent delta-hedged returns. This question does not have clear answer *a priori*. Indeed, as a derivative asset with zero net supply, the impact of illiquidity on options is more nuanced than other financial assets (e.g. stocks) with positive supply. This is because for assets with positive supply, the marginal investor is always on the long side, so that illiquidity unambiguously drives down price and lead to higher future returns. For bitcoin options in a dealer-driven market, the designated liquidity providers ultimately set prices, so the effect of illiquidity on options ultimately depends on the net holding position of designated liquidity providers ("dealers").

To infer the net holding positions of the liquidity providers, we exploit the fact that liquidity-taking client investors respond to designated liquidity providers' bid-ask quotes. Therefore, designated liquidity providers' trading directions can be inferred as the opposite of the order imbalance among all trades. Hence, we first apply the tick rule to determine the trading direction of each transaction, and then define imbalance as the following:

Imbalance: For a specific options contract n on a specific day t, imbalance is defined as

$$Imbalance_{nt} = \frac{\#\text{buy}_{\text{nt}} - \#\text{sell}_{\text{nt}}}{\#\text{buy}_{\text{nt}} + \#\text{sell}_{\text{nt}}},$$

where $\#\text{buy}_{nt}$ ($\#\text{sell}_{nt}$) denotes the number of buy-initiated (sell-initiated) trades for contract n on day t. It is immediately to see that imbalance falls within [-1, 1]. A positive imbalance indicates that most trades are triggered by buyers, while a negative imbalance indicates that most trades are triggered by sellers.

The first row in Table 6 reports summary statistics of the imbalance measure. On average, the imbalance measure tends to be negative, indicating sell pressures from liquidity takers. Hence, designated liquidity providers on average long the options, so that we have our first hypothesis:

Hypothesis 1: illiquidity precedes high return. That is, with average negative imbalance (i.e. liquidity-taking client investors on average sell bitcoin options), higher options illiquidity is associated with a lower options price, and thus a higher subsequent delta hedged return.

Insert Table 4 here

As a preliminary illustration of Hypothesis 1, Table 4 sort options into three groups with high, median, and low levels of relative spreads, and presents the average next-day (both equal-weighted and value weighted) delta-hedge returns within each group, as well as the return spread between the high and low groups. For both calls and puts and across all windows, higher illiquidity is followed by significantly higher delta-hedged returns. These findings are consistent with Hypothesis 1, which will be more formally tested later. Figure 4 illustrates the findings from Table 4.

Insert Figure 4 here

That said, imbalance also fluctuates over time, which can go positive from time to time. On these days, we should expect the positive association in Hypothesis 1 to flip sign. In other words, and days with higher imbalance, we expect lower positive associations between illiquidity and subsequent delta-hedged returns. In other words, we form the following hypotheses:

Hypothesis 2: the association between options illiquidity and subsequent delta-hedged return is lower when imbalance is higher.

To test both hypotheses, we develop the following regression: Illiquidity drive down(up) options prices under net selling(buying) pressure.

$$DHR_{t+1} = \alpha_0 + \alpha_1 Illiquidity_t + \alpha_2 Illiquidity_t \times imbalance_t + Controls + \varepsilon,$$

where DHR is delta-hedged return over day $t + 1$, illiquidity is measured by either the relative spread or the Amihud measure of Bitcoin options. To avoid a mechanical relationship between relative spreads and subsequent returns due to their common denominator of end-of-day option price, we use lagged relative spread to capture illiquidity. Coefficients on illiquidity measures captures their average impact of on subsequent delta-hedged return, while coefficients on the interaction of illiquidity measures and imbalance captures the additional effect of illiquidity as imbalance changes. Controls include option order imbalances and bitcoin spot liquidity also measured by the relative spread and the Amihud liquidity measure (of bitcoin spot),[11] option moneyness measured by the absolute value of option delta, bitcoin spot beta estimated from 365-day rolling window, daily spot return, option maturity measured by ln(days to expiration), and Bitcoin spot volatility estimated from the GARCH(1,1) model.

Insert Table 5 here

Table 5 presents the regression results. The coefficients on relative spread and Amihud liquidity measures are both significantly positive, suggesting that illiquidity is associated with a return premium (Hypothesis 1). The coefficients on the interaction terms between illiquidity measures are both significantly negative, indicating that a

[11] Because volumes in the Bitcoin spot market are much higher than those in the options market, and that we use spot volume from all over the world while option volume only in the United States, the Amihud measure for spots are much lower than that for options. Given that the absolute value of the Amihud measure does not carry much economic meaning (only the relative magnitude is informative), for easy comparison we scale up the Amihud measure for Bitcoin spots by 10^8.

higher imbalance is associated with an attenuation in the positive association between illiquidity and subsequent delta-hedged returns.

Besides statistical significance, the findings are also economically significant: When the relative spread increases by a level of 0.1, under fully buying pressure from client investors (an imbalance of 1), the daily delta-hedged return decreases by 0.42%, which translates to a decreased annual return of 153%. In addition, when the relative spread increases by a level of 0.1, designated liquidity providers facing an overall selling pressure would decrease options prices such that the expected annual return would increases by 113%.

5. Policy shock

To strengthen the argument of the previous section, we further exploit a natural experiment. On July 31, 2019, LedgerX announced the launch of its Omni trading platform, which under the approval of CFTC allows retail customers to "trade bitcoin, bitcoin options, and futures."[12] This policy change can be thought of as a shock that

[12] According to an interview with Juthica Chou, chief operating officer of LedgerX (https://unchainedpodcast.com/ledgerx-on-the-reasons-to-trade-bitcoin-options/), LedgerX requires a minimum $10 million deposit before the Omni launch, which was rescinded after Omni. The move also significantly lowers retail investor's entry barriers to option market.

changes the composition of options traders with different trading demands, and as a result, the overall imbalance of the options market.

Insert Figure 5 here

As Figure 5 illustrates, the incoming retail options investors after the policy shock are net buyers of options. Table 6 formally summaries the imbalance measures before and after the policy change, with a *t*-test showing significant differences in imbalance measure before and after. As the second and third row of Table 6 indicates, the incoming retail options investors after the policy shock indeed bring the on average negative imbalance before the policy change to close to zero after the change.

Insert Table 6 here

We reevaluate our Hypothesis 1 and 2 for the sample before and after the policy change. Since the inflow of retail investors brings along more balanced buy-sell pressures, we expect the return premium following heightened illiquidity to attenuate after the policy change. Table 7 presents results consistent with the reasoning: the effect of illiquidity on options prices diminishes after the policy, reflected by lower coefficients.

Insert Table 7 here

Table 7 also shows that after the policy change, coefficients for the interaction term between illiquidity and imbalance is still significantly negative, suggesting that the more balanced overall buy/sell pressure (the *level* of imbalance) does not mitigate the impact of the *changes* in imbalance on the return premium following illiquidity.

6. Conclusions

Despite over five years of development, the US Bitcoin options market is still highly illiquid. In addition, investors on average sell options, although the net sell-tilted imbalance has been eased when more small retail investors are admitted. Under such a market composition, the illiquid nature of Bitcoin options significantly affects their pricing, with higher illiquidity associated with higher subsequent delta-hedged return. The finding highlights the importance of paying attention to transaction costs in the Bitcoin options market. The finding may also provide guidance for regulators and prospective investors as more spot cryptocurrency exchanges probe into the derivatives market.[13]

[13] For example, as the cryptocurrency market enters another winter in 2022, spot cryptocurrency exchanges such as Coinbase are also probing into the derivatives market in the United States (https://www.coindesk.com/business/2022/06/24/coinbase-launches-first-crypto-derivatives-product-aimed-at-retail-traders/?utm_source=Sailthru&utm_medium=email&utm_campaign=Node%20-%20June%2024&utm_term=The%20Node).

As a first study into the US Bitcoin options market, we have left many unanswered questions. For example, our finding calls for further investigations into the reasons behind the high bid-ask spread of Bitcoin options: Is it due to Bitcoin's high volatility or frictions in the cryptocurrency market that hinder effective risk management of bitcoin options? Or, is it due to a lack of competition between designated liquidity providers or a lack of competition among exchanges? Or, is it due to a lack of demand for bitcoin options in the first place? Answers to these questions would lead to different policy recommendations, ranging from approving more Bitcoin options exchanges/licensing more Bitcoin options designated liquidity providers to enforcing guidelines to Bitcoin options designated liquidity providers or rethinking the value of Bitcoin options as a product. We leave these important questions to future research.

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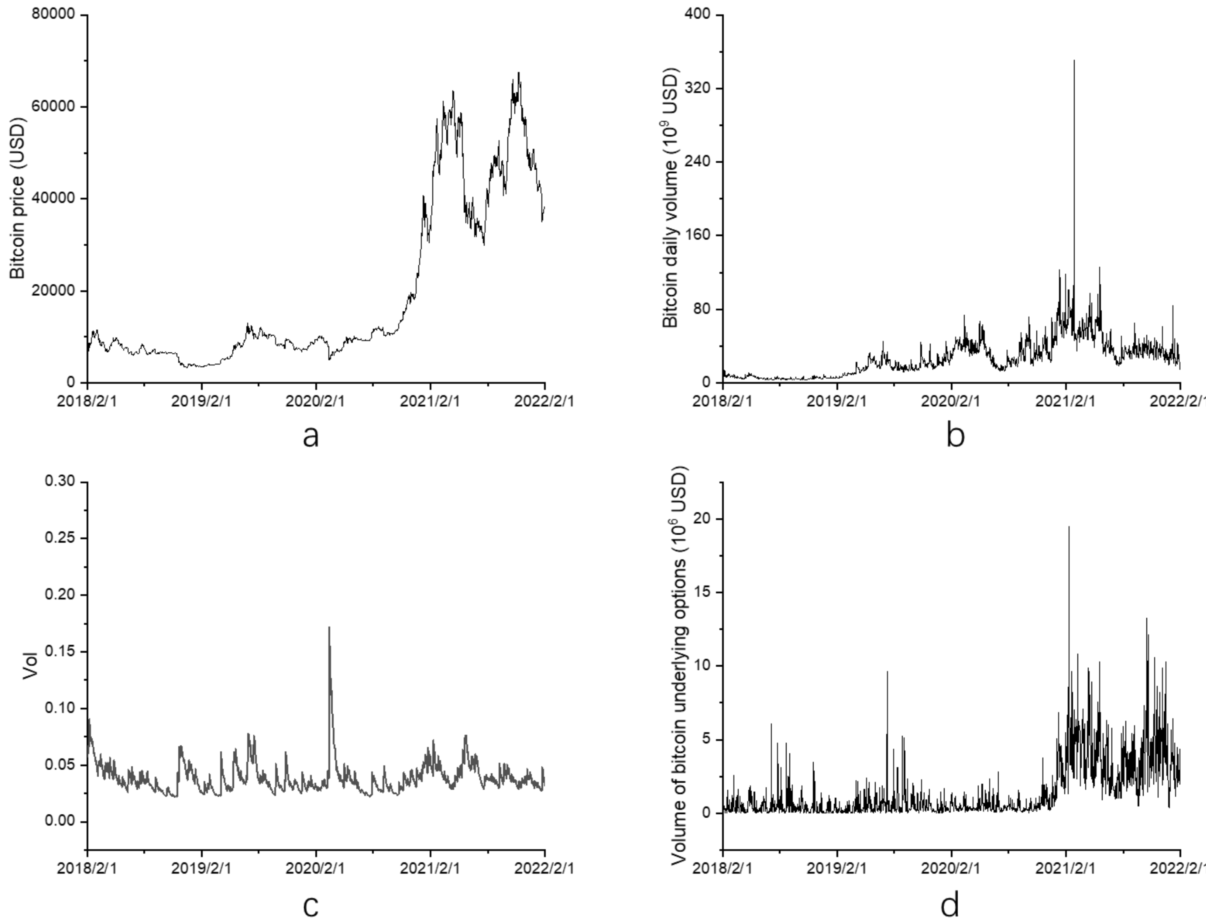
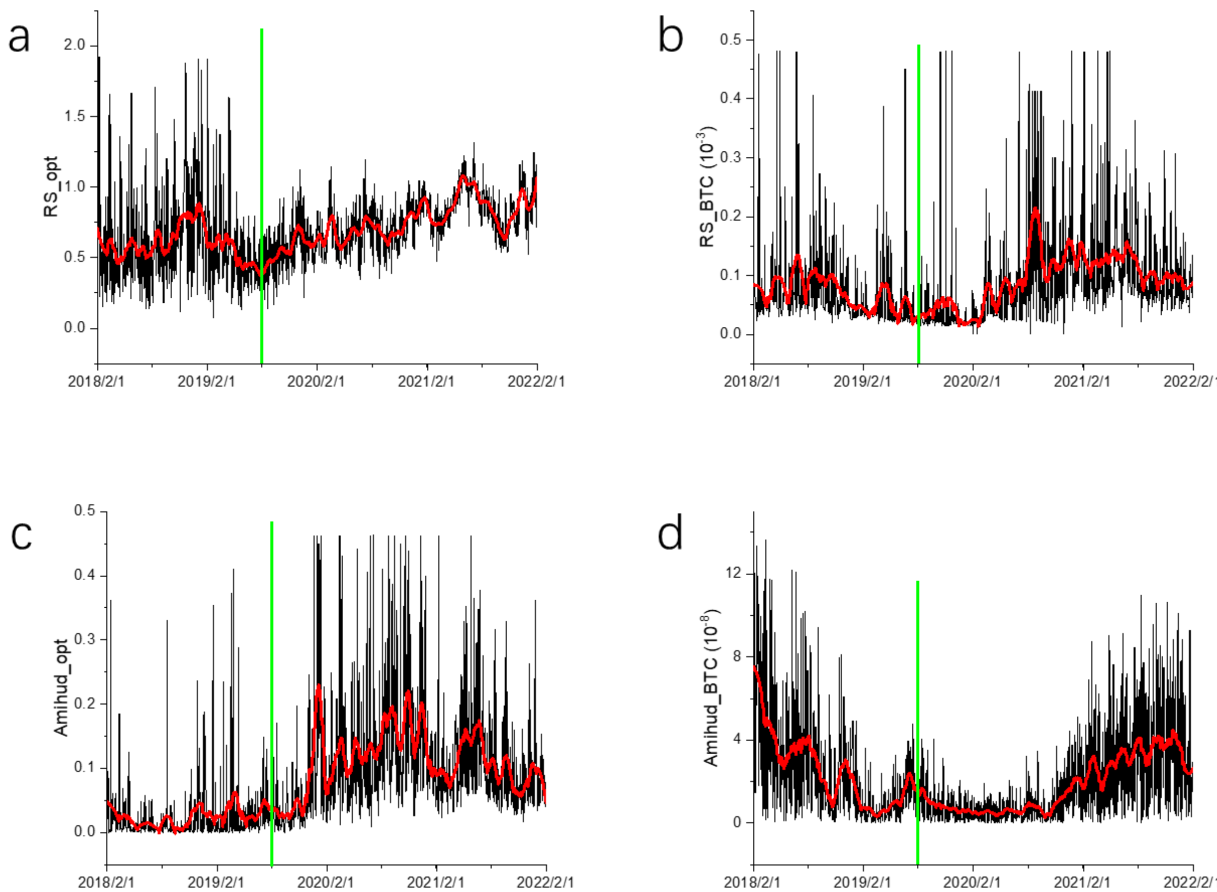
Figure 1: Time series of Bitcoin prices, volume, volatility, and options volume



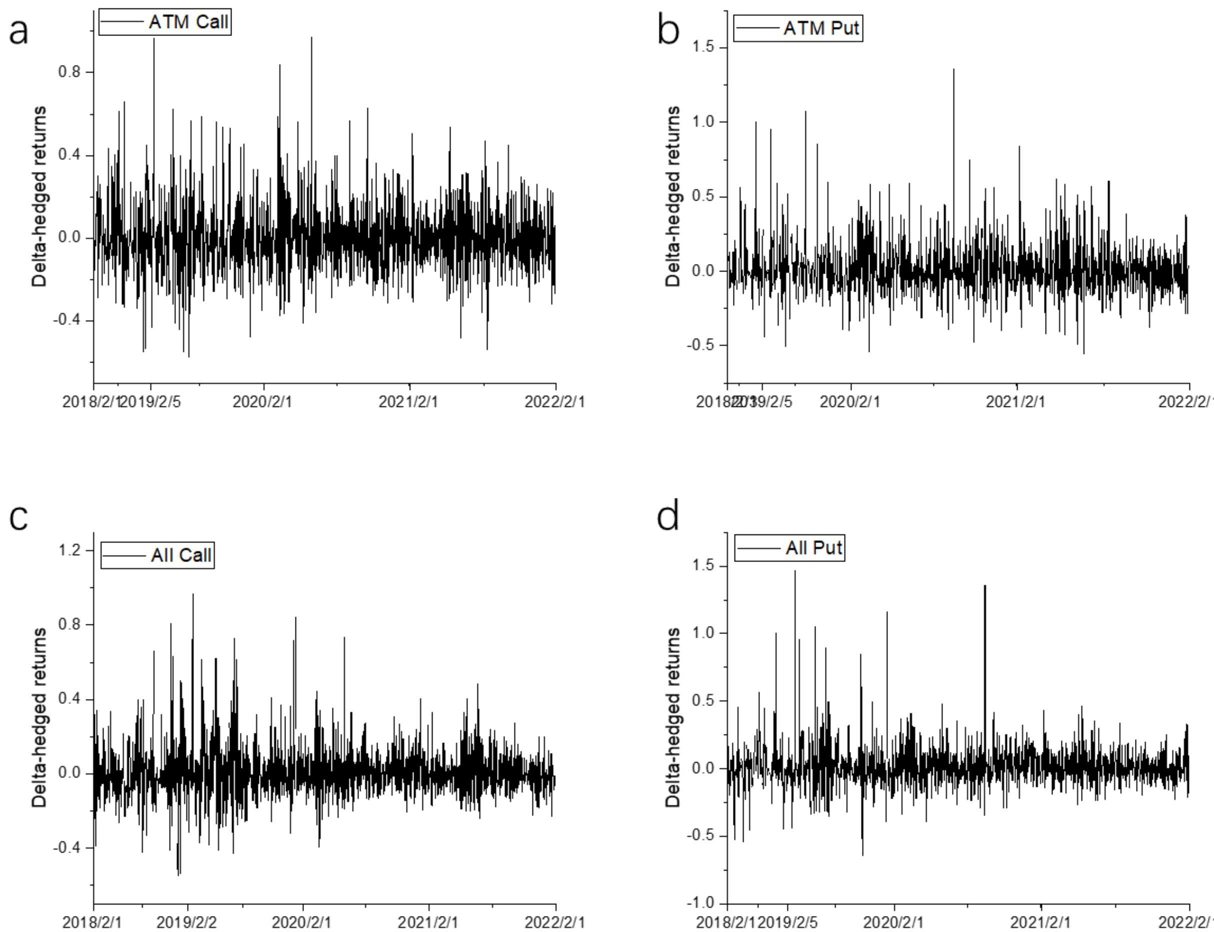
This figure plots the time series of (a) daily Bitcoin prices (in US dollars), (b) daily Bitcoin trading volume from CoinMarketCap (in billions of US dollars), (c) daily Bitcoin price volatility, estimated by GARCH(1,1) over all available history from April 30th, 2013 to January 31st, 2022, and (d) daily Bitcoin options trading volumes on LedgerX (in millions of US dollars). Our sample period is from February 1st, 2018 to January 31st, 2022.

Figure 2: Illiquidity Comparison: Bitcoin Options versus Spots



This figure chronicles the evolution of the daily relative spread for Bitcoin options over time (Panel A), as well as similar measures for Bitcoin spot for comparison (Panel B). After smoothing, we find both series to have similar trends across time (both tend to increase over time), indicating that illiquidity of options contracts is highly correlated with that of the underlying assets (the correlation is 0.52). Relative spreads of options are also much more volatile before a policy change (indicated by the green line) in August 2019 to be described in detail in Section 5. Similarly, we also compare the Amihud liquidity measures for options (Panel C) and that for Bitcoin spot (Panel D). While Amihud measures for Bitcoin options also tend to increase over time, those for Bitcoin spot tend to follow a U-shape. Relative spreads and Amihud measures thus tend to capture different aspects of Bitcoin options and spot illiquidity.

Figure 3: Average daily delta-hedged options Returns

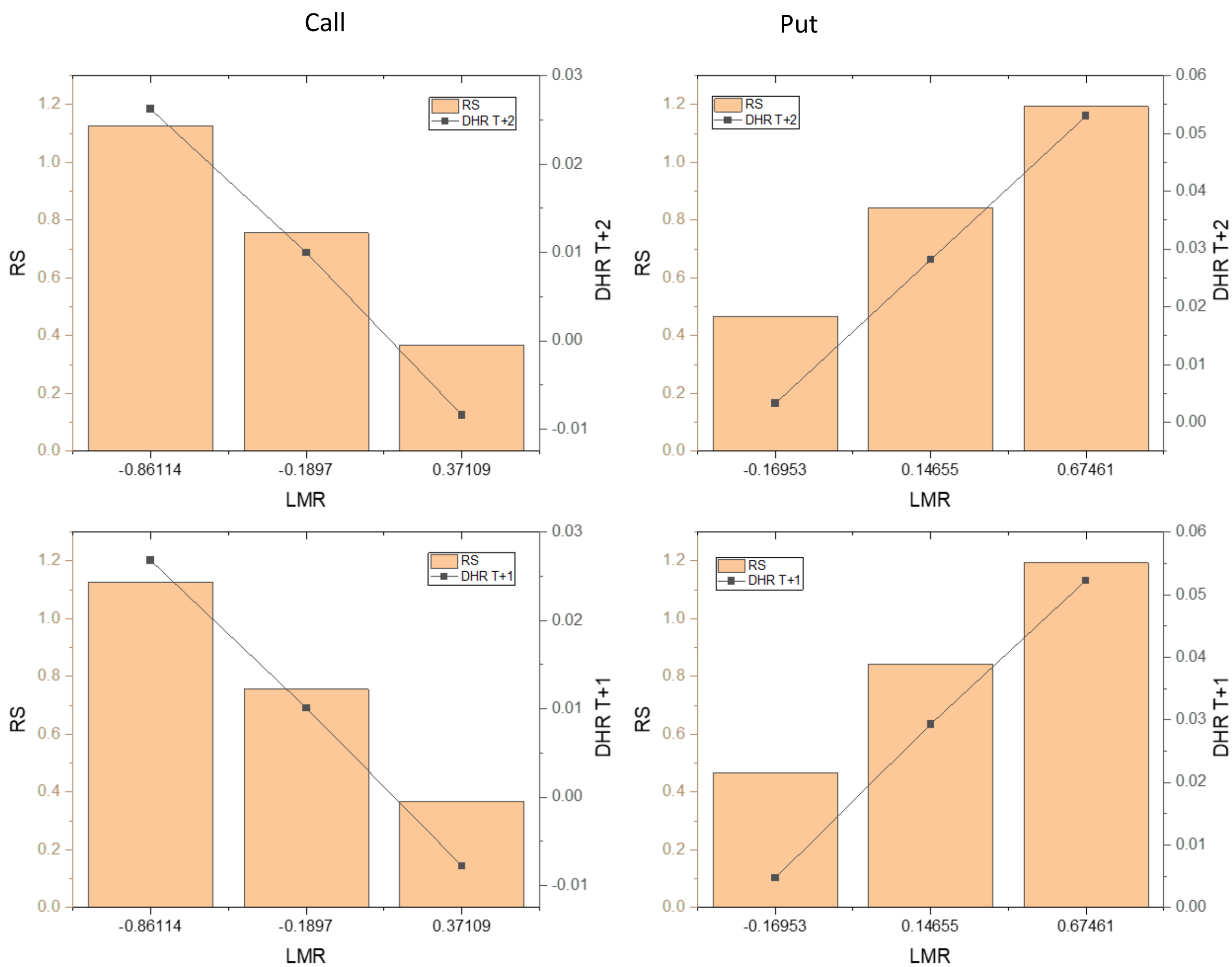


This figure presents the average daily delta-hedged options returns, separating between calls and puts as well as at-the-money (ATM) and all options. For a specific option contract n and day t, its delta-hedged return is defined as

$$\tilde{R}^{o}_{t+1,n} = R^{o}_{t+1,n} - R^{S}_{t+1} S_t \frac{\Delta_{t,n}}{O_{t,n}},$$

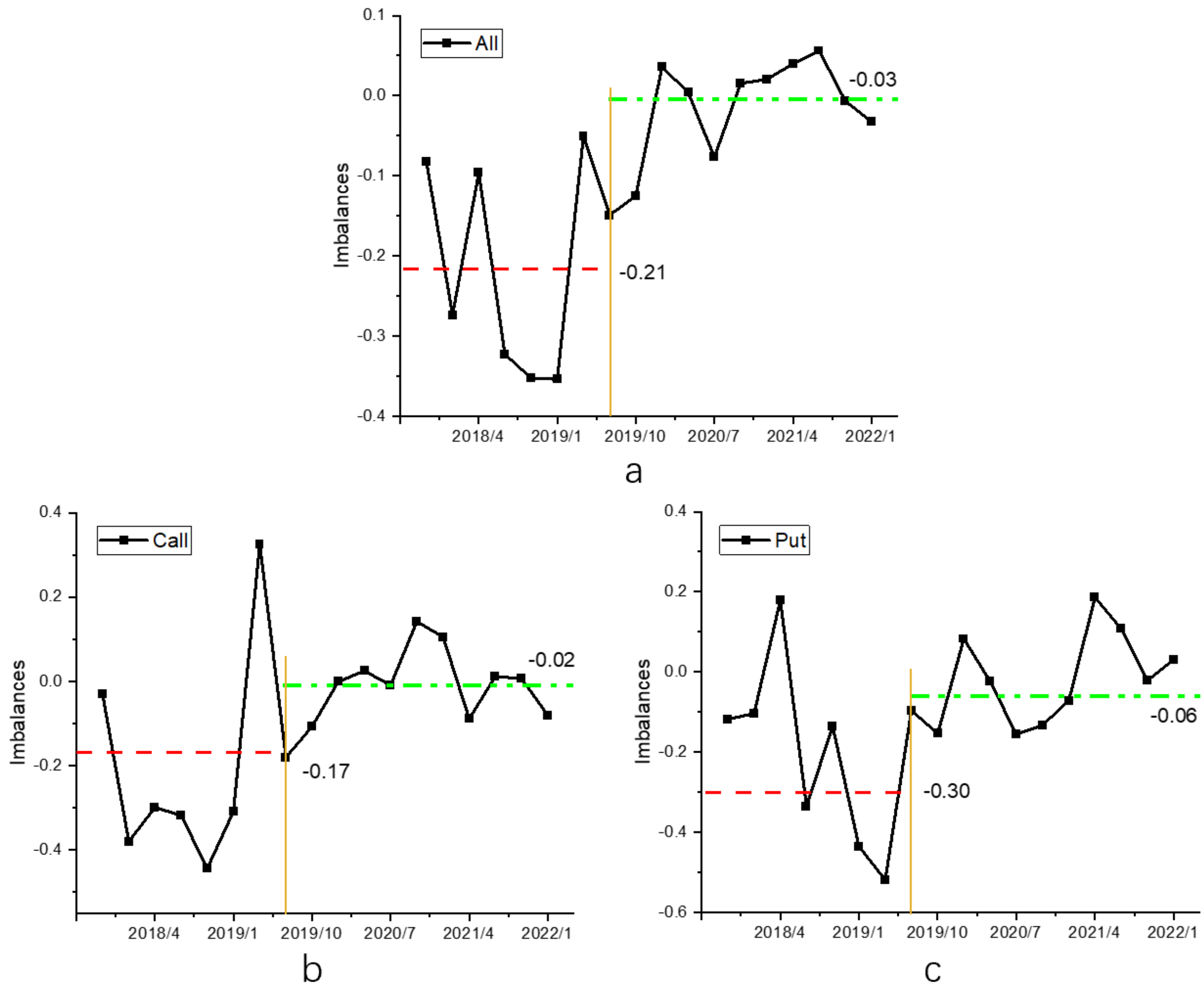
where $\tilde{R}^{o}_{t+1,n}$ denotes the daily delta-hedged options return, $R^{o}_{t+1,n}$ denotes the (raw) daily options return, R^{S}_{t+1} denotes the daily Bitcoin spot return, S_t denotes the spot market price of Bitcoin, $O_{t,n}$ denotes the options price, and $\Delta_{t,n}$ denotes the options delta based on the Black Scholes formula.

Figure 4: Relative Spreads and Delta Hedged Returns, sorted according to moneyness



This figure illustrates the relative spreads and delta-hedged returns for options with different moneyness levels. We first sort options into three groups with high, median, and low levels of moneyness, and presents the average relative spreads as well as next-day equal-weighted delta-hedge returns within each group. Option moneyness is measured by $LMR = \ln(\frac{S}{K})$ where S is the Bitcoin price and K option strike price. For both calls and puts, out-of-the-money (in-the-money) options have the highest (lowest) relative spreads as well as the highest (lowest) delta-hedged returns, consistent with findings in the literature on stock options as well as interest rate caps and floors. Because of the relationship illustrated here, later regressions control for options moneyness.

Figure 5: Trends of Imbalance over time



This figure illustrates the changes in imbalances before and after the policy shock in August 2019, which allows retail investors to participate in the options market. We notice that the incoming retail investors on average are options buyers, and their inflow brings the negative average net order imbalance before the policy change toward a more balanced market.

Table 1: Descriptive statistics of options data

	Time to maturity	Strike	Call vwap	Put vwap
	(1)	(2)	(3)	(4)
Mean	98.52	40,371.41	5,766.29	4,456.60
SD	88.17	39,276.31	8,971.52	11,739.17
Min	10	2,000	0.25	0.22
50%	60	30,000	1,760	1,107.08
Max	359	400,000	63,548	171,000
Observations	31,334	31,334	21,287	10,047

This table presents descriptive statistics of our options data, including time to maturity, strike prices, and volume-weighted average options prices for both calls and puts. All data are obtained from LedgerX from Feb 1st, 2018 to Jan 31st, 2022.

Table 2A: Descriptive statistics on illiquidity measures: Relative Spreads

	Call				Put				Bitcoin spot
	OTM	ATM	ITM	ALL	OTM	ATM	ITM	ALL	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Mean	0.999	0.529	0.316	0.749	1.078	0.609	0.36	0.834	0.009
Volume-weighted	0.938	0.53	0.349	0.808	0.95	0.443	0.227	0.733	
SD	0.542	0.377	0.264	0.549	0.53	0.435	0.383	0.563	0.008
Min	0.002	0.001	0.007	0.001	0.002	0.005	0.008	0.002	-0.008
25^{th} Q	0.536	0.250	0.129	0.291	0.644	0.277	0.120	0.346	0.003
Median	0.941	0.421	0.237	0.590	1.064	0.479	0.216	0.714	0.006
75^{th} Q	1.460	0.683	0.434	1.138	1.528	0.802	0.468	1.269	0.011
Max	2	1.998	2	2	1.999	2	2	2	0.048

This table presents the relative spreads of Bitcoin options, separating between calls and puts as well as moneyness (OTM, ATM, ITM, and all). For comparison, we also present summary statistics for the relative spreads in the Bitcoin spot market. For a given day t, the relative spread (RS) for contract n takes the last bid and ask of the asset and is defined as

$$RS_{nt} = \frac{last\ ask_{nt} - last\ bid_{nt}}{\left(\frac{last\ ask_{nt} + last\ bid_{nt}}{2}\right)},$$

that is, RS is defined as the ratio between the quoted spread and the mid-quote. A salient feature of the bitcoin options market is its illiquidity. Average relative spread can be as high as 74.9% for calls and 83.4% for puts. In comparison, relative spreads for stock options are typically 7% for calls and 8% for puts according to Christoffersen, Goyenko, Jacobs, and Karoui (2018). Such high relative spreads are not attributed to infrequently traded outliers, as the volume-weighted average presents similar magnitudes as the equally weighted means. Panel B repeats the exercise in Panel A but for Amihud measures instead of relative spreads. The Amihud measures for options are the ratios between absolute daily returns and volumes, while the ones for Bitcoin spots are scaled up by 10^8 for easy comparison.

Table 2B: Descriptive statistics on illiquidity measures: Amihud

	Call				Put				Bitcoin spot
	OTM	ATM	ITM	ALL	OTM	ATM	ITM	ALL	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Mean	1.74	1.42	1.65	1.66	4.15	2.36	2.03	3.31	2.03
Volume-weighted	0.05	0.04	0.09	0.04	0.10	0.07	0.09	0.09	
SD	8.49	5.83	3.57	7.14	14.36	6.79	4.18	11.52	2.33
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25th Q	0.02	0.02	0.06	0.02	0.05	0.05	0.07	0.05	0.42
Median	0.08	0.10	0.34	0.12	0.29	0.25	0.48	0.30	1.08
75th Q	0.43	0.55	1.60	0.66	1.70	1.29	1.97	1.58	2.84
Max	150.74	150.74	82.76	150.74	150.74	107.92	39.68	150.74	13.6

Table 3: Descriptive statistics of Delta Hedged Returns

	A. Daily delta-hedged returns call				*B. Daily delta-hedged returns put*				*C. Daily Bitcoin returns*	
	OTM	ATM	ITM	ALL	OTM	ATM	ITM	ALL		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
Average	0.017	0.012	-0.001	0.012	0.036	0.027	0.006	0.029	Average	0.002
SD	0.327	0.254	0.105	0.277	0.345	0.275	0.104	0.301	SD	0.042
Skewness	1.801	1.948	0.912	2.051	1.803	1.947	0.413	2.003	Skewness	-0.534
Kurtosis	6.343	9.893	5.187	9.389	5.77	8.363	5.283	7.949	Kurtosis	11.012
Avg #series	9.21	3.48	6.07	15.21	5.35	2.79	2.54	8.18	$\rho(1)$	-0.061

This table presents descriptive statistics of the daily delta-hedged returns for our options data, separating between calls and puts as well moneyness (OTM, ATM, ITM, and all). Delta-hedged return is defined as

$$\tilde{R}^{o}_{t+1,n} = R^{o}_{t+1,n} - R^{S}_{t+1} S_t \frac{\Delta_{t,n}}{O_{t,n}},$$

where $\tilde{R}^{o}_{t+1,n}$ denotes the daily delta-hedged options return, $R^{o}_{t+1,n}$ denotes the (raw) daily options return, R^{S}_{t+1} denotes the daily Bitcoin spot return, S_t denotes the spot market price of Bitcoin, $O_{t,n}$ denotes the options price, and $\Delta_{t,n}$ denotes the options delta based on the Black Scholes formula. Avg # series denotes the average numbers of options contracts within each group on each day. For comparison, we also present summary statistics for daily Bitcoin returns. $\rho(1)$ denotes the autocorrelation between bitcoin spot returns.

Table 4: Average Portfolio returns Sorted on Options Illiquidity

Panel A: Equal-weighted portfolios sorted on option RS

	Call options returns on t+2					*Put options returns on t+2*				
	1	2	3	3-1	Observations	1	2	3	3-1	Observations
Mean	0	0.009	0.019	0.019	7095	0.011	0.022	0.053	0.043	3349
t-stat	0.033	2.99	4.429	3.61***		2.426	4.214	7.777	4.84***	

	Call options returns on t+1					*Put options returns on t+1*				
	1	2	3	3-1	Observations	1	2	3	3-1	Observations
Mean	-0.005	0.012	0.023	0.027	7095	0.003	0.032	0.052	0.049	3349
t-stat	-2.114	3.864	5.194	5.62***		0.768	6.032	7.738	5.98***	

Panel B: Volume-weighted portfolios sorted on option RS

	Call options returns on t+2					*Put options returns on t+2*				
	1	2	3	3-1	Observations	1	2	3	3-1	Observations
Mean	0.008	0.028	0.020	0.011	7095	-0.020	0.047	0.031	0.050	3349
t-stat	0.635	1.856	1.329	0.567		-0.763	1.719	2.174	1.724**	

	Call options returns on t+1					*Put options returns on t+1*				
	1	2	3	3-1	Observations	1	2	3	3-1	Observations
Mean	-0.010	0.012	0.033	0.043	7095	0.011	0.033	0.070	0.059	3349
t-stat	-0.778	0.879	2.338	2.235**		0.603	1.845	2.321	1.645**	

This table sorts options into three groups with high, median, and low levels of relative spreads, and presents the average next-day (both equal-weighted and value weighted) delta-hedge returns within each group, as well as the return spread between the high and low groups. For both calls and puts and across all windows, higher illiquidity is followed by significantly higher delta-hedged returns.

Panel C: Equal-weighted portfolios sorted on option Amihud

	Call options returns on t+2					*Put options returns on t+2*				
	1	2	3	3-1	Observations	1	2	3	3-1	Observations
Mean	0.004	0.007	0.018	0.014	7095	0.025	0.023	0.037	0.012	3349
t-stat	1.123	1.979	5.096	2.98***		4.349	4.347	6.500	1.45*	
	Call options returns on t+1					*Put options returns on t+1*				
	1	2	3	3-1	Observations	1	2	3	3-1	Observations
Mean	0.000	0.011	0.018	0.018	7095	0.012	0.036	0.037	0.025	3349
t-stat	-0.015	3.219	5.023	3.82***		2.229	6.696	6.477	3.18***	

Panel D: Volume-weighted portfolios sorted on option Amihud

	Call options returns on t+2					*Put options returns on t+2*				
	1	2	3	3-1	Observations	1	2	3	3-1	Observations
Mean	0.016	0.035	0.058	0.042	7095	0.009	0.043	0.037	0.028	3349
t-stat	1.538	3.397	4.259	2.433***		0.503	2.932	2.206	1.150	
	Call options returns on t+1					*Put options returns on t+1*				
	1	2	3	3-1	Observations	1	2	3	3-1	Observations
Mean	0.010	0.029	0.024	0.014	7095	0.026	0.067	0.051	0.024	3349
t-stat	1.019	3.010	2.047	0.907		1.793	3.932	2.733	0.999	

Table 5: Options Liquidity and Returns

Panel A: All Options

DEPENDENT VARIABLE	Delta-Hedged Return					
	(1)	(2)	(3)	(4)	(5)	(6)
RSlag	0.027***	0.031***			0.022***	0.026***
	(8.02)	(6.91)			(6.76)	(5.98)
RSlag×imbalance	-0.042***	-0.039***			-0.024***	-0.030***
	(-12.11)	(-7.64)			(-8.40)	(-6.83)
Amihud			0.008***	0.007***	0.007***	0.007***
			(12.15)	(10.20)	(9.89)	(9.93)
amihud ×imbalance			-0.008***	-0.007***	-0.007***	-0.007***
			(-9.26)	(-7.49)	(-7.62)	(-7.32)
abs_delta		0.011*		-0.015***		0.013**
		(1.88)		(-3.68)		(2.27)
beta		-0.061***		-0.060***		-0.061***
		(-6.53)		(-6.77)		(-6.77)
ln_ret		0.704***		0.688***		0.687***
		(7.66)		(7.57)		(7.56)
lntime		0.003*		0.002		0.004**
		(1.90)		(1.05)		(2.23)
imbalances		-0.005		-0.017***		0.005
		(-1.58)		(-6.85)		(1.24)
RS_Bitcoin_Spot		0.017		-0.047		-0.044
		(0.09)		(-0.26)		(-0.23)
amihud_Bitcoin_Spot		0.002**		0.002**		0.002**
		(2.24)		(1.99)		(1.99)
vol		-0.003		0.005		-0.003
		(-0.41)		(0.68)		(-0.40)
Constant	-0.009***	0.014	0.001	0.037***	-0.017***	0.004
	(-3.54)	(0.99)	(0.73)	(2.87)	(-7.11)	(0.30)
Year fixed effect?	Y	Y	Y	Y	Y	Y
Observations	26,593	26,290	30,232	26,604	26,593	26,290
Adjusted R-squared	0.018	0.030	0.044	0.055	0.048	0.060

This table presents results from the following regression:

$$DHR_{t+1} = \alpha_0 + \alpha_1 Illiquidity_t + \alpha_2 Illiquidity_t \times imbalance_t + Controls + \varepsilon,$$

Panel B: Call Options

DEPENDENT VARIABLE	Delta-Hedged Return					
	(1)	(2)	(3)	(4)	(5)	(6)
RSlag	0.022***	0.019***			0.019***	0.015***
	(5.23)	(3.30)			(4.79)	(2.70)
RSlag×imbalance	-0.039***	-0.036***			-0.028***	-0.032***
	(-9.65)	(-5.93)			(-7.88)	(-5.74)
Amihud			0.008***	0.007***	0.007***	0.007***
			(8.73)	(7.68)	(6.92)	(7.42)
amihud ×imbalance			-0.007***	-0.005***	-0.006***	-0.005***
			(-6.33)	(-4.51)	(-5.03)	(-4.41)
abs_delta		0.006		-0.013***		0.003
		(0.84)		(-2.65)		(0.44)
beta		-0.053***		-0.056***		-0.054***
		(-4.93)		(-5.58)		(-5.33)
ln_ret		1.729***		1.726***		1.718***
		(18.92)		(19.05)		(18.84)
lntime		0.005**		0.003*		0.005**
		(2.21)		(1.68)		(2.51)
imbalances		-0.016***		-0.031***		-0.009**
		(-4.04)		(-10.79)		(-2.01)
RS_Bitcoin_Spot		-0.350*		-0.396**		-0.368*
		(-1.69)		(-1.98)		(-1.80)
amihud_Bitcoin_Spot		0.002*		0.002*		0.002*
		(1.82)		(1.83)		(1.75)
vol		-0.003		0.002		-0.005
		(-0.36)		(0.19)		(-0.55)
Constant	-0.009***	0.014	-0.001	0.032**	-0.016***	0.010
	(-3.22)	(0.83)	(-0.46)	(2.13)	(-5.74)	(0.60)
Year fixed effect?	Y	Y	Y	Y	Y	Y
Observations	18,502	18,292	20,683	18,494	18,502	18,292
Adjusted R-squared	0.016	0.076	0.031	0.089	0.033	0.093

where DHR is delta-hedged return over day t+1, illiquidity is measured by lagged relative spreads or Amihud measures of Bitcoin options. Controls include the absolute value of option delta to account for moneyness (abs_delta), bitcoin spot beta estimated from 365-day rolling window, daily spot return (ln_ret), option maturity in terms of ln(days to expiration) (lntime), option order imbalances, spot illiquidity also measured by relative spreads and Amihud liquidity measures (scaled up by 10^8), and spot volatility (vol).

Panel C: Put Options

DEPENDENT VARIABLE	Delta-Hedged Return					
	(1)	(2)	(3)	(4)	(5)	(6)
RSlag	0.036***	0.033***			0.028***	0.025***
	(6.18)	(4.44)			(4.91)	(3.34)
RSlag×imbalance	-0.046***	-0.040***			-0.018***	-0.025***
	(-7.52)	(-4.30)			(-3.61)	(-3.10)
Amihud			0.007***	0.007***	0.007***	0.007***
			(8.17)	(7.30)	(6.87)	(7.14)
amihud ×imbalance			-0.009***	-0.008***	-0.008***	-0.007***
			(-6.99)	(-5.77)	(-5.94)	(-5.64)
abs_delta		-0.002		-0.027***		0.004
		(-0.19)		(-2.95)		(0.32)
beta		-0.082***		-0.076***		-0.081***
		(-4.21)		(-3.98)		(-4.15)
ln_ret		-1.440***		-1.433***		-1.405***
		(-12.78)		(-12.87)		(-12.63)
lntime		-0.004		-0.009***		-0.006*
		(-1.26)		(-2.63)		(-1.85)
imbalances		-0.016**		-0.022***		-0.003
		(-2.56)		(-4.81)		(-0.39)
RS_Bitcoin_Spot		1.050***		0.897**		0.901**
		(2.77)		(2.46)		(2.45)
amihud_Bitcoin_Spot		0.006***		0.006***		0.006***
		(3.40)		(3.27)		(3.28)
vol		0.009		0.018		0.015
		(0.65)		(1.41)		(1.19)
Constant	-0.006	0.048*	0.005**	0.071**	-0.019***	0.040
	(-1.22)	(1.67)	(2.04)	(2.58)	(-4.09)	(1.38)
Year fixed effect?	Y	Y	Y	Y	Y	Y
Observations	8,091	7,998	9,549	8,110	8,091	7,998
Adjusted R-squared	0.023	0.061	0.066	0.107	0.074	0.111

Robust t-statistics are in parentheses with standard errors clustered at the contract level. Stars denotes p-statistics <0.01, <0.05, and <0.1, respectively.

Table 6: Statistical Description of Imbalance

Imbalance	Mean (1)	Std (2)	Min (3)	Median (4)	Max (5)	#Observations (6)
All	-0.040	0.797	-1	-0.028	1	27500
Before	-0.208	0.909	-1	-1	1	1470
After	-0.030	0.789	-1	0	1	26030
After-Before	0.178***					

This table presents summary statistics of the options trading imbalance before and after a policy shock that significantly increases retail participation. For options contract i on day t, $Imbalance_{it}$ is defined as

$$Imbalance_{it} = \frac{\sum (Buy \quad - Sell \quad)}{\sum (Buy \quad + Sell \quad)},$$

where "buy" and "sell" are the number of contracts initiated by buyers and sellers on day t. The policy change allows more retail investor participation, and lead to significantly higher imbalance, as the last line (After-Before) indicates.

Table 7: Options Liquidity and Returns before and after the policy shock

Panel A: All Options

DEPENDENT VARIABLE	Before						After					
	Delta-Hedged Return						Delta-Hedged Return					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
RSlag	0.073***	0.098***			0.055**	0.082***	0.026***	0.030***			0.021***	0.025***
	(2.95)	(2.95)			(2.47)	(2.71)	(7.67)	(6.67)			(6.38)	(5.73)
RSlag×imbalance	0.000	-0.033*			-0.005	-0.037*	-0.043***	-0.037***			-0.025***	-0.029***
	(0.00)	(-1.66)			(-0.39)	(-1.84)	(-12.17)	(-7.07)			(-8.50)	(-6.32)
Amihud			0.546***	0.655***	0.648***	0.647***			0.008***	0.007***	0.007***	0.007***
			(5.03)	(5.75)	(5.67)	(5.53)			(12.12)	(10.21)	(9.88)	(9.94)
amihud ×imbalance			0.077	0.036	0.104	0.050			-0.008***	-0.007***	-0.007***	-0.007***
			(0.71)	(0.34)	(0.97)	(0.44)			(-9.26)	(-7.29)	(-7.56)	(-7.17)
abs_delta		0.081*		-0.004		0.088**		0.010		-0.015***		0.012**
		(1.78)		(-0.15)		(2.09)		(1.58)		(-3.69)		(2.00)
beta		-0.030		-0.009		-0.003		-0.066***		-0.065***		-0.066***
		(-0.74)		(-0.23)		(-0.09)		(-6.85)		(-7.08)		(-7.10)
ln_ret		0.915***		0.869***		0.900***		0.697***		0.683***		0.679***
		(3.55)		(3.48)		(3.69)		(7.18)		(7.12)		(7.09)
lntime		0.001		0.011		0.012*		0.003*		0.002		0.004**
		(0.11)		(1.56)		(1.77)		(1.82)		(1.01)		(2.16)
imbalances		0.019		0.009		0.021*		-0.009***		-0.019***		0.002
		(1.51)		(1.10)		(1.68)		(-2.62)		(-7.44)		(0.49)
RS_Bitcoin_Spot		0.943		1.003		0.898		0.052		-0.020		-0.010
		(0.93)		(1.00)		(0.89)		(0.27)		(-0.11)		(-0.05)
amihud_Bitcoin_Spot		0.009***		0.006*		0.007**		0.001		0.001		0.001
		(2.61)		(1.92)		(2.21)		(1.33)		(1.11)		(1.09)
vol		0.063*		0.009		0.000		-0.017**		-0.008		-0.016**
		(1.75)		(0.26)		(0.01)		(-2.32)		(-1.22)		(-2.29)
Constant	-0.018	-0.125**	-0.016***	-0.085**	-0.049***	-0.162***	-0.008***	0.032**	-0.000	0.053***	-0.017***	0.021
	(-1.41)	(-2.33)	(-2.60)	(-2.11)	(-3.93)	(-3.27)	(-3.37)	(2.15)	(-0.00)	(3.86)	(-7.09)	(1.46)
Year fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	1,268	1,268	1,917	1,311	1,268	1,268	25,325	25,022	28,315	25,293	25,325	25,022
Adjusted R-squared	0.009	0.037	0.063	0.103	0.091	0.116	0.019	0.032	0.047	0.058	0.050	0.062

Panel B: Call Options

DEPENDENT VARIABLE	Before						After					
	Delta-Hedged Return						Delta-Hedged Return					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
RSlag	0.064**	0.066*			0.053**	0.057	0.021***	0.018***			0.018***	0.014***
	(2.31)	(1.69)			(2.08)	(1.60)	(4.94)	(3.20)			(4.49)	(2.60)
RSlag×imbalance	-0.008	-0.030			-0.007	-0.038*	-0.041***	-0.035***			-0.029***	-0.031***
	(-0.52)	(-1.31)			(-0.47)	(-1.72)	(-9.65)	(-5.53)			(-7.95)	(-5.37)
Amihud			0.553***	0.639***	0.661***	0.644***			0.008***	0.007***	0.007***	0.007***
			(4.43)	(4.68)	(4.81)	(4.64)			(8.70)	(7.69)	(6.90)	(7.43)
amihud ×imbalance			0.016	-0.028	0.049	-0.021			-0.007***	-0.005***	-0.006***	-0.005***
			(0.12)	(-0.21)	(0.38)	(-0.16)			(-6.32)	(-4.35)	(-4.97)	(-4.29)
abs_delta		0.021		-0.026		0.038		0.005		-0.013***		0.002
		(0.36)		(-0.85)		(0.71)		(0.73)		(-2.59)		(0.34)
beta		0.026		0.031		0.041		-0.060***		-0.063***		-0.061***
		(0.53)		(0.63)		(0.81)		(-5.45)		(-6.14)		(-5.90)
ln_ret		1.823***		1.782***		1.753***		1.726***		1.723***		1.715***
		(6.57)		(6.79)		(6.71)		(17.97)		(18.06)		(17.88)
lntime		0.005		0.015*		0.016**		0.004**		0.003		0.005**
		(0.55)		(1.92)		(2.02)		(1.98)		(1.46)		(2.30)
imbalances		0.003		-0.001		0.013		-0.020***		-0.034***		-0.012**
		(0.19)		(-0.10)		(0.91)		(-4.62)		(-10.96)		(-2.44)
RS_Bitcoin_Spot		1.424		1.556		1.405		-0.344		-0.397*		-0.359*
		(1.40)		(1.58)		(1.39)		(-1.63)		(-1.95)		(-1.73)
amihud_Bitcoin_Spot		0.008**		0.005*		0.006*		0.001		0.001		0.001
		(2.37)		(1.70)		(1.90)		(1.04)		(1.05)		(0.95)
vol		0.069		0.017		0.006		-0.018**		-0.014		-0.020**
		(1.59)		(0.42)		(0.14)		(-2.20)		(-1.64)		(-2.41)
Constant	-0.017	-0.139**	-0.020***	-0.124**	-0.052***	-0.179***	-0.009***	0.036**	-0.002	0.053***	-0.017***	0.031*
	(-1.10)	(-2.08)	(-2.65)	(-2.55)	(-3.40)	(-2.86)	(-3.14)	(2.01)	(-0.98)	(3.36)	(-5.77)	(1.81)
Year fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	1,268	1,268	1,917	1,311	1,268	1,268	25,325	25,022	28,315	25,293	25,325	25,022
Adjusted R-squared	0.009	0.037	0.063	0.103	0.091	0.116	0.019	0.032	0.047	0.058	0.050	0.062

Panel C: Put options

	Before						After					
DEPENDENT VARIABLE	Delta-Hedged Return						Delta-Hedged Return					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
RSlag	0.114*	0.106*			0.079	0.096*	0.035***	0.032***			0.027***	0.023***
	(1.88)	(1.73)			(1.50)	(1.68)	(5.97)	(4.29)			(4.67)	(3.17)
RSlag×imbalance	0.024	-0.023			-0.009	-0.028	-0.047***	-0.038***			-0.019***	-0.023***
	(0.71)	(-0.49)			(-0.28)	(-0.57)	(-7.59)	(-3.96)			(-3.68)	(-2.84)
Amihud			0.509**	0.577***	0.577***	0.544***			0.007***	0.007***	0.007***	0.007***
			(2.47)	(3.07)	(3.18)	(2.88)			(8.15)	(7.31)	(6.87)	(7.16)
amihud ×imbalance			0.238	0.340**	0.275*	0.370**			-0.009***	-0.008***	-0.008***	-0.007***
			(1.57)	(2.31)	(1.72)	(2.34)			(-7.00)	(-5.66)	(-5.91)	(-5.57)
abs_delta		0.063		-0.065		0.079		-0.004		-0.026***		0.003
		(0.80)		(-0.79)		(0.97)		(-0.32)		(-2.88)		(0.25)
beta		-0.173**		-0.137**		-0.140**		-0.081***		-0.076***		-0.081***
		(-2.63)		(-2.17)		(-2.26)		(-3.96)		(-3.75)		(-3.92)
ln_ret		-0.993***		-1.346***		-1.115***		-1.454***		-1.438***		-1.419***
		(-3.00)		(-4.13)		(-3.24)		(-12.20)		(-12.23)		(-12.08)
lntime		0.003		0.010		0.018		-0.004		-0.009***		-0.007*
		(0.19)		(0.54)		(1.06)		(-1.30)		(-2.65)		(-1.88)
imbalances		0.019		-0.014		-0.008		-0.020***		-0.023***		-0.005
		(0.76)		(-0.89)		(-0.34)		(-3.14)		(-5.05)		(-0.73)
RS_Bitcoin_Spot		-2.724		-3.587		-3.068		1.126***		0.976***		0.969***
		(-1.21)		(-1.61)		(-1.42)		(2.93)		(2.64)		(2.60)
amihud_Bitcoin_Spot		0.008		0.005		0.005		0.006***		0.005***		0.006***
		(1.05)		(0.70)		(0.82)		(3.23)		(3.10)		(3.14)
vol		0.040		-0.020		-0.015		0.004		0.014		0.011
		(0.57)		(-0.32)		(-0.24)		(0.29)		(1.11)		(0.86)
Constant	-0.026	-0.018	-0.005	0.046	-0.048**	-0.075	-0.005	0.054*	0.004	0.075**	-0.019***	0.044
	(-1.11)	(-0.18)	(-0.50)	(0.48)	(-2.07)	(-0.82)	(-1.07)	(1.77)	(1.52)	(2.56)	(-4.00)	(1.45)
Year fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	344	344	564	354	344	344	7,747	7,654	8,985	7,756	7,747	7,654
Adjusted R-squared	0.012	0.048	0.056	0.119	0.087	0.121	0.024	0.062	0.069	0.110	0.077	0.113

This table reevaluates our Hypothesis 1 and 2 for the sample before and after the policy change using the same regression as in Table 5. Robust t-statistics are in parentheses with standard errors clustered at the contract level. Stars denotes p-statistics <0.01, <0.05, and <0.1, respectively.