Bitcoin Microstructure and the Kimchi Premium

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Abstract

Between January 2016 and February 2018, Bitcoin were in Korea on average 4.73% more expensive than in the United States, a fact commonly referred to as the Kimchi premium. We argue that capital controls create frictions as well as amplify existing frictions from the microstructure of the Bitcoin network that limit the ability of arbitrageurs to take advantage of persistent price differences. We find that the Bitcoin premia are positively related to transaction costs, confirmation time in the blockchain, and to Bitcoin price volatility in line with the idea that the delay and the associated price risk during the transaction period make trades less attractive for risk averse arbitrageurs and hence allow prices to diverge. A cross country comparison shows that Bitcoin tend to trade at higher prices in countries with lower financial freedom. Finally unlike the prediction from the stock bubble literature, the Kimchi premium is negatively related to the trading volume, which also suggests that the Bitcoin microstructure is important to understand the Kimchi premium.

Keywords: Bitcoin, Limits to Arbitrage, Cryptocurrencies, Fintech

1 Introduction

I think the internet is going to be one of the major forces for reducing the role of government. The one thing that's missing but that will soon be developed, is a reliable e-cash.

Milton Friedman in 1999 - Nine years later, Bitcoin was created.

Many proponents of cryptocurrencies such as Bitcoin list independence from government influence as key advantage of this new technology. In an ideal world, payments can be made and funds exchanged globally without any central authority or government regulation.[1] Yet we argue in this paper that government regulations in fiat currencies, especially capital controls, create new and amplify existing frictions in the global Bitcoin market. In Korea, for example, Bitcoin frequently trade at a higher price than in other markets, a phenomenon referred to as the Kimchi premium. Between Between January 2016 and February 2018 the average Kimchi premium was 4.73% but it reached levels as high as 54.48% in January 2018. Figure 1 shows a time series plot as well as a histogram of the historical Kimchi premium. In frictionless financial markets such a price difference could not persist as it would be immediately arbitraged away. Traders could buy Bitcoin in another market, say the US, then transfer them to a Korean Bitcoin exchange, sell them for Korean won, and convert the won to US dollars for an instant profit. However, institutional frictions prevent arbitrageurs from keeping Bitcoin prices in Korea aligned with the rest of the world. Divergence in Bitcoin prices are not only a Korean phenomenon. As we document in this paper, international differences in Bitcoin prices can be high and persist over longer periods of time. Even within the US prices differ somewhat between exchanges.[2] In this paper we analyze two main frictions that can contribute to a potential misalignment of Bitcoin

[1] Satoshi Nakamoto, a pseudonym for the legendary inventor of Bitcoin, included the headline of the Financial Times on Jan 3, 2009, “Chancellor on brink of second bailout for banks” in the first block, the genesis block, of the Bitcoin Blockchain. Many see this as an expression of distrust in the current financial system. As the first reason for the existence of Bitcoin, Bitcoin-Wiki states that ‘’Bitcoin is P2P electronic cash that is valuable over legacy systems because of the monetary autonomy it brings to its users.”

[2] Several websites allow users to monitor spreads and identify possible arbitrage opportunities: e.g., www.tokenspread.com, data.bitcoinity.org/markets/arbitrage. Figure 4 in the appendix shows such an arbitrage matrix.

prices across major markets: capital controls and frictions emanating from the microstructure of the Bitcoin network.

Due to microstructure of the Bitcoin network arbitrageurs are confronted with obstacles that are absent in many traditional markets. An arbitrageur faces two main sources of risk when executing the arbitrage trade described above. First, the transfer of Bitcoin from a foreign exchange to a Korean exchange takes time during which the Bitcoin price can change dramatically. Since Bitcoin can usually not be shorted in the markets where they are selling at a higher price the premium cannot be locked in; Bitcoin at a Korean exchange can only be sold once the transfer is complete. Because Bitcoin can be much more volatile than many transitional assets, price risk can pose a significant deterrent for arbitrageurs. Second, time varying transaction costs erode potential arbitrage profits. Demand for transactions fluctuates over the day and over time. As fees increase, profits from arbitrage decrease allowing the price difference between Bitcoin in Korea and the rest of the world to rise.

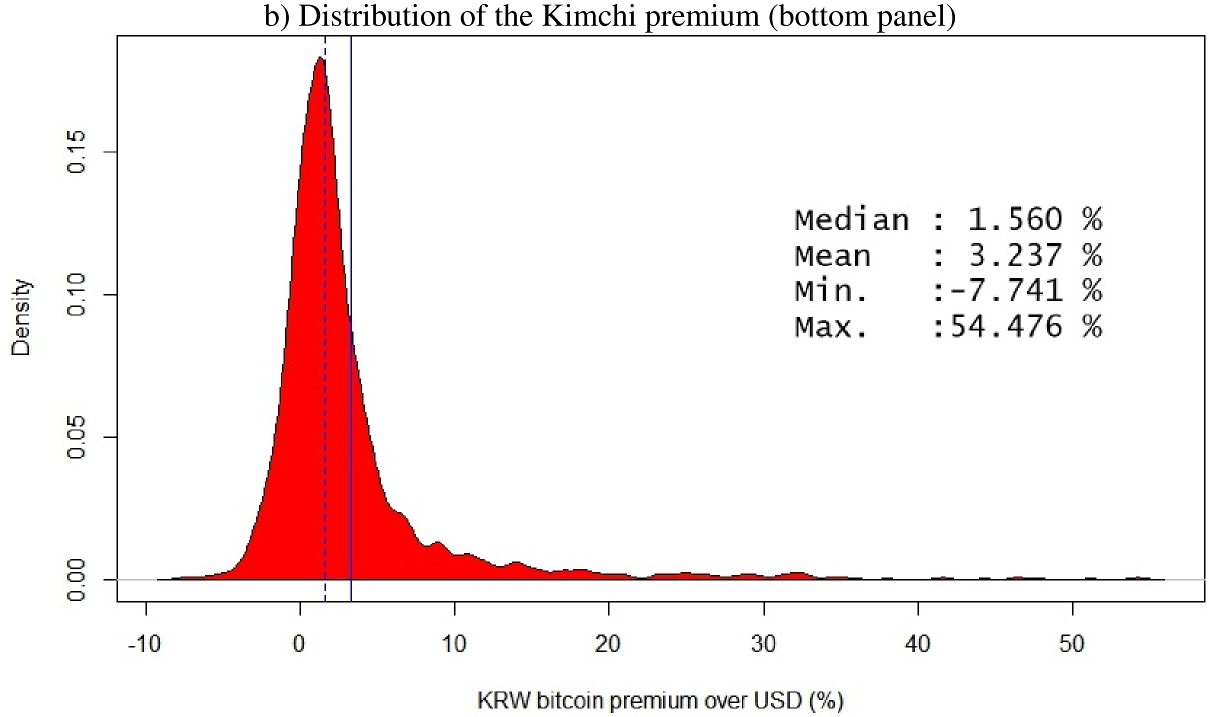
Frictions in traditional capital markets add limitations to arbitrage. Korean capital controls limit the amount of money that can be sent abroad, or at least complicate the transfer of funds, and thus create a one way friction for the fiat currency part of the arbitrage trade. In the aftermath of the global financial crisis and the European sovereign debt crisis, Korea introduced capital controls that create administrative burden and additional time delay when sending money abroad.

Our main finding is that both Bitcoin microstructure effects as well as exchange controls explain a significant portion of Kimchi premium. We start out with an in-depth comparison of the Korean Bitcoin market with the European market where more detailed data is available and markets are well developed and liquid. We find that in both markets microstructure effects are correlated with price deviations. Price deviations relative to the US market are significantly positively related to Bitcoin volatility, supporting the idea that price risk for traders limits arbitrage activity. The Kimchi premium is also positively related to the median confirmation time in the block chain, supporting the idea that longer transaction times create more uncertainty for

Figure 1. The Bitcoin Kimchi Premium: Bitcoin frequently trade at a higher price in Korea than in other markets. The premium for purchasing Bitcoin with Korean won (KRW) versus US dollars (USD) is calculated: $(\text{KRWBTC}_{\text{price in USD}})/(\text{USDBTC}_{\text{price}}) - 1$, where the Bitcoin price in USD is the mean price of all USD transactions on the Bitstamp exchange for that day. The Bitcoin price in KRW is similarly defined from the Korbit exchange. Conversion from KRW to USD is done using the OANDA daily average rate.

a) The Kimchi premium over time (top panel)

b) Distribution of the Kimchi premium (bottom panel)



arbitrageurs allowing prices to diverge. Finally price differences are also increase in transaction fees paid to miners, consistent with the idea that higher fees reduce the attractiveness of the arbitrage trade. In particular, if the trader offers higher fees, miners are more likely to include the transaction in a block, hence making the transfer of Bitcoin faster. Therefore, the effect of transaction fees should be inclusive of that of the median confirmation time, which is shown in our regression analysis.

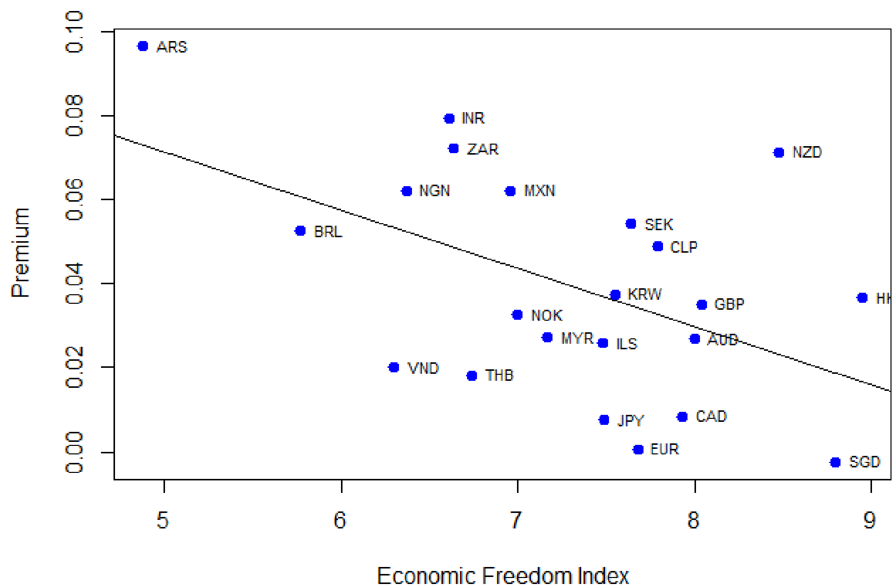
Comparing the European to the Korean market, however, we find two important differences. First, the impact of microstructure effects on price divergences are several times larger for Korea than for the European market. Second, we find the Kimchi premium to be positive while the average premium for the European market is near zero. We argue that capital controls are the reason why the average premium in positive and also make the the premium more sensitive to microstructure effects. Because of the asymmetry of capital controls (it is easier to move funds to Korea than the other way around) arbitrage is harder on one direction, allowing the Kimchi premium to be positive on average. Because of the capital controls arbitrage is more costly and hence the premium in Korea is more sensitive to transaction costs, volatility, and transaction times compared to the European market.

To further analyze the impact of capital controls we collect data on Bitcoin premia for an international sample and analyze how premia vary with various measures of financial freedom. Controlling for microstructure effects we find that countries with higher financial freedom have on average lower premia. Figure 2 plots the median Bitcoin premium from March 2017 to the end of February 2018 as a function of financial freedom.[3] As a stylized fact, the graph shows higher average premia in financially more restrictive countries which is consistent with our view that financial restrictions are causing higher Bitcoin prices in some countries.

We also examine Korean premia in other cryptocurrencies such as Ethereum, Lite-coin, and Ripple. Instead of using fiat currency, arbitrageurs could complete the arbitrage trade by buying other crypto currencies with the proceeds of selling Bitcoin in Korea and sending them abroad

[3]In This graph we use the Economic Freedom Ranking by the Fraser institute as explained in more detail in Section 5

Figure 2. Bitcoin Premia and Financial Freedom: The Bitcoin premium is measured as the median percentage price difference to the USD price from March 2017 to the end of February 2018. Bitcoin transaction prices are from bitcoincharts.com, foreign exchange data from the Federal Reserve Bank of St. Louis (where available) and OANDA otherwise. To measure financial freedom we use the Economic Freedom Ranking by the Fraser institute.



without being subject to capital controls. We find that other crypto currencies have practically identical premia to Bitcoin at Korean exchanges and those premia are highly correlated over time with the Kimchi premium.

In addition to our finding on the two main factors to derive the Kimchi premium, it is notable that the Kimchi premium is negatively related to the trading volume. This result sounds quite counterintuitive in the sense that the trading volume is usually positively related to the size of a bubble in common stock markets as shown by the traditional bubble literature (see, e.g., Scheinkman and Xiong (2003) and Xiong and Yu (2011)). More precisely in our study, the trading volume, with nothing else controlled for, is positively associated with the Kimchi premium. However, if we add the trading volume into the regression together with volatility and transaction fees, the Kimchi premium shows the negative relation with the trading volume while its positive correlations with the other two factors become stronger. Our findings are consistent with two countervailing forces. On one hand, a higher volume helps to reduce the Kimchi premium through increased liquidity in the Korean Bitcoin market. On the other hand, high volume increases blockchain transaction fees and blockchain confirmation times (and possibly exchange cash-out times) and thus reduces the ability to arbitrage. Given that the volatility is extremely high, a high volume contributes more to increasing liquidity than increasing transaction fees, which leads to the negative relationship between the premium and the volume. Therefore, we argue that this negative relationship is attributed to the Bitcoin microstructure characteristics that do not exist in a common stock market.

Our paper is related to the recent emerging and fast-growing literature on blockchain and cryptocurrencies such as Athey, Parashkevov, Sarukkai, and Xia (2016), Cong, Li, and Wang (2018), Detzel, Liu, Strauss, Zhou, and Zhu (2018), Pagnottayand and Buraschi (2018) and Sockin and Xiong (2018), Griffin and Shams (2018). While most of these papers focus on cryptocurrency pricing and/or asset pricing implications, we investigate the mechanism and the factors that lead to the different pricing.[4] Gandal, Hamrick, Moore, and Oberman (2018) investigate how suspicious trading activities caused a price spike in late 2013. Easley, O'Hara, and Basu (2017), Huberman, Leshno, and Moallemi (2017), Cong, He, and Li (2018) investigate the Bitcoin mining structure, competition of mining pools, and its impact on transaction fees. These papers are important to understand speculative trading in the Bitcoin market and how Bitcoin transaction fees are determined. Our paper adds to the literature by providing the explanation of how these mechanisms generate pricing difference. In a contemporary paper Makarov and Schoar (2018) analyze spreads in an international sample of Bitcoin prices are relate these to signed order flow.

Our work is also related to a broad literature on bubbles and limits of arbitrage (see Xiong (2013) and Gromb and Vayanos (2010) for a survey). There are various constraints and limitations known in the literature to impede arbitrage trading. Among such constraints[5], risk (the

[4]Hu, Parlour, and Rajan (2018) provides several stylized facts on cryptocurreny markets as well as a survey of the literature on Bitcoin valuation.

[5]The constraints include information asymmetry, short-sale constraints, leverage margin constraints, constraints

price volatility in our case) and international trading frictions (the capital controls in our case) seem the most relevant to explain Bitcoin price differences. Specifically, we find that the Kimchi premium has a significant positive relation to Bitcoin price volatility and capital controls.[6]

There is one notable difference between our results and those from the traditional bubble literature investigating the joint effect of short-sale restrictions and heterogeneous beliefs in the stock market (e.g. Miller (1997), Harrison and Kreps (1978), Chen, Hong, and Stein (2002), Scheinkman and Xiong (2003), Hong, Scheinkman, and Xiong (2006), and Mei, Scheinkman, and Xiong (2009)). Under a short-sale constraint, the optimists are more likely to be marginal buyers and the stock price tends to reflect optimists' valuation more than that of pessimists, which leads to a bubble (meaning a higher value than the fundamental value). This conventional bubble literature predicts that the size of bubble is positively related to the volatility and the trading volume. Our result on volatility is in line with the literature, but trading volume differs from the previous literature in our case. There is short-sale restriction in the Bitcoin market. In particular, Bitcoin futures were introduced in the U.S. in early 2018, but not in Korea at the time of writing. In this sense, it might be natural to expect a positive relationship between the Kimchi premium and Bitcoin trading volume in Korean exchanges. While the bubble argument would suggest that volume and worldwide Bitcoin returns are positively correlated, it does not explain the Kimchi premium. Therefore, we strongly believe that the negative correlation indicates the importance of the Bitcoin microstructure for generating differential pricing, which is the crucial difference between Bitcoin and common stock markets.

Our paper is also closely related to a long literature on internationally dual-listed stocks (or Siamese twins) (see e.g., Rosenthal and Young (1990), Froot and Dabora (1999), De Jong, Rosenthal, and Van Dijk (2009), Gagnon and Karolyi (2010) and references therein) documenting occurrences of significant price differences in those stocks listed in two countries. Each of these papers finds that the price differences are attributed to tax, accounting, holding costs of

on equity capital, etc.

[6]See, e.g. Edwards (1999) on the effectiveness of capital controls

the stock like idiosyncratic risk[7], and so on. These factors, however, are unlikely to be relevant to the Bitcoin market. Rather our findings indicate that the Bitcoin microstructure amplifies the capital control effect on the price difference.

Finally, our paper is related to the purchasing power parity (PPP) puzzle literature in international economics.[8] Viewing Bitcoin as an internationally traded asset (or commodity), we can compare the Bitcoin price differential across countries with that of worldwide sold goods such as McDonald Big Mac sandwich[9] (Pakko and Pollard (2003) and Clements, Lan, and Seah (2012)). Our dataset has the unique advantage that we can provide evidence at a much higher frequency that much of the existing literature. There are several factors identified by the PPP literature which lead to an international price difference: transportation costs, sales (or value-added) taxes, trade restrictions (such as safety guard), domestic labor productivity (when there are non-tradeable goods such as services), government expenditure, and current account deficits. All of these factors are irrelevant to the Bitcoin market, except perhaps the transportation cost which plays a similar role as the transaction fee in the Bitcoin market. In the PPP case, the transportation costs always add nontrivial contributions to the PPP deviation. However, it is notable that the transaction fee effect on the Bitcoin price difference becomes negligible without capital controls as we find that the average Bitcoin price difference is near zero between Europe and US, between which there are almost no capital controls. Therefore, this discrepancy between the PPP case and the Bitcoin case also emphasizes the importance of the capital controls contributing to the Kimchi premium.

The rest of the paper is organized as follows: Section 2 presents the institutional background on Bitcoin microstructure and Korean capital controls, Section 3 details the data we use in our analysis, in Section 4 we compare the Korean and the European market in detail, Section 5 expands our sample internationally, in Section 6 we examine other cryptocurrencies, and Section 7 concludes.

[7]The idiosyncratic risk means the risk unrelated to the risk of other securities in either of the competing markets

[8]See, e.g., Rogoff (1996) and Taylor and Taylor (2004).

[9]The Big Mac price index is annually published by *Economist* since 1986.

2 Institutional background

2.1 Bitcoin microstructure

The microstructure of Bitcoin markets stands out in many ways from traditional markets. Transactions, i.e. the transfer from one wallet to another wallet, get posted within the Bitcoin peer-to-peer network in the mem-pool, from where miners pick transactions to be mined into a block, which gets then added to the blockchain. Many exchanges require a certain number of confirmations to credit Bitcoin that are transferred to the exchange to an account. A transaction with n confirmations means that this transaction has been included in a mined block and that there have been $n-1$ subsequent blocks mined in the blockchain. Time delay arises from the time it takes for a transaction to be included in a mined block and from the time it takes to mine the required number of subsequent blocks. The time to be included in a block, which is referred to as confirmation time, can vary substantially. The historic maximum of the daily median confirmation time is 47 minutes, for our sample the daily median confirmation time is 11 minutes on average.[10] Note that the confirmation for individual transactions can differ substantially from the median, especially when the tranmsactions offer low fees to the miners. The average time between successfully mined blocks is 10 minutes.

Transaction fees are endogenously determined in the Bitcoin network. When posting a transaction to the mem-pool the originator can set a fee that he or she is willing to pay to the miner for the transaction to be included in the block. Miners can select transactions from the pool and keep the fees upon successfully mining a block. Transactions with higher fees have a higher probability to be included in a block. An arbitrageur thus faces a tradeoff between offering a high fee that will get the transaction processed faster and mitigate price risk and the cost of the higher fee which will directly reduce the arbitrageur's profit.

When trading on Bitcoin exchanges another layer of delay arises. Most exchanges offer clients accounts similar to an account with a traditional stock broker. Trades are usually only

[10]source: `https://blockchain.info/`

possible between account holders at the same exchange and a trade is just recorded in the ledger of the exchange, not on the blockchain. The Bitcoin transferred from the seller to the buyer are held in the wallets of the exchange on the blockchain before and after the trade; the exchange just records a change of ownership in its internal records. Account holders can request a transfer to a private wallet out of the exchange account which will trigger a ledger entry on the blockchain. While there is no data available on processing times by exchanges, anecdotal evidence on several Bitcoin forums shows that processing times can be substantial with traders waiting up to several days before exchanges transfer Bitcoin from their exchange-account to a private wallet from which a transfer (to another exchange) can be initiated. In particular, 5-10 hours of processing time from a U.S. exchange to a Korean exchange is commonly reported by major mass media in Korea. For example, Chosun Ilbo, a Korean newspaper, tested the arbitrage and reported a processing time of 9 hours from Coinbase to Bithumb on December 26, 2017 when the Kimchi premium was about 28%.[11] Also, the deposit and withdrawal of fiat money can be subject to considerable delay. For example in Canada, processing times for deposits and withdrawals can take up to several months. In part the delay is caused by banks' refusal to deal with cryptocurrency companies. Quadriga, one of the two established exchanges in Canada has to rely on a Portuguese bank to process many of its fiat currency transfers.[12] In Figure 5 we present further anecdotal evidence from forum posts for Coinbase, a US exchange.

2.2 Capital Controls

On June 13, 2010, in the aftermath of the global financial crisis and the European sovereign debt crisis, Korea introduced capital controls that were revised several times since. The Korean foreign exchange transaction law has been very restrictive. According to the most recent

[11]Chosun Ilbo (Daily Chosun) is the # 1 news paper company in South Korea in terms of the total number of daily printing. See the following news article by the Chosun Ilbo on January 4: `http://news.chosun.com/site/data/html_dir/2018/01/04/2018010400441.html`.

[12]See article *'"I just want my money back." Couple had $100K wire stuck for months after trying to buy Bitcoin'*, GlobalNews, March 27, 2018.

law revision (valid since July 18th, 2017)[13], an individual can send money up to 3,000 USD per transfer and up to 20,000 USD in total between January 1st and December 31st through a particular financial institution. The total maximum is limited to 50,000 USD a year through different institutions.[14] There are several alternative ways to send cash abroad. First, one can use a Korean credit card when buying Bitcoin at an exchange in the US. However, the maximum amount of purchases outside of Korea is limited to 10,000 USD per year. In addition, this transaction is considered as commodity purchase, which means the buyer should pay customs on buying Bitcoin. One can send US dollars to someone (e.g., relatives or friends in the US) who can help arbitrage trading through Paypal. In this case, however, Paypal automatically reports this transaction to the US Internal Revenue Service (IRS) and the IRS normally considers this money inflow to the receiver as taxable income if the transfer amount is sufficiently large or the transfers occur on a regular basis. In addition, many Korean lawyers[15] say that under the current South Korean law it is not very clear if transferring Bitcoin between a Korean exchange and exchanges in other countries is considered as capital in- and out-flow or commodity export/import. This legal interpretation issue might pose an additional risk since the government might investigate transfer activities ex-post and accuse market participants of violation of the law depending on how they interpret the law.

So far, we have discussed on the legal restrictions that domestic Koreans face as capital controls. There is also difficulty for foreigners to open an account in Korean cryptocurrency exchanges. In order to do so, there are two requirements: a domestic bank account and a domestic cell phone number. In order to obtain them, foreigners need to go through several steps of permissions and/or recommendations from a government-endorsed institution or personnel. It is almost impossible to obtain them by just temporarily visiting South Korea. In Figure 5 we present anecdotal evidence from forum posts where people are actively seeking Korean partners

[13] See the government website on small foreign remitment: http://www.mosf.go.kr/nw/nes/detailNesDtaView.do?searchBbsId1=&searchNttId1=MOSF_000000000009556&menuNo=4010100.

[14] There are some exceptions. For example, the maximum per year is up to 100,000 USD for educational reasons such as tuition with proper evidence.

[15] See, e.g. http://hongbyun.tistory.com/22.

for arbitrage trading. One post suggests to meet in person at an airport to complete the arbitrage.

3 Data Sources and Model Variables

Bitcoin is very popular in Korea. As of February 1st, 2018, there are 16 cryptocurrency exchanges in South Korea. The five largest exchanges, in terms of trading volumes, are Upbit (#1 world ranking), Bithumb (#7), Coinone (#14), Korbit (#18), and Coinnest (#21).[16] Korbit was the first Korean Bitcoin exchange that opened in April, 2013. Then, Bithumb (January, 2014), Coinone (August 2014), Coinnest (July 2017) and Upbit (October, 2017) followed. Until Upbit started an exclusive partnership with Bittrex (a major U.S. based exchange) on October 2017, Bithumb, Coinone, and Korbit had been the three major exchanges.[17]

Our primary variable of interest is the Bitcoin premium in local currency over the Bitcoin price in USD. For Korea the KRW Bitcoin premium over USD, the Kimchi premium, is defined as

$$Premium_{KRW} = \frac{\text{KRW/BTC price} \times \text{USD/KRW exchange rate} - \text{USD/BTC price}}{\text{USD/BTC price}} \quad (1)$$

The premium for the European market is defined similarly based on EUR prices.

For daily Bitcoin prices in USD, KRW, and EUR we look at all transactions on specific Bitcoin exchanges (data accessed via bitcoincharts.com). Exchanges were selected due to data availability, length of trading history, and both current and historical market share. USD data is from Bitstamp. Bitstamp has offices in Luxembourg, London, and Berkeley. They are currently the 3rd largest exchange for USD trades by volume and have the longest trading history of the current major players. In the early days of Bitcoin trading the USD leader was Mt. Gox which famously went bankrupt following a security breach. The sample used for regressions runs

[16] The number inside the parenthesis is the world ranking in trading volumes (all the cryptocurrencies) by Coinhills on February 1st, 2018 (see `https://www.coinhills.com/market/exchange/`.

[17] Among the top three, Korbit is the only one which provides a history of all the trades in unix-time

from 2016-01-01 through 2018-02-28 and contains 13,151,367 total trades. The total notional value (valued at the time of each trade) is USD 33.9b. KRW data is from Korbit. Korbit was South Korea's first Bitcoin exchange. Korbit is fourth by volume for KRWBTC as of February 1, 2018, but has been second or third during the majority of the sample period. The sample contains 4,889,844 total trades with a total notional value (at the time of each trade) of KRW 14.2t. EUR data is from Kraken. Kraken is currently the largest exchange for EURBTC by volume, with more than half the total volume. The sample contains 15,349,375 trades with a total notional value (valued at the time of each trade) of EUR 19.1b.

The daily USD price we utilize for analysis is the mean price of all USD transactions on the Bitstamp exchange for that day. The KRW and EUR daily prices are similarly defined using Korbit and Kraken exchanges, respectively. To convert the KRW and EUR prices to USD we utilize data from OANDA. The daily prices utilized are the average price (not the close) over the 24-hour period (UTC time standard) aggregated from multiple exchanges. We find this the best fit for our purpose as the Bitcoin markets operate 24/7.

We estimate short term volatility for Bitcoin prices as the sum of 10 minute squared log-returns over one day. Microstructure noise can arise from spreads between bid and ask prices and from shifts in transaction prices due to the random execution of large trades at either end of the 10 minute interval. We take two measures to mitigate potential biases due to microstructure noise. First, we compute daily volatility for a given exchange as the average of two volatility measures, based on 10 minute returns shifting the time interval by 5 minutes. Second, we define volatility as the median volatility over several exchanges.[18] To test for robustness we also compute long term volatility for a given exchange as the sum of squared 12 hour returns over a period of 20 days. We then define long term volatility as the median volatility over several exchanges. Our results are robust with respect to this alternative volatility measure.

The Bitcoin blockchain median confirmation time data is from www.blockchain.info. This

[18] Data availability differs per time period as data is not available for all exchanges at all times. We include data from the following exchanges: bitfinex, Bitstamp, BTCC, btc-e, coinbase, Gemini, hitbtc, itbit, kraken, OK-Coin, Poloniex as available on bitcoinchain.com.

is the median time in minutes for a Bitcoin transaction to be accepted into a mined block and added to the public ledger; this number is computed only from transactions with miner fees and might therefore underestimate actual confirmation times. For days with missing data (of which there are none in the most recent 2 years) we interpolate linear between days. The maximum gap in the data set was 1 day. Results were unchanged when using the previous day's value or removing missing days completely from analysis.

The mean blockchain transaction fee is measured in USD and calculated from data from blockchain.info. It is the total value of all transaction fees paid to miners converted to USD (not including the value of block rewards), divided by the number of daily confirmed Bitcoin transactions on the blockchain for that day.

For the KRW and EUR volumes we look at the daily total number of exchange transactions (in thousands) on Korbit and Kraken respectively. This approach was taken rather than volume in Bitcoin due to the wildly differing Bitcoin prices at the start versus the end of the sample period. All results are robust to using an alternative volume measure of the daily USD equivalent total valuation of transactions. For the KRW-USD and EUR-USD foreign exchange volatilities we use the standard deviation of 1-day logarithmic returns in the daily average KRW-USD and EUR-USD exchanges from OANDA, over the most recent 20 days.

The 1-day Bitcoin return variable is the 1-day logarithmic return in the USD-BTC price, where USD-BTC daily price is calculated as described above for the Kimchi premium calculation. The FOMC week variable is a dummy variable which takes a value of 1 if that day is within 3 days of a US Federal Reserve Federal Open Market Committee (FOMC) meeting start date (one week centered on the start date of the FOMC meeting). Results are unchanged if a leading week is used instead of centered, and all FOMC meetings during the regression sample period were regularly scheduled (the last unscheduled meeting was in March 2014). The FOMC sets monetary policy for the US (including a target for the overnight interbank interest rate). Corbet, Larkin, Lucey, Meegan, and Yarovaya (2017) found that certain classes of digital assets (currencies, mineable), of which Bitcoin is a member, have volatility spillover transfer from

US monetary policy announcements. There is also a broad literature on the impact of FOMC meetings/announcements on the volatilty, returns, and trading volume of other assets both in the US and globally. For example, Fischer and Ranaldo (2011) found that foreign exchange trading volume was significantly increased on FOMC days, and Lucca and Moench (2015) document large average excess returns on US equities ahead of the monetary policy decisions made at scheduled FOMC meetings. The Bitcoin news in Korea variable is the total number of daily news articles published in Korea with keyword ”Bitcoin” from Factiva.[19] A summary of the variables used in our empirical analysis can be found in Table 8 in the appendix.

4 Empirical Results

To analyze the determinants of the Kimchi premium we regress daily observations of the relative price difference for Bitcoin in Korea and the US on several factors or proxies for potential frictions inhibiting the arbitrage. All Bitcoin for fiat currency transaction times are converted to UTC time standard. Days with missing trading data are excluded. All results were robust to testing on a sample with linear interpolation between missing days.

Regression results are shown in Table 1. Bitcoin price risk is a significant component to the Kimchi premium size. In periods of high volatility, the cost of waiting for blockchain confirmations could be very significant and deter arbitrageurs. Model (1) documents a positive relation between the Kimchi premium and short term BTC volatility. Model (2) shows that higher fees make the arbitrage less profitable and thus coincide with higher premia. As shown in model (3) higher median confirmation times on the block chain are also associated with higher Bitcoin premia. An arbitrageur could potentially jump the queue get her transaction processed faster by offering a higher transaction fee to miners, yet such a higher transaction fee would also cause a direct reduction in arbitrage profits and hence allow for a larger premium. Model (4) shows that higher volume by itself is associated with higher fees. Considering all these factors

[19]Bitcoin is . 비트코인 in Korean.

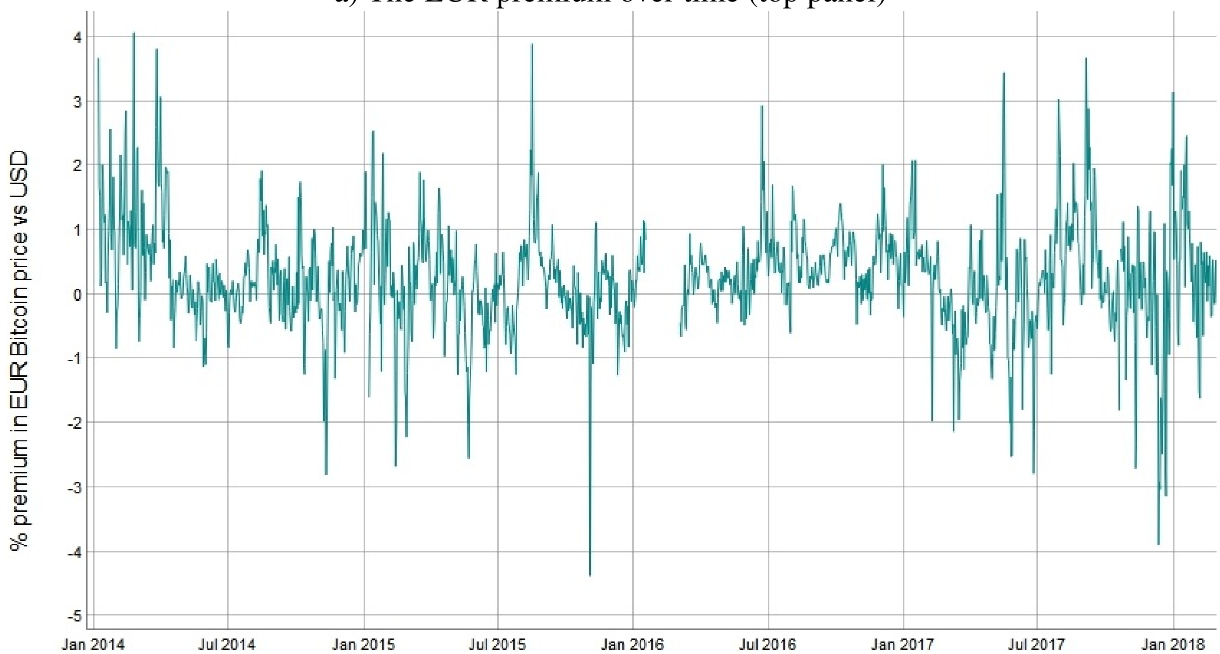
Table 1: Regression results for the KRW Bitcoin premium over USD. Daily time series regressions: the dependent variable is the premium for purchasing Bitcoin with Korean won (KRW) versus US dollars (USD) and is calculated: $(\text{KRWBTC}_{\text{price in USD}})/(\text{USDBTC}_{\text{price}})-1$, where the Bitcoin price in USD is the mean price of all USD transactions on the Bitstamp exchange for that day. The Bitcoin price in KRW is similarly defined with data from the Korbit exchange. Conversion from KRW to USD is done using the OANDA daily average rate. The independent variables are defined as in Table 8.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Bitcoin short term volatility	0.0667*** (0.0041)				0.0348*** (0.0047)	0.0374*** (0.0049)	0.0436*** (0.0051)
Mean blockchain transaction fee		0.0069*** (0.0003)			0.0065*** (0.0004)	0.0066*** (0.0004)	0.0069*** (0.0004)
Blockchain median confirmation time			0.0027*** (0.0007)		0.0006 (0.0006)	0.0005 (0.0006)	0.0004 (0.0006)
KRW-BTC volume (thousands of transactions)				0.0045*** (0.0003)	−0.0014*** (0.0004)	−0.0017*** (0.0004)	−0.0018*** (0.0004)
KRW-USD volatility					−0.4514 (1.9711)	−0.5734 (1.9664)	−0.8579 (1.9429)
Bitcoin 1-day lagged return						0.1353** (0.0589)	0.1249** (0.0581)
FOMC week							−0.0182*** (0.0055)
BTC news Korea							−0.0001*** (0.00003)
Constant	−0.0008 (0.0038)	0.0242*** (0.0022)	0.0172** (0.0087)	0.0195*** (0.0030)	0.0046 (0.0115)	0.0049 (0.0115)	0.0078 (0.0114)
Observations	788	790	790	790	788	788	788
R^2	0.2500	0.4525	0.0166	0.2261	0.4901	0.4935	0.5078

Note: *p<0.1; **p<0.05; ***p<0.01

Figure 3. The Bitcoin EUR Premium: Bitcoin sometimes trade at a higher price even between relatively frictionless markets (here EUR vs. USD) The premium for purchasing Bitcoin with Euros (EUR) versus US dollars (USD) is calculated: $(\text{KRWBTC}_{\text{price in USD}})/(\text{USDBTC}_{\text{price}}) - 1$, where the Bitcoin price in USD is the mean price of all USD transactions on the Bitstamp exchange for that day. The Bitcoin price in EUR is similarly defined from the Kraken exchange. Conversion from EUR to USD is done using the OANDA daily average rate.

a) The EUR premium over time (top panel)



b) Distribution of the EUR premium (bottom panel)

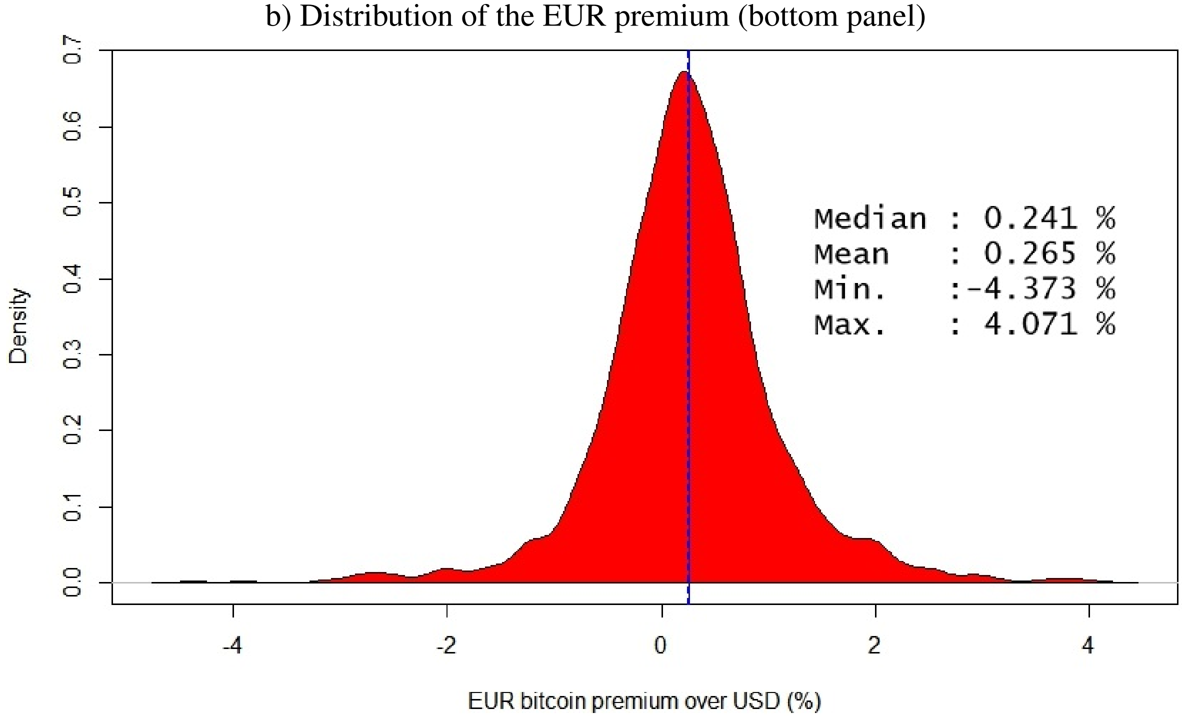


Table 2: Regression results for the EUR Bitcoin premium over USD. Daily time series regressions: the dependent variable is the absolute value of the premium for purchasing Bitcoin with Euro (EUR) versus US Dollars (USD) and is calculated: $(EURBTC_{\text{price in USD}})/(USDBTC_{\text{price}})-1$, where the Bitcoin price in USD is the mean price of all USD transactions on the Bitstamp exchange for that day. The Bitcoin price in EUR is similarly defined with data from the Kraken exchange. Conversion from EUR to USD is done using the OANDA daily average rate. The independent variables are defined as in Table 8.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Bitcoin short term volatility	0.0041*** (0.0003)				0.0042*** (0.0006)	0.0041*** (0.0006)	0.0040*** (0.0006)
Mean blockchain transaction fee		0.0003*** (0.00003)			0.0001*** (0.00003)	0.0001*** (0.00003)	0.0001*** (0.00003)
EUR-USD volatility					0.1623 (0.2682)	0.1536 (0.2673)	0.1514 (0.2675)
Blockchain median confirmation time			0.0001** (0.0001)		0.00001 (0.0001)	0.00002 (0.0001)	0.00002 (0.0001)
EUR-BTC volume (thousands of transactions)				0.0001*** (0.00001)	−0.00004** (0.00002)	−0.00004** (0.00002)	−0.00004** (0.00002)
Bitcoin 1-day lagged return						−0.0135** (0.0056)	−0.0135** (0.0056)
FOMC week							−0.0003 (0.0006)
Constant	0.0034*** (0.0003)	0.0055*** (0.0002)	0.0050*** (0.0007)	0.0047*** (0.0003)	0.0031*** (0.0011)	0.0031*** (0.0011)	0.0031*** (0.0011)
Observations	740	742	742	742	740	740	740
R^2	0.1619	0.1076	0.0062	0.0759	0.1880	0.1943	0.1945

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

we document in model (5) that only short term volatility and transaction fees stay significantly positive, while volume turns negative. Median confirmation time seems to be a similar proxy for bottlenecks in the blockchain to transaction fees and becomes insignificant. FX-volatility is not a driving factor behind the Kimchi premium as FX-volatility is substantially smaller than BTC volatility. Higher volume may help reduce the Kimchi premium through increased liquidity in the Korean Bitcoin market, while at the same time increase blockchain transaction fees and/or blockchain confirmation times (and potentially exchange cash-out times) thus reducing ability to arbitrage and increasing the Kimchi premium. In model (6) we find that a one day lagged BTC returns are associated with a higher Kimchi premium, perhaps because of momentum in BTC prices. Model (7) demonstrates that news events are important for the Kimchi premium, in particular, to reduce the premium. The reason is that there has been more negative news than positive news on average.[20] The premium is lower in weeks of FOMC meetings and when more news articles on Bitcoin get published in Korea.

To separate the effect of frictions emanating from within the microstructure of the Bitcoin network from Korea specific factors like the capital controls we perform a similar analysis for the European market. Figure 3 plots the relative price difference of Bitcoin in the EUR market relative to the USD market. Price differences are substantial, yet the divergence of Bitcoin prices is smaller than in the Korean market and fairly symmetric in its distribution (average 0.27%, minimum -4.37%, maximum 4.07%). In our regression analysis for the European market we explain the absolute value of the premium as we are are primarily interested in explaining the cause of price divergences.[21] Regression results for the EUR premium can be seen in Table 2.

The coefficients for the short term volatility, transaction fee, and confirmation time have the same sign but are at least ten times smaller than in the case of the Korean market. These

[20]Good Korean news on cryptocurrency trading could potentially drive up the Kimchi premium. However, our results on average indicate that there was more negative news. For example, the Korean government banned ICOs (Initial Coin Offerings) in September 29, 2017 and suddenly announced a policy to ban cryptocurrency exchanges (but retreated it within a day) in January 11, 2018. There were massive reports and discussions related to these announcements in the news articles, which turns out to have negative impact on the premium.

[21]In the Korean case, regression results are very similar for explaining the absolute premium since the premium is positive almost for the entire sample.

findings are consistent with an interpretation that Bitcoin price divergences are in part driven by microstructure effects within the Bitcoin network and that increased volatility makes arbitrage more risky and hence allows prices to diverge more. Yet the smaller amount of frictions in the European market facilitates arbitrage and hence price divergence is much smaller. Increased volume in European Bitcoin markets seems to be associated with smaller divergence but the effect is of small economic significance.

5 Bitcoin Premia and Financial Freedom

Comparing Korea to the Eurozone, the results in Secton 4 show that price divergences between markets exist and their magnitude is related to the microstructure of the Bitcoin network that creates time-varying costs which inhibit the arbitrage of price differences away. Our results also show that the premium is on average close to zero for the Euro-market while it is positive for the Korean market. We also see that the premium in Korea is at least ten times more sensitive to factors associated with arbitrage risk such as short term volatility, fees, or confirmation time. The anecdotal evidence suggests that this is due to the capital controls imposed by the Korean government. To examine in greater detail how open access to financial markets impacts Bitcoin premia we extend our analysis to an international sample and relate premia to measures of financial freedom.

We collect daily Bitcoin price at data for 22 countries from bitcoincharts.com. Since trading volume is low in some markets we take the median Bitcoin price in local currency per day. Due to data availability we restrict our sample from the beginning of 2015 to the end of our sample period on Feb 23, 2018. In cases of more than one exchange with available data we take the average price across available exchanges. Where available we use foreign exchange data from the Federal Reserve Bank in St. Louis, otherwise we use data from OANDA to convert local currency Bitcoin prices to USD. Premia are computed as in Section 4 as the percentage deviation from the USD price. Table 3 summarizes our sample. It can be seen that premia

Table 3. Summary statistics international sample: Median, mean, and standard deviation of Bitcoin premia in percent over the USD price for a sample of international markets collected from bitcoincharts.com. Column 3 shows the source of the foreign exchange data used to convert local currency Bitcoin prices to USD.

Country	ISO	FX-Data	number of observations	Premium (in %) median	mean	std.dev.
Argentina	ARS	OANDA	788	9.46	19.42	20.88
Australia	AUD	St. Louis Fed	788	0.96	1.37	2.38
Brazil	BRL	St. Louis Fed	788	4.41	5.54	5.53
Canada	CAD	St. Louis Fed	788	-0.02	-0.11	1.71
Chile	CLP	OANDA	683	2.56	3.50	5.81
Euro-Zone	EUR	St. Louis Fed	788	0.06	-0.02	0.86
Great Britain	GBP	St. Louis Fed	788	3.65	3.88	1.56
Hong Kong	HKD	St. Louis Fed	753	2.50	2.10	5.16
Israel	ILS	OANDA	787	0.57	0.80	3.34
India	INR	St. Louis Fed	788	2.63	3.80	6.20
Japan	JPY	St. Louis Fed	788	0.42	0.72	1.74
Korea	KRW	St. Louis Fed	788	1.39	2.97	6.42
Mexico	MXN	St. Louis Fed	788	5.58	6.29	3.61
Malaysia	MYR	OANDA	782	0.40	0.63	12.31
Nigeria	NGN	OANDA	543	20.45	26.35	24.69
Norway	NOK	St. Louis Fed	788	3.67	3.96	2.41
New Zealand	NZD	St. Louis Fed	788	6.75	6.95	3.66
Sweden	SEK	St. Louis Fed	788	5.38	5.51	2.26
Singapore	SGD	St. Louis Fed	747	-0.42	-0.49	1.26
Thailand	THB	St. Louis Fed	788	0.63	1.16	3.73
Venezuela	VND	OANDA	605	1.17	1.95	4.09
South Africa	ZAR	OANDA	613	6.84	7.74	4.48

vary by country. Nigeria stands out with a median premium of 20.45%, which is the result of high premia following an unexpected devaluation of the Nigerian Naira by President Buhari in June 2016. In the following ten months high premia are observed which could be the result of people buying Bitcoin as trust in the national currency erodes. In unreported results we repeat our regression analysis without Nigeria and find that our main findings still hold.

We use two indices to measure capital controls and other regulatory restrictions. First we take the economic Freedom Ranking (EFR) by the Fraser Institute. They aggregate 42 distinct variables in five major areas: size of government, the legal system and security of property rights, sound money, freedom to trade internationally, and regulation.[22] We used Germany as a proxy for the Euro area. Second we use an index on capital controls (CCI) by Fernández, Klein, Rebucci, Schindler, and Uribe (2015). They collect in great detail capital controls for a variety of financial instruments from stocks and bonds to other investments such as real estate. In our study we use their sub-index on restrictions of outflows of money market instruments, which is the shortest maturity bucket in their analysis.

Since our sample only comprises a bit more than two years and the indices of economic freedom and capital controls are only published annually (not available for 2018 yet), and do not vary much, we cannot use a fixed effect panel model as the fixed effect would absorb heterogeneity in economic freedom. We therefore use a random effects panel model with daily observations and year fixed effects to analyze the impact of economic freedom on Bitcoin premia. Table 4 presents our results. The general results without measures of economic freedom (column 1) show the same direction of effects as in our analysis of the Korean market. Higher volatility, longer confirmation time, and higher fees make it harder to complete the arbitrage, coinciding with higher premia.

As we would predict the EFR has a significant negative correlation (more freedom is associated with a lower Bitcoin premium), and higher capital controls are associated with higher premia, showing that countries with greater economic freedom have lower Bitcoin premia. In terms of the EFR, a move from the median (Turkey, score 6.83) to the 75% quantile (Peru, score 7.47) and to the top (Hong Kong, score 8.95) would result in a reduction of in its Bitcoin premium by 1.4 and 3.2 percentage points, respectively. Similarly, tighter capital controls coincide with higher bitcoin premia. Our findings are therefore consistent with the idea that Bitcoin premia are more likely to occur in countries that impose restrictions on financial markets.

[22] see www.fraserinstitute.org/economic-freedom/approach

Table 4: International Bitcoin Premia The dependent variable is the premium for Bitcoin with local currency (LC) versus US collars (USD) and is calculated: $(\text{LCBTC}_{\text{price in USD}})/(\text{USDBTC}_{\text{price}}) - 1$, where the Bitcoin price in USD is the mean price of all USD transactions on the Bitstamp exchange for that day. The Bitcoin price in local currency is the median price of exchanges on bitcoincharts.com. Conversion from LC to USD is done using FX data from the St. Louis fed and using the OANDA daily average rate. The independent variables are defined as in Table 8. Standard errors are clustered by country.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Bitcoin short-term	0.0130^{***}	0.0175^{***}	0.0176^{***}	0.0130^{***}	0.0175^{***}	0.0176^{***}	0.0130^{***}
volatility	(0.0030)	(0.0045)	(0.0044)	(0.0030)	(0.0045)	(0.0044)	(0.0030)
Blockchain median	0.0004		0.0004	0.0004		0.0004	0.0004
confirmation time	(0.0007)		(0.0007)	(0.0007)		(0.0007)	(0.0007)
Mean blockchain	0.0010^{**}			0.0010^{**}			0.0010^{**}
transaction fee	(0.0004)			(0.0004)			(0.0004)
Economic Freedom		-0.0216^{*}	-0.0216^{*}	-0.0216^{*}			
Ranking		(0.0126)	(0.0126)	(0.0126)			
Capital Controls					0.0348^{*}	0.0348^{*}	0.0348^{*}
Outflow					(0.0201)	(0.0200)	(0.0201)
Constant	0.0341^{**}	0.1936^{*}	0.1899^{*}	0.1913^{*}	0.0246	0.0209^{*}	0.0223^{**}
	(0.0142)	(0.1088)	(0.1034)	(0.1030)	(0.0160)	(0.0112)	(0.0108)
Observations	11,628	11,628	11,628	11,628	11,628	11,628	
R^2	0.0202	0.0599	0.0602	0.0646	0.0347	0.0350	

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

6 Other Cryptocurrencies

As a robustness check we analyze how the Kimchi premium is related to the premiums of other cryptocurrencies such as ethereum (ETH), ripple (XRP), and litecoin (LTX).[23] For example, if the ethereum premium (defined similarly to the Kimchi premium) in South Korea was lower than the Kimchi premium, one could undertake arbitrage by buying Bitcoin in a U.S. exchange, sending it to a Korean exchange, selling the Bitcoin to buy ethereum in the Korean exchange, sending those ethereum to the U.S. exchange, and selling those ethereum for a profit. Such a transaction would only involve cryptocurrencies and hence not be subject to government fiat capital controls. We can apply similar arguments to any cases when the ethereum price difference is not equal to the Bitcoin price difference in both countries.

We use the hourly closing price data in USD and KRW for Bitcoin (BTC), Ethereum (ETH), Litecoin (LTC), and Ripple (XRP) from CryptoDataDownload.com. For the KRW exchange Bithumb was used, and Kraken for the USD exchange. Exchanges were selected for ability to trade the desired cryptocurrencies, as well as volume, and the length of sample. Daily price for each cryptocurrency was calculated as the arithmetic mean of the hourly closing prices for each hour that day. The Kimchi premium for each cryptocurrency was then calculated as in Equation (1) for the main regressions. It should be noted that the trading days of January 11-13, 2018 are excluded from the sample as Kraken had a trading halt of approximately 48 hours due to a system upgrade and associated bugs which included those days. Results are robust to using a sample which utilizes Bitstamp data to replace those 3 days.

Consistent with the absence of arbitrage opportunities we find that premium differences across cryptocurrencies are very small. Table 5 shows that the average premiums across cryptocurrencies are very close to each other. The standard deviation tends to be higher if the premium is higher, which further mitigates the premium difference (when one wants to try arbitrage trading for such a small premium difference). Given that most exchanges in the world charge

[23]On May 16th, 2018, the total market cap of bicoin, ethereum, ripple and litecoin is about 143.0, 71.0, 27.9, and 7.9 Billion USD, respectively.

minimum 0.5% and up to 1-2% transaction costs, the premium differences are not enough to cover the the total transaction costs to execute the arbitrage. In addition, Table 6 shows that the correlation between the Kimchi premium and each cryptocurrency is very high. Similarly the pairwise correlation between all those premia are very high as shown by Table 7.

Table 5. Summary statistics of Korean cryptocurrency premia 2017-10-01 to 2018-04-30.

Statistic	N	Mean	St. Dev.	Min	Max
KRWBTCprem	209	0.072	0.100	−0.045	0.487
KRWETHprem	209	0.076	0.109	−0.044	0.550
KRWLTCprem	209	0.075	0.106	−0.045	0.525
KRWXRPprem	209	0.074	0.111	−0.044	0.535

Table 6. Regression of the Kimchi premium on other currency premia. 2017-10-01 to 2018-04-30. Jan 11, 12, 13 removed due to Kraken halting trading

	Dependent variable:		
	BTCprem		
	(1)	(2)	(3)
ETHprem	0.9108^{***}		
	(0.0080)		
LTCprem		0.9312^{***}	
		(0.0070)	
XRPprem			0.8864^{***}
			(0.0103)
Constant	0.0033^{***}	0.0028^{***}	0.0067^{***}
	(0.0011)	(0.0009)	(0.0014)
Observations	209	209	209
R^2	0.9841	0.9884	0.9726
Note:		$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$	

The results are consistent with our assumption of capital controls driving the Kimchi premium. If one of the other crypto currencies had no premium or a lower premium than Bitcoin

Table 7. Pairwise Correlation Matrix, Korean cryptocurrency premia. 2017-10-01 to 2018-04-30

	KRWBTCprem	KRWETHprem	KRWLTCprem	KRWXRPprem
KRWBTCprem	1	0.992	0.994	0.986
KRWETHprem	0.992	1	0.998	0.995
KRWLTCprem	0.994	0.998	1	0.994
KRWXRPprem	0.986	0.995	0.994	1

arbitrageurs could use that currency to move funds out of Korea and complete the arbitrage. Since cryptocurrencies are not subject to capital controls no arbitrage opportunities between cryptocurrencies should be possible. This implies that all crypto currencies should have very similar premia. Similar to the logic with Bitcoin other crypto currencies can trade at a premium since the arbitrage is restricted because of the capital controls. The analysis shows that the Kimchi premium is therefore not something unique to Bitcoin but rather a result of Korea's capital controls that prevent arbitrageurs from aligning Korean prices with those of the world market.

Anecdotal evidence shows that traders in Korea are closely following the premia in different cryptocurrencies. Figure 6 shows a typical cryptocurrency trading discussion website in South Korea. As seen in the screen shot and its description, Korean investors keep track of not only the Kimchi premium on Bitcoin but also other cryptocurrency premiums. If they find one premium is significantly lower (or higher) than another premium, they would sense it as the signal that the corresponding coin is under- or over-valuated within the Korean market, which leads to push up or down the coin premium. Consequently, the coin premiums are more and less the same in each time, as seen in the green number inside each parenthesis in Columns 3 to 7 in the table in the figure. Traders also watch out the premiums across major Korean exchanges. This mechanism would be a main reason why the Korean premiums stays more and less the same across cryptocurrencies over time.

7 Conclusion

We document that despite its global reach and absence of regulation Bitcoin and other cryptocurrencies can trade at substantial and persistent premia relative to other markets like the US. Comparing Korean and European markets we find that Bitcoin trades on average at a significantly higher price in Korea and that the premium that Korean investors have to pay is more sensitive to factors that make arbitrage more costly like transaction fees, confirmation times, and short term volatility. We argue that capital controls for fiat money is the main source of these frictions. Looking at an international sample we find that Bitcoin trades at a higher price in countries with less economic freedom. We also find that the trading volume is negatively associated with the Kimchi premium contrary to the prediction of the general stock market bubble literature, which confirms that the Bitcoin microstructure is important to understand the Kimchi premium.

It is notable that when Sangi Park, the Minister of Justice in Korea announced the ban of crypto-exchanges on January 11, 2018,[24] he concluded from the existence of the ”Kimchi premium” that cryptocurrecy trading in Korea is abnormal. Likewise, many Korean government officials often branded cryptocurrency traders as irrational and stated that the exchanges (or the way the exchanges are operated) contributed to the irrational Kimchi premium. The Korean government has continuously intervened in cryptocurrecy markets since the summer of 2017.[25]

We argue that capital controls imposed by the Korean government rather than behavioral explanations are the cause of the Kimchi premium. Instead of irrational traders or poorly functioning exchanges it seems that the Korean government is the main contributor to the Kimchi premium. Our paper also shows that the dream of a global currency that is free from government interventions remains an illusion.

[24] The fact that the head of the task force team on the cryptocurrency trading in the Korean government is the Minister of Justice, not the Minister of Finance implies that the Korean government considered cryptocurrecy trading as gambling.

[25] The timeline of the Korean government interventions are found in Section 2.타임라인 (Timeline) of the following website: https://namu.wiki/w/대한민국의 암호화폐 규제 논란.

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A Appendix - Theory

The appendix provides the theoretical background on our empirical conjectures. We model the arbitrage transaction as a real option exercise such as Brennan and Schwartz (1985) and McDonald and Siegel (1986).

A.1 Description

If the Kimchi premium is sufficiently high, each arbitrageur will buy bitcoins in an U.S. exchange, transfer them to the Korean exchange, and finally sell the bitcoins in the Korean exchange. We call all these three activities together 'arbitrage trading'. The whole process cannot take place immediately. Rather there is time delay about which we will discuss later.

Notice that due to the capital control imposed by the Korean government, each arbitrageur is allowed to transfer a limited amount of cash (dollars) from South Korea to the U.S. (or any other country) per year, which means one can execute the arbitrage transaction only finite number of times a year. Without loss of generality, we assume that one can execute the arbitrage transaction "only once", but instead he/she will fully exploit the cash transfer limit when executing it. In this sense, the arbitrage trading can be considered as an irreversible investment opportunity. It is important to note that this irreversibility arises from the capital control. Without the capital control, one can execute arbitrage trading infinitely times and thus there is no reason for arbitrageurs to wait to obtain the maximum profit by using one-time opportunity. This is the case of Europe and the U.S. between which the price differential is negligible over time.

Note that there are two types of risks when executing the arbitrage trading: (i) risk from the transaction time lag and (ii) risk in the fee to transfer a bitcoin from a wallet to a wallet. First, it takes time to send bitcoins from a wallet in a U.S. exchange to one in a Korean exchange. This time lag creates risk due to a high short-term volatility of the premium: the arbitrageur may fail to obtain the price differential because the premium may become negligible before the bitcoins arrive the arbitrageur's wallet in the Korean exchange. Second, in order to expedite the wallet-to-wallet transfer of bitcoin, one can pay extra fees to a miner. Then, it can shorten the time lag, but it is sometimes very costly in the sense that this transaction fee is not deterministic, but stochastically changing over time. There are other fees such as transaction fees paid to each exchange and the fee for currency exchange, which are also somehow time-varying. Note that we ignore these fees in our formal model in Section A.2.

Without loss of generality, we assume that arbitrageurs are *homogeneous* in terms of cost of executing the arbitrage trading since they are constrained under the same capital control. Note that our results will hold as long as there exists a significant number of cost-homogeneous arbitrageurs although there is no homogeneity in the whole population of arbitrageurs. If these cost-homogeneous arbitrageurs simultaneously execute the arbitrage trading, the premium suddenly drops down to a negligible level as a result of massive trading, which often appears as a spike in the time series of the premium as seen in Figure 1. Before then, the premium can keep increasing to a fairly high level since arbitrageurs should wait due to the short-term volatility risk. In other words, arbitrageurs delay to execute the arbitrage transaction until the premium becomes sufficiently high. In summary, we suggest the following predictions:

A. The higher the short-term volatility, the greater the Kimchi premium.

B. The higher the fee volatility, the greater the Kimchi premium.

C. Spikes in the premium time series tend to accompany with the massive influx of bitcoins into a Korean exchange.

First, note that statement B is not easy to test due to the data issue including endogeneity. An easier task is to simply consider the average fee in each block and investigate its impact on the premium. According to a standard real option argument, it is easy to see that as the cost of executing arbitrage trading becomes higher, the executions is further delayed. So, we suggest the following substitute statement:

B'. The higher the fee, the greater the Kimchi premium.

Second, also note that for statement C, we investigate whether there is massive influx of bitcoin into Korean exchange(s) before or near the spike. However, we do not have enough data period to see if it is the case. Instead, statement C is restated as the following statement.

C'. There is no massive influx of bitcoins into a Korean exchange (i.e., no arbitrage transaction is executed) in the times when the Kimchi premium is sufficiently small.

A.2 Formal Model

Now we provide a formal description of the model. We extend the delivery lag model of a real option suggested by Alvarez and Keppo (2002). Time is continuous. Arbitrageurs are risk-neutral and is endowed with one bitcoin in the U.S. exchange. They can execute only one arbitrage trading. The current time is $t = 0$ at which the Kimch premium is small enough so that no arbitrageurs are willing to trade. Suppose the Kimchi premium $X(t)$ (price differential) follows geometric Brownian motion:[26]

$$dX(t) = \mu X(t)dt + \sigma X(t)dB_t, \quad X_0 = x,$$

where B_t is a standard Brownian motion and μ and σ are positive constants.

We model the mean value of a wallet-to-wallet transaction fee to a miner $C(t)$ as follows.

$$dC(t) = \mu_c C(t)dt + \sigma_c C(t)(\rho dB_t + \sqrt{1-\rho^2}dB_t^c), \quad C_0 = c,$$

where B_t^c is a standard Brownian motion independent of B_t. Here μ_c and σ_c are positive constant. ρ is the correlation between $X(t)$ and $C(t)$.

[26]One can consider the arithmetic Brownian motion or mean reversion process. The result will not be changed.

Suppose the arbitrageur execute the arbitrage transaction at t. Then, at time $t+\Delta(X_t)$, his/her net profit will be

$$X(t+\Delta(X_t))-C(t),$$

where the time delay $\Delta=\Delta(x)$ is a function of the premium.

Then, the value function (expected profit) of the arbitrageur $V(x)$ is defined by

$$V(x):=\max_{\tau}\mathbf{E}\left[e^{-r\tau}(e^{-r\Delta(X(\tau))}X(\tau+\Delta(X(\tau)))-C(\tau))\,|\,X_0=x\right], \tag{2}$$

where r is the risk-free rate with $r>\mu$.

The problem will formally be the same if the cost is fixed (see, e.g.,McDonald and Siegel (1986)). Thus, without loss of generality we assume $C_t=C=1$. Instead of normalizing C_t as 1, later we will interpret the optimal threshold by using the ratio of $X(t)/C(t)$. With this assumption and using the Markov property, we rewrite (2) as

$$V(x)=\max_{\tau}\mathbf{E}\left[e^{-r\tau}(\pi(X(\tau))-1)\,|\,X_0=x\right]\quad\text{for all } t\geq 0, \tag{3}$$

where the profit function $\pi(x)$ is defined by $\pi(x):=xe^{-(r-\mu)\Delta(x)}$. Note that

$$\pi(X_t)-1\leq X_t-1,$$

which implies that the value from the time lag is smaller than the value without the time lag. This effect further delays the execution of the arbitrage trading, which can potentially generates a fairly high premium. Proposition 1 describes the optimal exercise strategy. Before we provide the proposition, we define $\lambda>0$ by the positive root of the following characteristic equation:

$$\frac{1}{2}\sigma^2\lambda(\lambda-1)+\mu\lambda-r=0.$$

Proposition 1 *Let $x^*(\sigma)$ is the solution to the following algebraic equation:*

$$e^{-(r-\mu)\Delta(x^*(\sigma))}\left((r-\mu)\Delta(x^*(\sigma))-\lambda\right)x^*(\sigma)=\lambda.$$

Assume that

(a) $\pi'(x) > 0$ *on* $(0, x^*(\sigma))$.

(b) $f(x) := x^{-\lambda}\pi(x)$ *attains a unique interior global maximum at* $x^*(\sigma)$ *and* $f'(x) < 0$ *on* $(x^*(\sigma), \infty)$.

Then, $x^*(\sigma)$ is the optimal exercise boundary. In other words, it is optimal to execute the arbitrage transaction if and only if X_t touches $x^*(\sigma)$. Moreover, $x^*(\sigma)$ is increasing in σ.

Proof. See Theorem 1 in Alvarez and Keppo (2002). ■

Proposition 1 provides several results under certain mathematical conditions. First, the risk from a time lag makes arbitrageurs wait to exercise. Therefore, they do not execute the arbitrage trading in the times when the premium is small. As a result, we tend not to observe the massive influx of bitcoins into a Korean exchange during those time. Second, the higher the volatility, the higher the threshold $x^*(\sigma)$ and thus the longer the arbitrageurs wait. Thus, a higher volatility causes a higher premium. Third, considering the fee normalization, we see that an increases in fee increases the threshold. This means that the higher the fee, the higher the premium.

A.3 Extension

We can extend the model to the case where the time until the bitcoin transfer from the U.S. exchange to the Korean exchange is determined by the transaction fee $aC(t)$ Dollars to a miner with $a \in [0, \infty)$ as well as the level of the premium. Here, $a > 0$ is a choice variable. In addition, assume $\Delta = \Delta(a, x)$ and

$$\frac{\partial \Delta(a,x)}{\partial a} < 0 \quad \text{and} \quad \frac{\partial \Delta(a,x)}{\partial x} > 0,$$

which means that an increase in a decreases the transaction time while an increase in x increases the transaction time. In this case, (2) is rewritten as

$$V(x) := \max_{a,\tau} \mathbf{E}\left[e^{-r\tau}(e^{-r\Delta(a,X(\tau))}X(\tau + \Delta(a, X(\tau))) - aC(\tau)) \,|\, X_0 = x\right]. \tag{4}$$

and (2) after the normalization of the average fee $C(t)$ is rewritten as

$$\max_{a,\tau} \mathbf{E}\left[e^{-r\tau}(\pi(a, X(\tau)) - a) \,|\, X_0 = x\right] \quad \text{for all } t \geq 0, \tag{5}$$

where the profit function $\pi(x)$ is defined by $\pi(x) := xe^{-(r-\mu)\Delta(a,x)}$. Note that there are two choice variables. Each arbitrageur will choose the optimal stopping time and the optimal fee to a miner. In conclusion, while this extension makes the algebra complex, it does not change the main results in Section A.2.

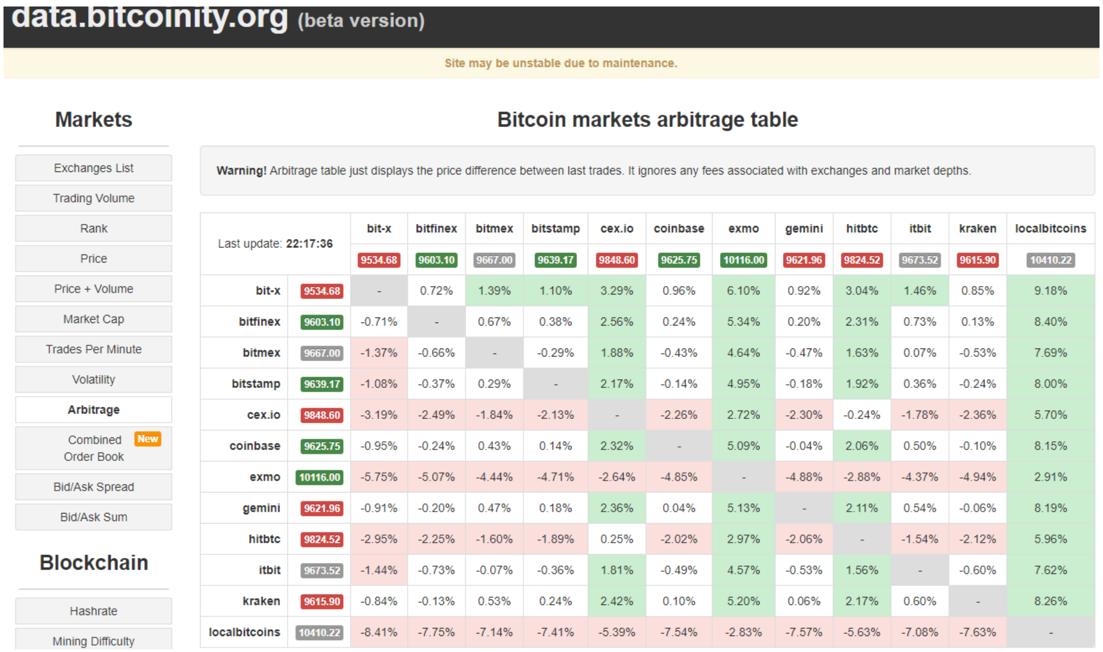
In addition to this extension, we can consider the idiosyncratic shock on the time lag $\Delta(a, x)$, which sounds more realistic. While we are not sure if this model is tractable, the intuition is clear based on a standard real option argument: this assumption creates more uncertainty in the model, which results in further delay and a higher Kimchi premium. Therefore, the theoretical results in Section A.2 are unchanged and even reinforced to favor our empirical results.

B Supplementary figures and tables

Table 8. Variable Definitions

Variable Name	Variable Definition
Kimchi premium (KRW premium over USD)	Calculated as $(\text{KRWBTC}_{\text{price in USD}})/(\text{USDBTC}_{\text{price}}) - 1$, where the Bitcoin price in USD is the mean price of all USD transactions on the Bitstamp exchange for that day. The Bitcoin price in KRW is similarly defined with data from the Korbit exchange. Conversion from KRW to USD is done using the OANDA daily average rate.
|EUR premium over USD|	The absolute value of $(\text{EURBTC}_{\text{price in USD}})/(\text{USDBTC}_{\text{price}}) - 1$, where the Bitcoin price in USD is the mean price of all USD transactions on the Bitstamp exchange for that day. The Bitcoin price in EUR is similarly defined from the Kraken exchange. Conversion from EUR to USD is done using the OANDA daily average rate.
Bitcoin short-term volatility	The sum of 10 minute USDBTC squared returns over one day. We define short-term volatility as the median volatility over several exchanges: bitfinex, bitstamp, BTCC, btc-e, coinbase, Gemini, hitbtc, itbit, kraken, OK-Coin, Poloniex.
Blockchain median confirmation time	The median time (in minutes) for a Bitcoin transaction to be accepted into a mined block and added to the public ledger (note: only includes transactions with miner fees). Source: *blockchain.info*. To interpolate missing days, the most recent known value is used (max gap in data set is 1 day).
KRWBTC volume	The daily total number of KRW and BTC exchange transactions on the Korbit exchange. Measured in thousands.
KRWUSD volatility	The standard deviation of 1-day logarithmic returns in the daily average KRWUSD exchange rate from OANDA, over the most recent 20 days.
EURBTC volume	The daily total number of EUR and BTC exchange transactions on the Kraken exchange. Measured in thousands.
EURUSD volatility	The standard deviation of 1-day logarithmic returns in the daily average EURUSD exchange rate from OANDA, over the most recent 20 days.
Mean blockchain transaction fee	Measured in USD. The total value of all transaction fees paid to miners converted to USD (not including the value of block rewards), divided by the number of daily confirmed Bitcoin transactions on the blockchain for that day. Source: *blockchain.info*.
Bitcoin 1-day return	One day log-return of the USD-BTC price.
BTC news Korea	The total number of daily articles published in Korea with keyword Bitcoin (비트코인) .

Figure 4. Bitcoin price differences across US exchanges: Screenshot from bitcoinity.org representing price differences in percent of Bitcoin across major US-Crypto exchanges.


data.bitcoinity.org (beta version)

Site may be unstable due to maintenance.

Markets

Exchanges List
Trading Volume
Rank
Price
Price + Volume
Market Cap
Trades Per Minute
Volatility
Arbitrage
Combined Order Book New
Bid/Ask Spread
Bid/Ask Sum

Blockchain

Hashrate
Mining Difficulty

Bitcoin markets arbitrage table

Warning! Arbitrage table just displays the price difference between last trades. It ignores any fees associated with exchanges and market depths.

Last update: **22:17:36**		bit-x	bitfinex	bitmex	bitstamp	cex.io	coinbase	exmo	gemini	hitbtc	itbit	kraken	localbitcoins
		9534.68	9603.10	9667.00	9639.17	9848.60	9625.75	10116.00	9621.96	9824.52	9673.52	9615.90	10410.22
bit-x	9534.68	-	0.72%	1.39%	1.10%	3.29%	0.96%	6.10%	0.92%	3.04%	1.46%	0.85%	9.18%
bitfinex	9603.10	-0.71%	-	0.67%	0.38%	2.56%	0.24%	5.34%	0.20%	2.31%	0.73%	0.13%	8.40%
bitmex	9667.00	-1.37%	-0.66%	-	-0.29%	1.88%	-0.43%	4.64%	-0.47%	1.63%	0.07%	-0.53%	7.69%
bitstamp	9639.17	-1.08%	-0.37%	0.29%	-	2.17%	-0.14%	4.95%	-0.18%	1.92%	0.36%	-0.24%	8.00%
cex.io	9848.60	-3.19%	-2.49%	-1.84%	-2.13%	-	-2.26%	2.72%	-2.30%	-0.24%	-1.78%	-2.36%	5.70%
coinbase	9625.75	-0.95%	-0.24%	0.43%	0.14%	2.32%	-	5.09%	-0.04%	2.06%	0.50%	-0.10%	8.15%
exmo	10116.00	-5.75%	-5.07%	-4.44%	-4.71%	-2.64%	-4.85%	-	-4.88%	-2.88%	-4.37%	-4.94%	2.91%
gemini	9621.96	-0.91%	-0.20%	0.47%	0.18%	2.36%	0.04%	5.13%	-	2.11%	0.54%	-0.06%	8.19%
hitbtc	9824.52	-2.95%	-2.25%	-1.60%	-1.89%	0.25%	-2.02%	2.97%	-2.06%	-	-1.54%	-2.12%	5.96%
itbit	9673.52	-1.44%	-0.73%	-0.07%	-0.36%	1.81%	-0.49%	4.57%	-0.53%	1.56%	-	-0.60%	7.62%
kraken	9615.90	-0.84%	-0.13%	0.53%	0.24%	2.42%	0.10%	5.20%	0.06%	2.17%	0.60%	-	8.26%
localbitcoins	10410.22	-8.41%	-7.75%	-7.14%	-7.41%	-5.39%	-7.54%	-2.83%	-7.57%	-5.63%	-7.08%	-7.63%	-

Figure 5. Sample forum posts on reddit.com illustrating (top) delays/problems with cryptocurrency exchanges and (bottom) knowledge of and attempts to arbitrage the Kimchi premium.

Coinbase/GDAX Warning - $50,000 Wire DEPOSIT Missing Since December 12th (self.CryptoCurrency)[a]

submitted by Reddit user four95 on January 4 2018

Verified account. US account. I've wired tens of thousands to it before. Suddenly, a $50,000 wire is still not credited with no resolution or support from Coinbase. It's been 3 weeks.

Check my post history. I've sent wire documents, had the bank trace the wire (Coinbase has the money), forwarded these documents to Coinbase support, and still get no help. I request a direct contact number for support, no reply. No help through phone support. I'm pretty much getting a "kick rocks" treatment by Coinbase.

Everyone thinks this kind of stuff won't happen to them until it does.

EDIT: Upvoting for visibility would be greatly appreciated. Perhaps then someone from Coinbase can help resolve the issue. Thank you.

~~Edit #2: Case ******~~

Edit #3: **Woke up to a reply from support and the money in my account! I love you reddit. I hope Coinbase can fix their support system soon so this stuff doesn't happen, and when it does there is at least a steady line of communication regarding the status.**

Looking for Arbitrage partner? Use this Thread instead of Spamming this Board with Ads (self.CryptoKorea)[b]

Reddit user 40x15y posted on January 10 2018:

Hello I am looking for a Korean partner to do arbitrage with. I am based in Manila, Philippines. I plan to do continuous trading with you. We can start at 0.05btc and work our way to 1btc in 20 cycles, while alternating who first sends money or btc to equalize both our risks. I can also trade with you via face to face meeting in Seoul or in Philippines. I am doing this business for long term so our business relationship is important to me. If you are interested please email me at ****@****.com.

Reddit user puffpuffnpass posted on January 11 2018:

Hi guys I'm from Hong Kong, looking for arbitrage partners. I have already traded with 4 Koreans and all we continue to cycle twice a week meeting in the airport,flying to each other, earning the spread happily. Looking to expand now!! Only few hours of flight, we can always meet to build trust Contact: ****@****.com Telegram id: ****

[a] `https://www.reddit.com/r/CryptoCurrency/comments/7o0t2l/coinbasegdax_warning_50000_wire_deposit_missing/`

[b] `https://www.reddit.com/r/CryptoKorea/comments/7pe1sk/looking_for_arbitrage_partner_use_this_thread/`

Figure 6. Other Korea premiums for major cryptocurrencies: The figure is a screenshot from www.ppopmppu.co.kr, which is a typical cryptocurrency trading discussion forum site showing real time premium differences across Korean exchanges. The first column is the name of each coin. The second column is the USD Bitfinex prices with Korean KRW inside the parenthesis. Columns 3 to 7 present the KRW prices at Upbit, Bithum, Coinone, Korbit, and Gopax, respectively. The green number inside each parenthesis in Columns 3 to 7 is the Korea premium of the corresponding coin. The sentence below the table says that the price information is updated every 40 seconds. The current exchange rate (KRW/USD) is at the bottom right corner (1075.3 KRW/$ at 18:01 pm, May 11th, 2018). Check `http://www.ppomppu.co.kr/zboard/crypto_exrate/crypto_exrate.php?cmd=popup` for the real time information.

www.ppomppu.co.kr/zboard/crypto_exrate/crypto_exrate.php?cmd=popup

Search

가상화폐 시세 및 한국프리미엄 정보

PPOMPPU

설정

* 한국거래소 (%)는 해외거래소 기준 한국프리미엄입니다

코인	Bitfinex	(원화 / 24시간 변동률)	업비트		빗썸		코인원		코빗		고팍스	
BTC	$8,703	(9,357,906 / +2.02%▲)	9,816,000	(4.90%)	9,825,000	(4.99%)	9,816,000	(4.90%)	9,830,000	(5.04%)	9,835,500	(5.10%)
BCH(BCC)	$1,478	(1,589,293 / +0.61%▲)	1,667,000	(4.89%)	1,670,000	(5.08%)	1,670,000	(5.08%)	1,670,000	(5.08%)	1,677,000	(5.52%)
ETH	$735	(790,432 / +6.71%▲)	828,200	(4.78%)	828,500	(4.82%)	828,900	(4.87%)	829,150	(4.90%)	830,000	(5.01%)
ETC	$18.87	(20,286 / +3.22%▲)	21,250	(4.75%)	21,300	(5.00%)	21,300	(5.00%)	21,300	(5.00%)	-	
XRP	$0.74	(795 / +7.44%▲)	834	(4.92%)	835	(5.05%)	833	(4.79%)	834	(4.92%)	833	(4.79%)
DASH	$418	(449,647 / +3.01%▲)	469,950	(4.52%)	469,000	(4.30%)	-		-		-	
LTC	$145	(156,101 / +1.76%▲)	163,700	(4.87%)	163,600	(4.80%)	164,050	(5.09%)	-		163,800	(4.93%)
XMR	$209	(224,727 / +3.30%▲)	236,100	(5.06%)	235,700	(4.88%)	-		-		-	
ZEC	$261	(280,546 / +5.76%▲)	298,900	(6.54%)	295,500	(5.33%)	-		-		292,000	(4.08%)
QTUM	$17.51	(18,829 / +7.23%▲)	19,820	(5.27%)	19,750	(4.89%)	19,740	(4.84%)	-		19,800	(5.16%)
BTG	$59.43	(63,905 / +4.20%▲)	66,610	(4.23%)	67,500	(5.63%)	196,800	(207.96%)	-		-	
EOS	$14.67	(15,778 / +3.55%▲)	-		16,670	(5.65%)	16,640	(5.46%)	-		16,725	(6.00%)

*시세 및 한국프리미엄 정보 자동업데이트 주기는 약 40초이며, 참고용으로만 사용해주세요

환율 : 1075.3원 (2018.05.11 18:01 기준)