Trading and Illiquidity in Cryptocurrency

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June 25, 2021

Abstract

Bitcoin markets exist huge price gaps and liquidity deviations. Some trading platforms are more liquid than others. Liquidity momentum and price gaps exist persistently between exchanges. This paper studies the relationship between price gaps and liquidity deviations. And it shows that they are positively correlated with each other. By applying the Google search index to capture the public attention towards the Bitcoin market, the liquidity factors model implies that the liquidity level is positively correlated with the Google search index. Moreover, the Tesla announcements event study focuses on how the Bitcoin market reacts to exogenous shocks. It documents that liquid Bitcoin exchanges become more liquid, and illiquid Bitcoin exchanges tend to be more illiquid during the news-impacting periods.

1 Introduction

Bitcoin has attracted public attention since the beginning of 2021. The rapid growth and subsequent fall of its price over a short period became the news headline. On February 8, 2021, the Bitcoin price increased by 4,000 US dollars after Tesla announced that it had purchased 1.5 billion US dollars worth of Bitcoin. High volatility has become one of the major characteristics of Bitcoin. As one of the most well-known and liquid cryptocurrencies, Bitcoin is built on blockchain technology. It requires no verification for payments and transactions. Even though it has a relatively short history, the Bitcoin market has evolved dramatically. There are more than 200 exchanges of Bitcoin worldwide. The price of Bitcoin has surged from 5,000 US dollars in July 2017 to 60,000 US dollars in April 2021. Enormous attention has been paid to such dramatic price change.

Moreover, Bitcoin exchanges in different countries are independent and non-integrated. Persistent price differences and liquidity gaps exist between exchanges. For instance, the average price deviation between Bitstamp (USA) and Bitx (South Africa) is 1005.13 US dollars from July 2020 to May 2021. Due to the absence of a centralized custodian in the cryptocurrency market, investors will have more incentive to trade in a more liquid market. A more liquid market implies more arbitrageurs, which can enhance the efficiency of the market. The tendency leads to market liquidity momentum: the liquid market keeps a high liquidity level, and the illiquid market tends to be less liquid. However, few papers study the correlation between price deviations and liquidity deviations and how the market liquidity level reacts to exogenous shocks. This paper attempts to fill in this gap.

In the following, the stylized facts of liquidity measures in different exchanges are presented. Six liquidity measures are introduced, which are the number of transactions (TX), the trading dollar volume ($Vol), the Amihud ratio (Amihud), the Kyle and Obizhaeva ratio (KO), the Abdi and Ranaldo ratio (AR), and the Roll serial covariance ratio (Roll). The hourly liquidity measures across eight countries are applied for analysis. These six measures reflect similar results: some exchanges are much more liquid than others, and this pattern keeps existing. The liquidity level of exchange shows no time series increasing or decreasing trend overall. Liquid exchanges keep to be liquid, and most illiquid exchanges do not have

an apparent trend to become liquid.

Second, global liquidity measures are constructed by applying the Paasche liquidity index. The number of transactions (TX) and the trading dollar volume ($Vol) measure the liquidity level of the market. The higher the value, the more liquid the market. However, the Amihud ratio (Amihud), the Kyle and Obizhaeva ratio (KO), the Abdi and Ranaldo ratio (AR), and the Roll serial covariance ratio (Roll) describes the illiquidity level of the exchanges. The higher the value, the more illiquid the market. These liquidity measures can only describe the liquidity level in a single trading platform. The Paasche liquidity index presents the global liquidity level of the Bitcoin market by combining the dollar trading weighted liquidity measures in eight exchanges. The Paasche liquidity measures also show that trading in the Bitcoin market was active from July 2017 to July 2018. Then the market became less liquid from July 2018 to July 2020. Finally, after July 2020, it became booming again.

Third, the paper shows the relationship between the price deviations and liquidity deviations across exchanges. The price deviations apply the price at Bitstamp (USA) as a benchmark. They are calculated by using the Bitcoin price at other exchanges to subtract the Bitcoin price at Bitstamp (USA). And the liquidity deviations are also calculated by subtracting the liquidity level at Bitstamp (USA). After controlling the price momentum, time fixed effect, and exchange fixed effect, the price deviations are positively correlated with the liquidity gaps. One possible explanation is that capital controls in different countries result in price inefficiency and persistent illiquidity. Foreign capital is hard to flow in/out, which leads to inefficient arbitrage. As a result, the price gaps and high illiquidity levels usually coexist.

Fourth, this paper documents a liquidity factors model. It indicates that the liquidity level is positively correlated with the Google search index. The Google search index refers to the regional searching trend for the keyword "Bitcoin". A higher Google search index means the public puts more attention on the Bitcoin market. After controlling the time fixed effect, exchanges fixed effect, and liquidity momentum, the coefficients of the Google search index are still significantly positive.

Finally, the Tesla event study focuses on the abnormal liquidity during the news-impacting period. Use the predicted value of the liquidity factors model as a benchmark; the abnormal

liquidity can be calculated. Different stories happen in the liquid and illiquid markets. For Bitstamp (USA), one of the most liquid exchanges worldwide, the market became more liquid when the news hit the market. However, Kraken (Canada), a less liquid market, became more illiquid during the events. One possible explanation is that capital tends to flow into a more liquid market when exogenous shocks appear since a more liquid market means higher efficiency.

The paper is related to several streams of literature. Studies related to cryptocurrency liquidity are still infant comparing with the traditional financial markets. Low frequency liquidity measures have been discussed more in the stock market. Roll (1984) introduced the serial covariance liquidity estimator. Amihud (2002) constructed the Amihud illiquidity measure based on price impact. Abdi and Ranaldo (2017) formed a low frequency liquidity measure by focusing on the high and low prices. Kyle and Obizhaeva (2016) uses the return volatility to capture the liquidity benchmark. All of these liquidity measurements capture the liquidity level from different perspectives. Brauneis et al. (2021) studies the efficiency of liquidity measures by comparing the low frequency measures with high frequency liquidity estimators in cryptocurrency markets. It shows that even the low frequency measures are not as efficient as the high frequency estimators, certain low frequency measures can capture the liquidity level well in exchanges with specific characteristics, like Amihud (2002) and Kyle and Obizhaeva (2016) are suitable to describe the liquidity level in the most liquid exchanges. In this paper, I apply six different liquidity measures and construct a compound illiquidity measure by calculated the unweighted average of these measures. The momentum study in the Bitcoin market is related to a series of papers such as Moskowitz and Grinblatt (1999) and Jegadeesh and Titman (1993). Several researches have started to apply the Google search index to simulate public attention, like Asness et al. (2013) and Da et al. (2011). Also, several papers focusing on the event study of cryptocurrency are introduced. Yue et al. (2021) shows that cryptocurrency liquidity increases (decreases) after positive (negative) news announcement, and the effects of positive news are more persistent. Larisa Yarovaya and Jalan (2021) shows that the herding behavior in cryptocurrency markets has no amplification effect by imposing COVID-19 as a "black swan" event.

The rest of the paper is organized as follows. Section 2 and section 3 introduce the data

and provide summary statistics of the liquidity measures, price deviations, and liquidity deviations across exchanges. Section 4 presents the study focusing on the correlation between price deviations and liquidity level deviations; and the liquidity level factors analysis. In section 5, the Tesla event study is discussed to study the abnormal liquidity level when the Bitcoin market is hit by big news and compare the differences of the abnormal liquidity between the liquid Bitcoin market and the illiquid Bitcoin market. Section 6 concludes.

2 Data Description

Bitcoin historical trading data is from the bitcoincharts website, which applies APIs by the exchanges to extract the historical trading data in different trading platforms. It contains the information of every transaction: trading time in UTC, Bitcoin price in local currency, and trading amount of Bitcoin. The data series ranges from July 1, 2017, to May 17, 2021. However, data after April 2021 at Korbit (Korea) is not recorded.

By applying the data, I construct hourly liquidity measures. In order to analyze the difference between exchanges in different countries, eight trading platforms are included: Kraken (Canada), Bitbay (Poland), Bitx (South Africa), Btcmarkets (Australia), Bitstamp (USA), Korbit (Korea), Kraken (EU), and Zaif (Japan). Trading of Bitcoin in different regions only accepts the local currency. For example, Kraken in Canada only accepts the Canadian Dollar, Bitbay in Poland accepts the Poland Zloty, and Bitx in South Africa needs the South African Rand for trading. To compare the price in different exchanges, prices are all transferred into US Dollar. The spot exchange rates in units of US dollar per foreign currency are from the Bank for International Settlements. We focus on seven currencies: Canadian Dollar, Poland Zloty, South African Rand, Australian Dollar, Euro, South Korean Won, and Japanese Yen. Consistent with the Bitcoin historical trading data, the spot exchange rate is daily data from July 1, 2017, to 17 May, 2021.

By focusing on the keyword "Bitcoin", Google search indexes in Canada, Poland, South Africa, Australia, USA, Korea, EU, and Japan are downloaded. For European Union, I use the unweighted average value of the google trend indexes in all Euro-using countries.

3 Summary Statistics

3.1 Measure of liquidity

In order to measure the liquidity level of Bitcoin in different trading platforms, six measurements are introduced, which are the number of transactions (TX), the trading dollar volume ($Vol), the Amihud ratio (Amihud), the Kyle and Obizhaeva ratio (KO), the Abdi and Ranaldo ratio (AR), and the Roll serial covariance ratio (Roll). TX and $Vol measure the absolute value of average transactions and trading volume. The higher the value of them, the more liquid the market. However, for Amihud, KO, AR, and Roll, they are illiquidity ratios. The higher the value, the more illiquid the market.

3.1.1 The number of transactions (TX)

The number of transactions captures the unweighted average transactions number that happened in a given period:

$$TX_t = \frac{1}{N} \sum_i TX_{t,i}$$

In the formula, N represents the number of transactions in a given period. When the trading platform has more transactions in the given period, we could say that the exchange is more active and liquid. As a result, the higher the value of TX, the more liquid the market.

For the data from July 2017 to May 2021, the minimum value of the hourly TX index is 0, and the maximum is 489. And the average value of the TX index differs across exchanges. The average value of the TX index at Zaif (Japan) is 45.8. However, the average value at Kraken (Canada) turns to be 2.6.

Figure 1 shows the hourly TX index in 8 different exchanges: Bitbay (Poland), Bitstamp (USA), Bitx (South Africa), Btcmarkets (Australia), Kraken(Canada), Korbit (Korea), Kraken (EU), and Zaif (Japan). Systematic divergence of TX index exists across exchanges. The TX index value is much higher in Bitstamp (USA), Kraken (EU), and Zaif (Japan). However, for Bitbay (Poland), Btcmarkets (Australia), and Kraken (Canada), the value of the TX index is low overall. Also, there is no apparent trend for the TX index across exchanges from the time series perspective. For exchanges with relatively low TX, their TX

values keep being tiny as time goes by.

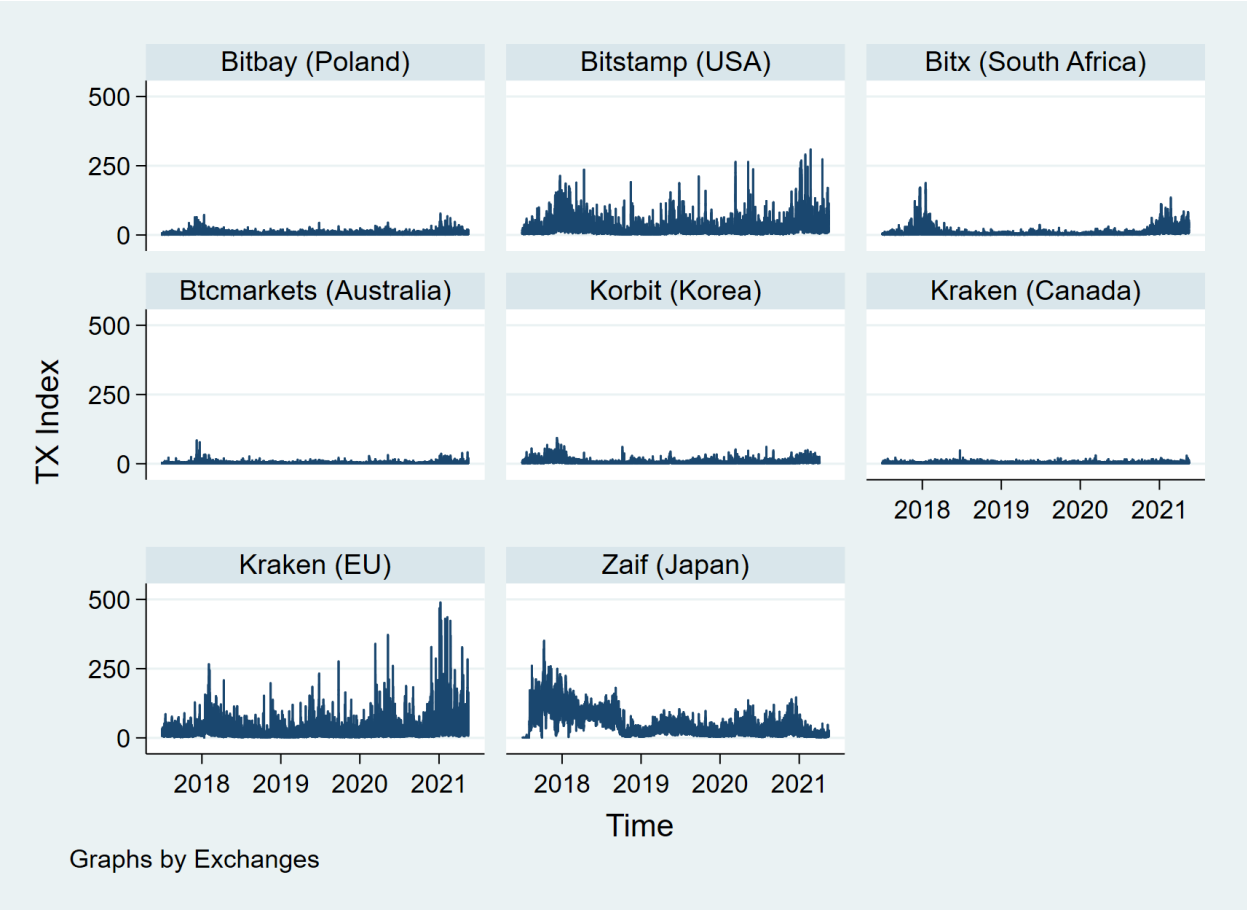

Figure 1: Hourly TX Index in Different Exchanges

3.1.2 The trading dollar volume ($Vol)

The trading dollar volume describes the unweighted average trading volume in the US dollar in a given period:

$$\$Vol = \frac{1}{N} \sum_{i} \$Vol_{t,i}$$

Similar to TX, $Vol measures the activeness of the market from the trading volume view. The higher the $Vol, the more capital inflows and outflows in the exchange and the more liquid the exchange. Exchanges in different countries use local currency to trade. To compare the trading volumes in different exchanges, all trading volumes are transferred to US Dollar. The transfer will not influence the comparison because the volatility of exchange rates is

much smaller than the Bitcoin price volatility. For the eight exchanges' Bitcoin data from July 2017 to May 2021, the maximum value of hourly $Vol is 4125142 US dollars, and the minimum is 0. The hourly $Vol varies dramatically across exchanges.

Figure 2 displays that the trading dollar volume varies across exchanges. Bitstamp (USA) and Kraken (EU) have higher dollar trading volumes. In contrast, trading in other exchanges is relatively inactive. For Zaif (Japan), it has a high TX index but a low $Vol index. One explanation is that trading in Zaif (Japan) is active, but each transaction's trading volume is tiny. TX index and $Vol index describe liquidity from different perspectives.

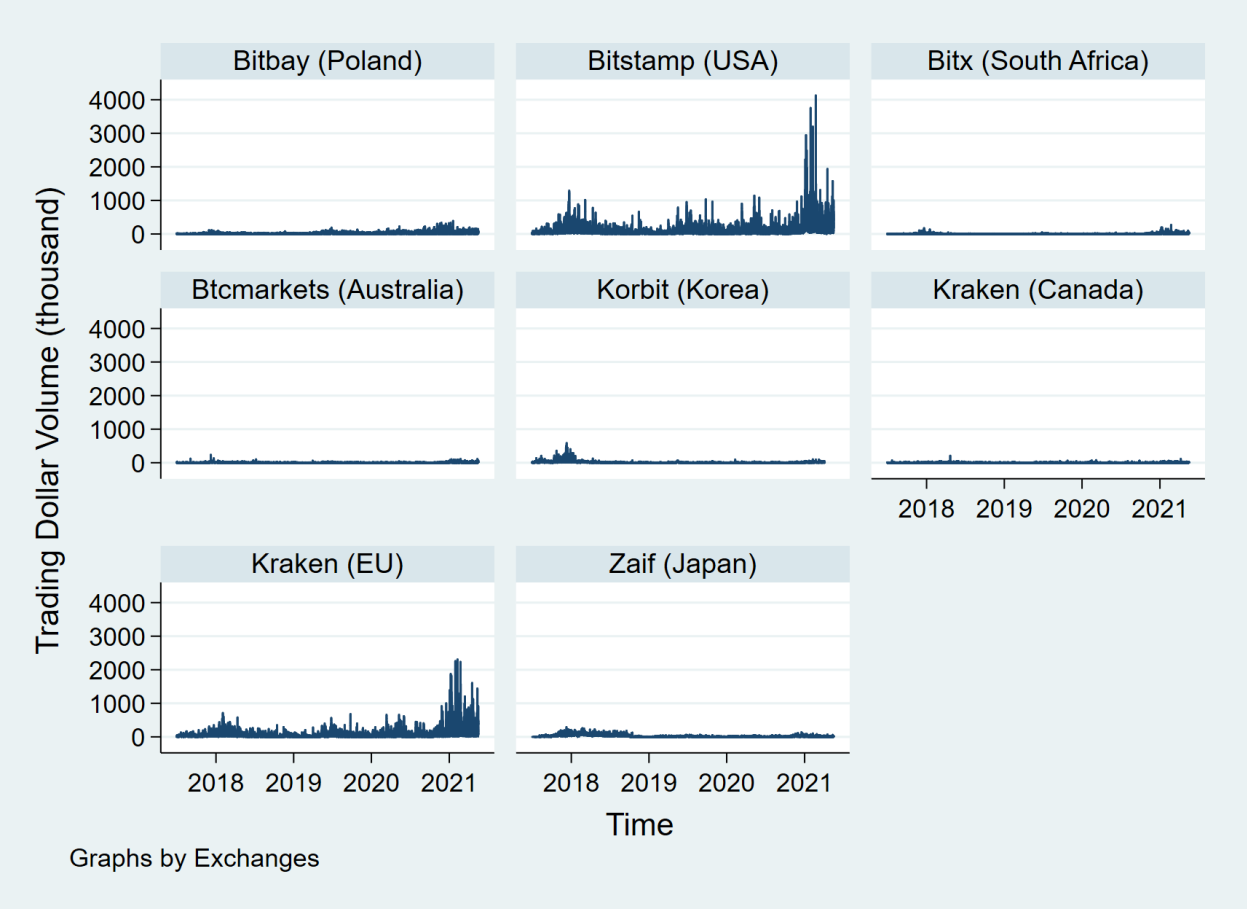

Figure 2: Hourly $Vol Index in Different Exchanges

3.1.3 The Amihud ratio (Amihud)

The Amihud ratio applies the unweighted average of the return of open price to close price in a time interval divided by the dollar trading volume. It can be calculated by

$Amihud_t = \frac{1}{I}\sum_i \frac{|C_{t,i}/O_{t,i}-1|}{\$Vol_{t,i}}$. $C_{t,i}$ is the close price, and $O_{t,i}$ is the open price.

Different from TX and \$Vol, the Amihud ratio is an illiquidity measure. It measures the price impact. The higher the value, the more illiquid the market. The maximum value of the Amihud ratio is 7.06e-5, and the minimum is 0. As the Amihud value is too small, it is multiplied by 10e6 in the following analysis.

Figure 3 presents the Amihud index in different exchanges. Bitstamp (USA), Kraken (EU), and Zaif (Japan) have lower Amihud index values, which indicates these markets are liquid. Furthermore, Bitbay (Poland), Kraken (Canada), and Btcmarkets (Australia) are more illiquid as they have a higher Amihud index. For all exchanges, the Amihud value tends to be smaller after 2021. Especially for the Kraken (Canada), it shows a decreasing trend for its Amihud value as time goes by.

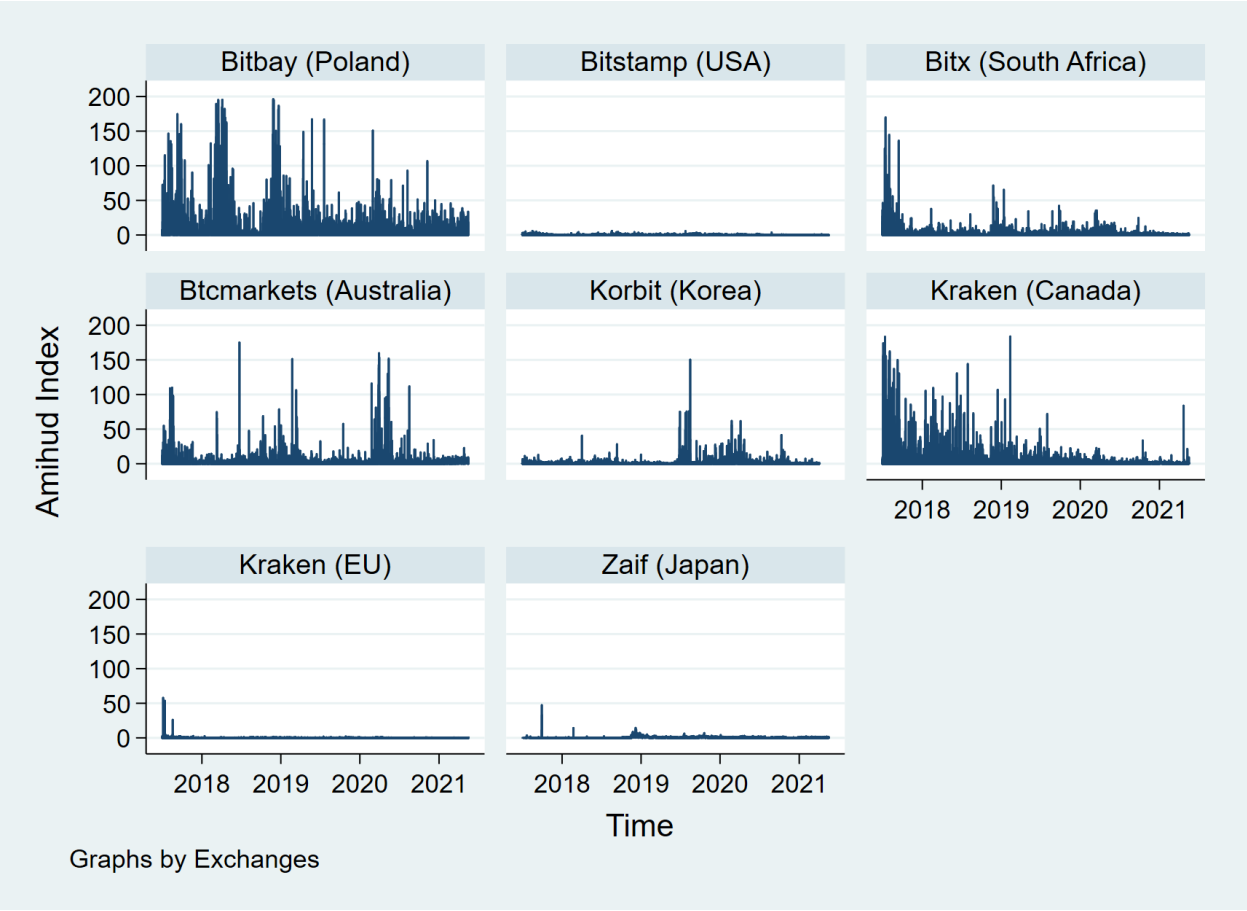

Figure 3: Hourly Amihud Index in Different Exchanges

3.1.4 The Kyle and Obizhaeva ratio (KO)

The Kyle and Obizhaeva ratio uses the ratio of volatility to dollar volume to capture the liquidity level: $KO_t = [\frac{\overline{\sigma^2_{t,i}(r)}}{\sum_i \$Vol_{t,i}}]^{1/3}$. The $\overline{\sigma^2_{t,i}(r)}$ represents the mean of the squared returns in a given time interval.

KO ratio captures the illiquidity level by focusing on the volatility. The higher the value, the more illiquid the market. Similar to the Amihud, its original value is very tiny. As a result, it is multiplied by 10e4 in the following studying.

Figure 4 shows that the KO index values at Bitstamp (USA), Kraken (EU), and Zaif (Japan) are low, which means the liquidity levels in these exchanges are relatively high. Furthermore, Kraken (Canada), Bitbaay (Poland), and Btcmarkets (Australia) are illiquid as they have high KO index values. Even though the KO index and the Amihud index measure liquidity from different perspectives, they display similar results.

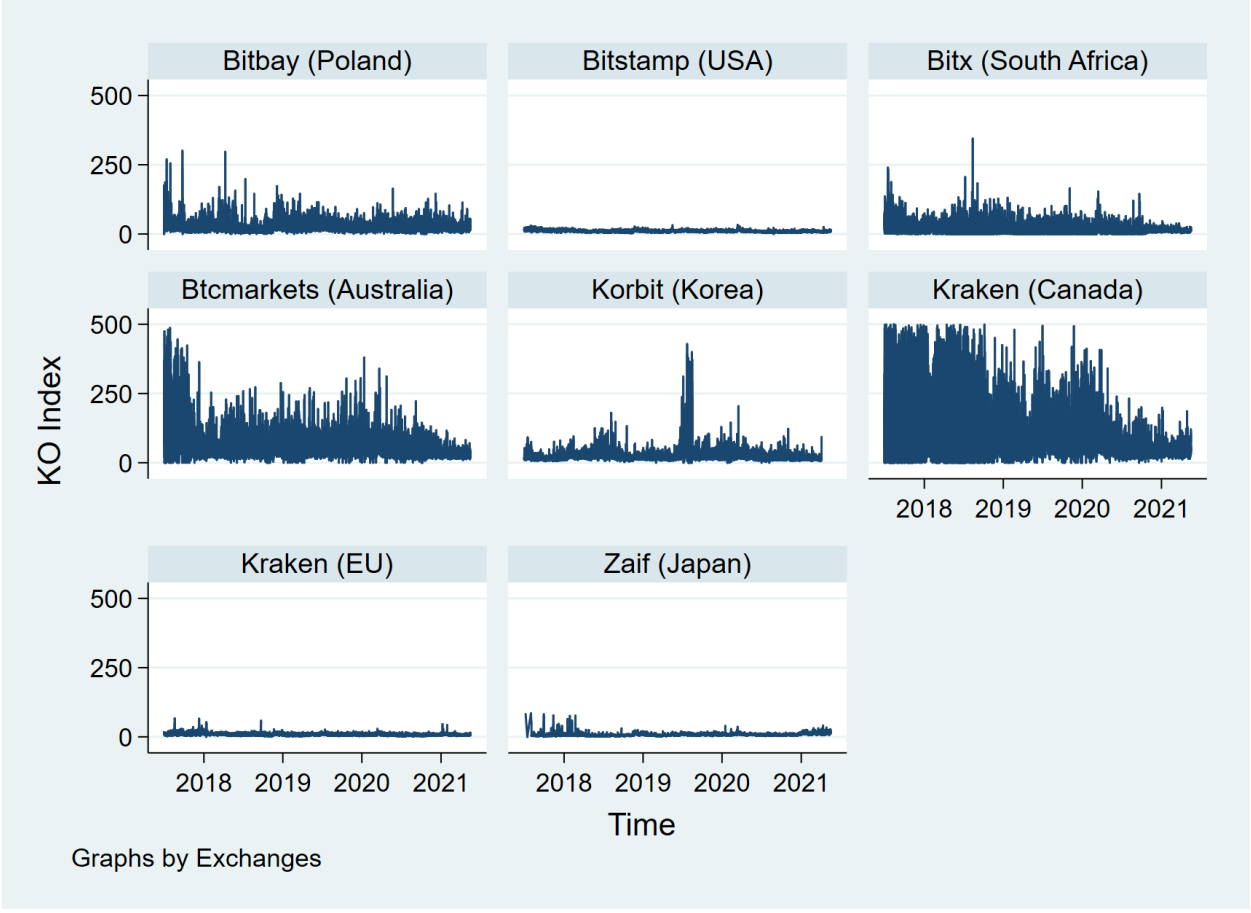

Figure 4: Hourly KO Index in Different Exchanges

3.1.5 The Abdi and Ranaldo ratio (AR)

The Abdi and Ranaldo ratio estimates the liquidity by the logarithms of high price, low price, and close price in a given time interval: $AR_i = \sqrt{max\{4(c_i - \tilde{p}_i)(c_i - \tilde{p}_{i+1}), 0\}}$; $h_i = ln(H_i)$; $l_i = ln(L_i)$; $c_i = ln(C_i)$; $\tilde{p}_i = \frac{h_i + l_i}{2}$. Then we can get the AR estimator by calculating the unweighted average in time interval t: $AR_t = \frac{1}{N-1} \sum_{i=1}^{N-1} AR_{t,i}$.

AR ratio is an illiquidity ratio: the higher the value, the more illiquid the market. Still, it is multiplied by 10e4 as its original value is too small. Figure 5 shows that the AR values at Bitstamp (USA) and Kraken (EU) are relatively low. For Zaif (Japan), the AR index is high before July 2018. Then it turns to be small. Kraken(Canada) has the highest AR index value comparing to other exchanges, even though it shows a decreasing trend. Different from the Amihud index and the KO index, the AR index at Bitbay (Poland) and Btcmarkets (Australia) do not show apparent high values as Kraken (Canada) does.

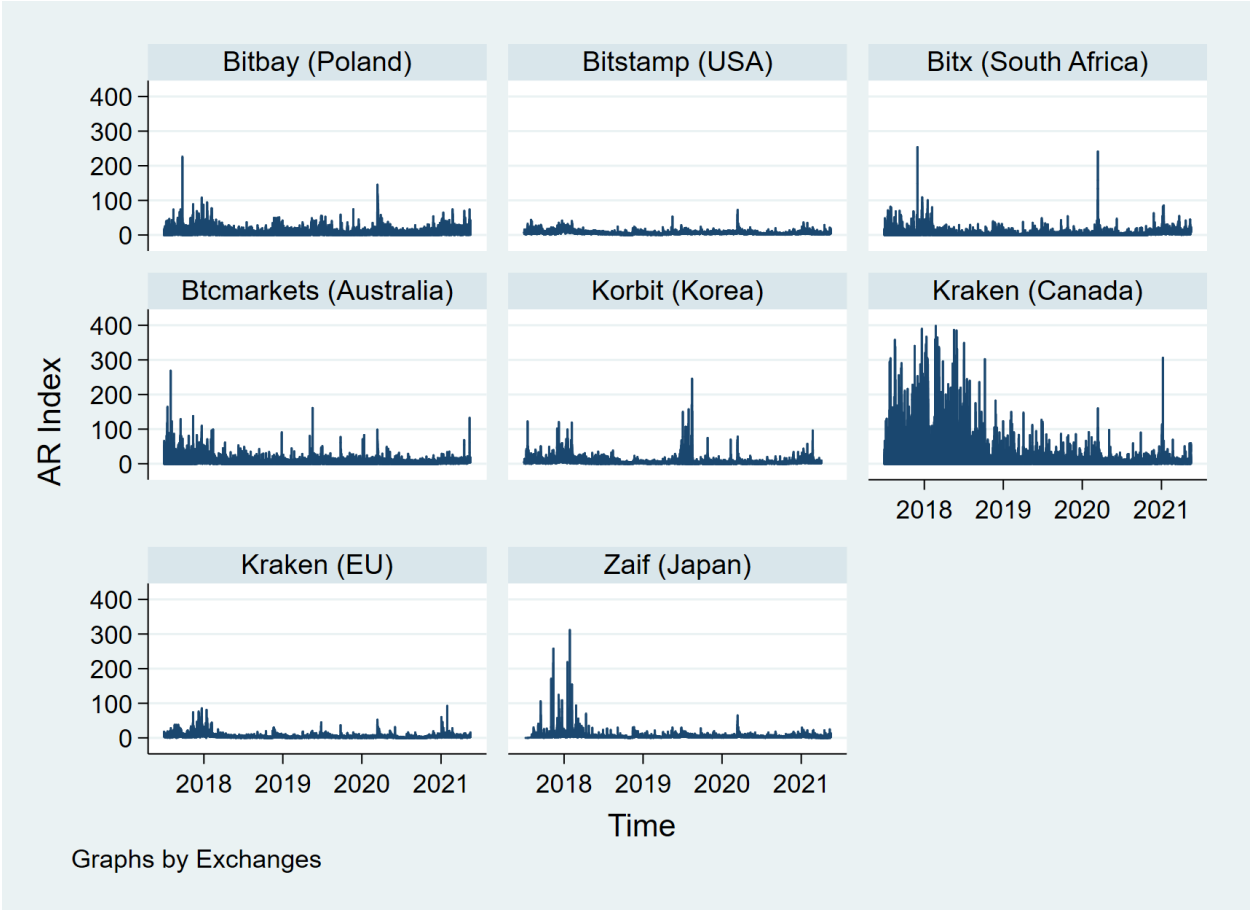

Figure 5: Hourly AR Index in Different Exchanges

3.1.6 The Roll serial covariance ratio (Roll)

The Roll serial covariance ratio focuses on the serial covariance of price changes in adjacent intervals: $Roll_t = 2 \cdot \sqrt{-min(cov[\frac{\Delta C_{t,i}}{C_{t,i-1}}, \frac{\Delta C_{t,i-1}}{C_{t,i-2}}], 0)}$. If the serial covariance is positive, then we set Roll equal to 0.

The Roll ratio is similar to previous illiquidity ratio measures: the higher the value, the more illiquid the market. It is also multiplied by 10e4 because of its tiny original value. Figure 6 shows that Kraken (Canada), Bitbay (Poland), Btcmarkets (Australia), and Bitx (South Africa) have relatively high Roll index values, which means that these exchanges are illiquid. Still, Bitstamp (USA), Zaif (Japan), and Kraken (EU) have relatively low Roll index. Even though these six liquidity measures describe the market liquidity level from different views, they present similar results.

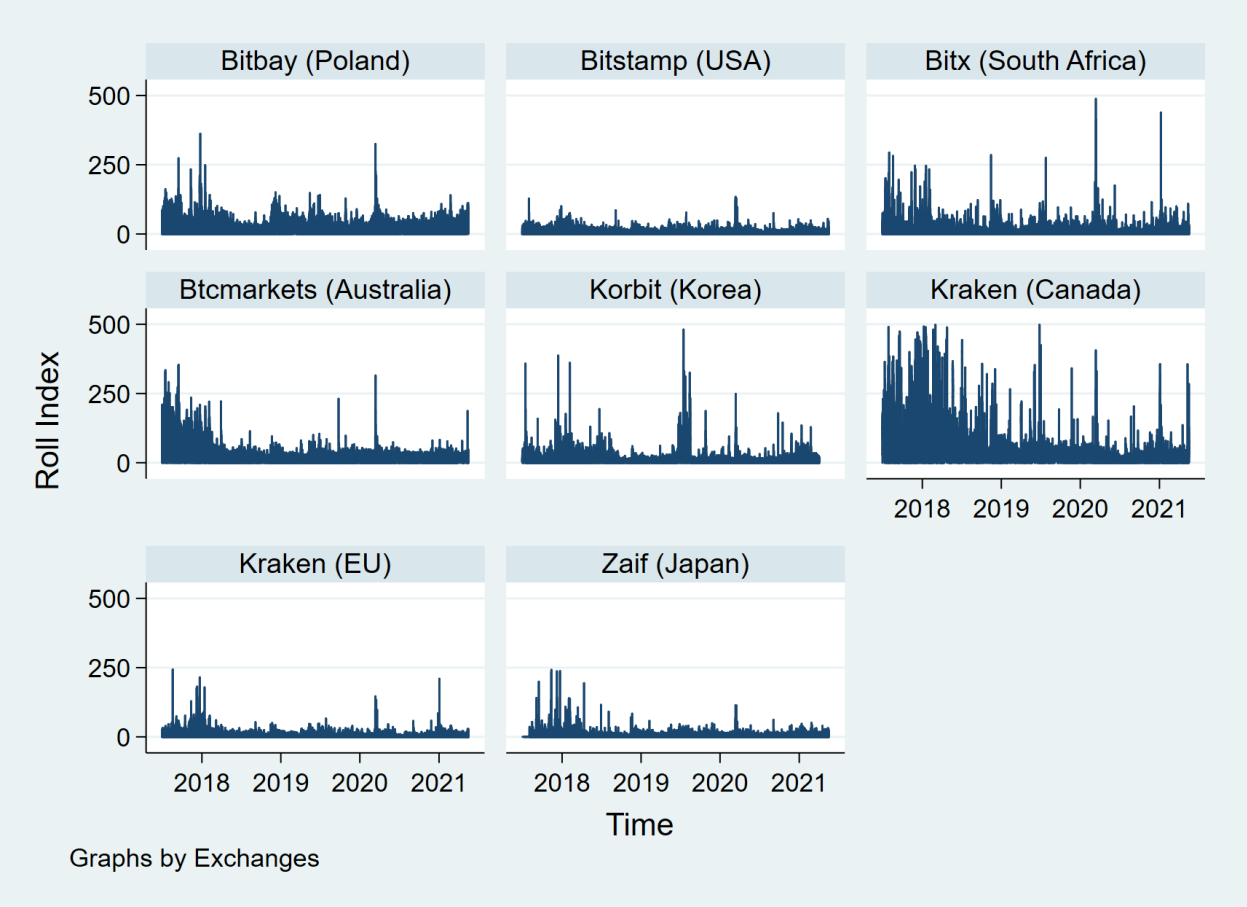

Figure 6: Hourly Roll Index in Different Exchanges

3.2 Global liquidity measure

We have already discussed six liquidity measures: the number of transactions (TX), the trading dollar volume ($Vol), the Amihud ratio (Amihud), the Kyle and Obizhaeva ratio (KO), the Abdi and Ranaldo ratio (AR), and the Roll serial covariance ratio (Roll). Among them, TX and $Vol use the average value of transactions number and trading volumes in a given period to estimate the liquidity level. The higher the value, the more liquid the market. The Amihud ratio, the KO ratio, the AR ratio, and the Roll ratio are illiquidity ratios. They measure liquidity from different views, like price impact, return volatility, and covariance. The higher the value of these illiquidity ratios, the more illiquid the market.

However, these six liquidity indexes can only measure the liquidity level at a specific exchange. In order to construct global liquidity measures, I apply the Paasche liquidity index. It combines the liquidity level at each exchange with the dollar volume trading.

$$Global\ Liquidity\ Index_t = \frac{\sum \$Vol_{it} * Liquidity\ Index_{it}}{\sum \$Vol_{it} * Liquidity\ Index_{i0}} * 100$$

Combining the liquidity indexes at eight exchanges, we can get the global liquidity level. For example, the global Amihud index is calculated by:

$$Global\ Amihud_t = \frac{\sum \$Vol_{it} * Amihud_{it}}{\sum \$Vol_{it} * Amihud_{i0}} * 100$$

We can get the global measures in the same way for the KO index, the Roll index, the TX index, and the AR index.

Figure 7 displays the daily global Amihud index. It presents no apparent trend from the perspective of time series. For every period, the global Amihud index tends to have some extreme illiquid moments and some very liquid moments. We can also tell that the global Amihud index is higher from July 2019 to July 2020 than other periods. It means that the global Bitcoin market is less liquid from July 2019 to July 2020 than in other periods. For the global TX, the global KO, the global AR, and the global Roll, they show similar results as the global Amihud index does. The global Bitcoin market is less liquid from July 2019 to July 2020. However, the market starts to become active again in 2021.

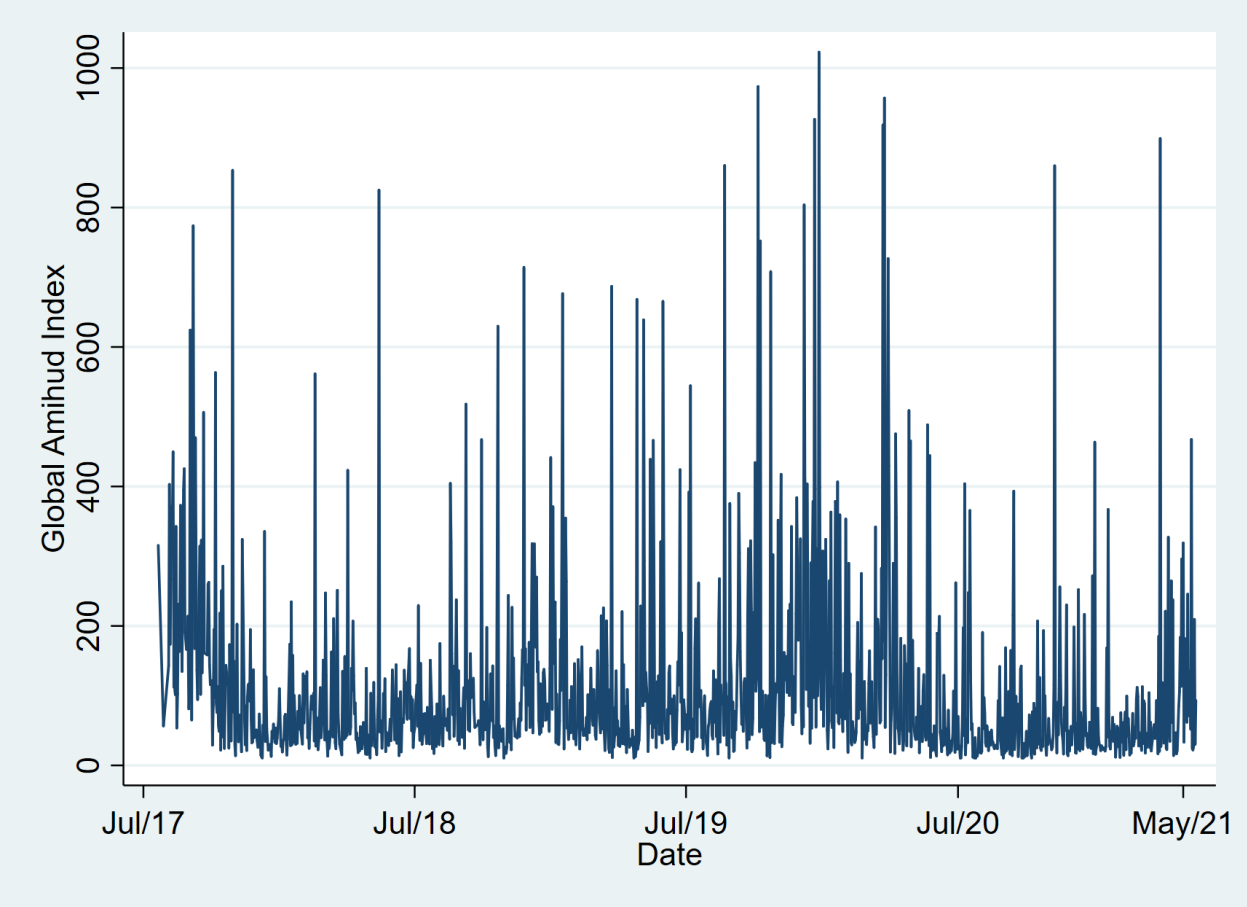

Figure 7: Daily Global Amihud Index

Table 1 shows the average values of these global liquidity indexes in different periods. The global TX, the global Amihud index, and the global KO index show that the Bitcoin market liquidity level from July 2017 to July 2018 is high. While the global AR and global Roll display that the market is illiquid back to this period. One explanation is that these liquidity measures capture the market liquidity level from different views. The TX index describes the number of transactions in a given period. The Amihud index focuses on the price index. The KO index grasps the price volatility. While for the AR index and Roll index, they study price changes in given intervals. Overall, the Bitcoin market was active from July 2017 to July 2018. Then it became less liquid from July 2018 to July 2020. Finally, after July 2020, the market became booming again.

Table 1: Average Value of the Global Liquidity Index

Time	Global TX	Global Amihud	Global KO	Global AR	Global Roll
July 2017 - July 2018	801.60	104.04	5.10	181.85	109.21
July 2018 - July 2019	321.38	133.92	14.22	74.31	63.79
July 2019 - July 2020	191.97	151.05	18.45	81.45	69.68
July 2020 - May 2021	301.72	78.72	22.18	70.84	59.57

3.3 Price and liquidity deviations

As we have discussed before, the liquidity level between exchanges varies dramatically. Some exchanges, like the Bitstamp (USA), the Kraken (EU), and the Zaif (Japan), are more liquid overall. In comparison, the Bitbay (Poland), the Kraken (Canada), and the Btcmarkets (Australia) are less liquid.

To get the liquidity deviations between exchanges, the liquidity level at Bitstamp (USA) is applied as a benchmark. The liquidity deviations can be calculated by applying the liquidity level at certain exchanges to subtract the liquidity level at Bitstamp (USA). For example, the liquidity deviations between Bitbay (Poland) and Bitstamp (USA) can be calculated by:

$$\Delta Bitbay\ (Poland)\ liquidity = \ liquidity\ at\ Bitbay\ (Poland) - liquidity\ at\ Bitstamp\ (USA)$$

Besides the liquidity deviations between exchanges, price gaps also exist between trading platforms. Use the Bitcoin price at Bitstamp (USA) as a benchmark; the price deviations between exchanges can be calculated. For instance, we can get the price deviation at Bitbay (Poland) by:

$$\Delta Bitbay\ (Poland)\ price = \ price\ at\ Bitbay\ (Poland)\ - \ price\ at\ Bitstamp\ (USA)$$

Figure 8 shows the Amihud index deviations. As we have mentioned above, the liquidity deviations apply the liquidity level at Bitstamp (USA) as a benchmark. For example, the Amihud index deviation at Bitbay (Poland) can be calculated by: $\Delta Bitbay\ (Poland)\ Amihud = Amihud\ at\ Bitbay\ (Poland) - Amihud\ at\ Bitstamp\ (USA)$. The Amihud index deviations at Kraken (EU), Zaif (Japan), and Korbit (Korea) are smaller than other exchanges. For Bitbay (Poland), Kraken (Canada), and Btcmarkets (Australia), they have higher Amihud

index deviations. However, the Amihud index deviations do not show a time series trend for all exchanges. Except for the deviations between Bitstamp (USA) and Kraken (Canada), it tends to be smaller as time goes by. The KO index deviations, Roll index deviations, and AR index deviations present similar results. The figures for other liquidity deviations display similar results.

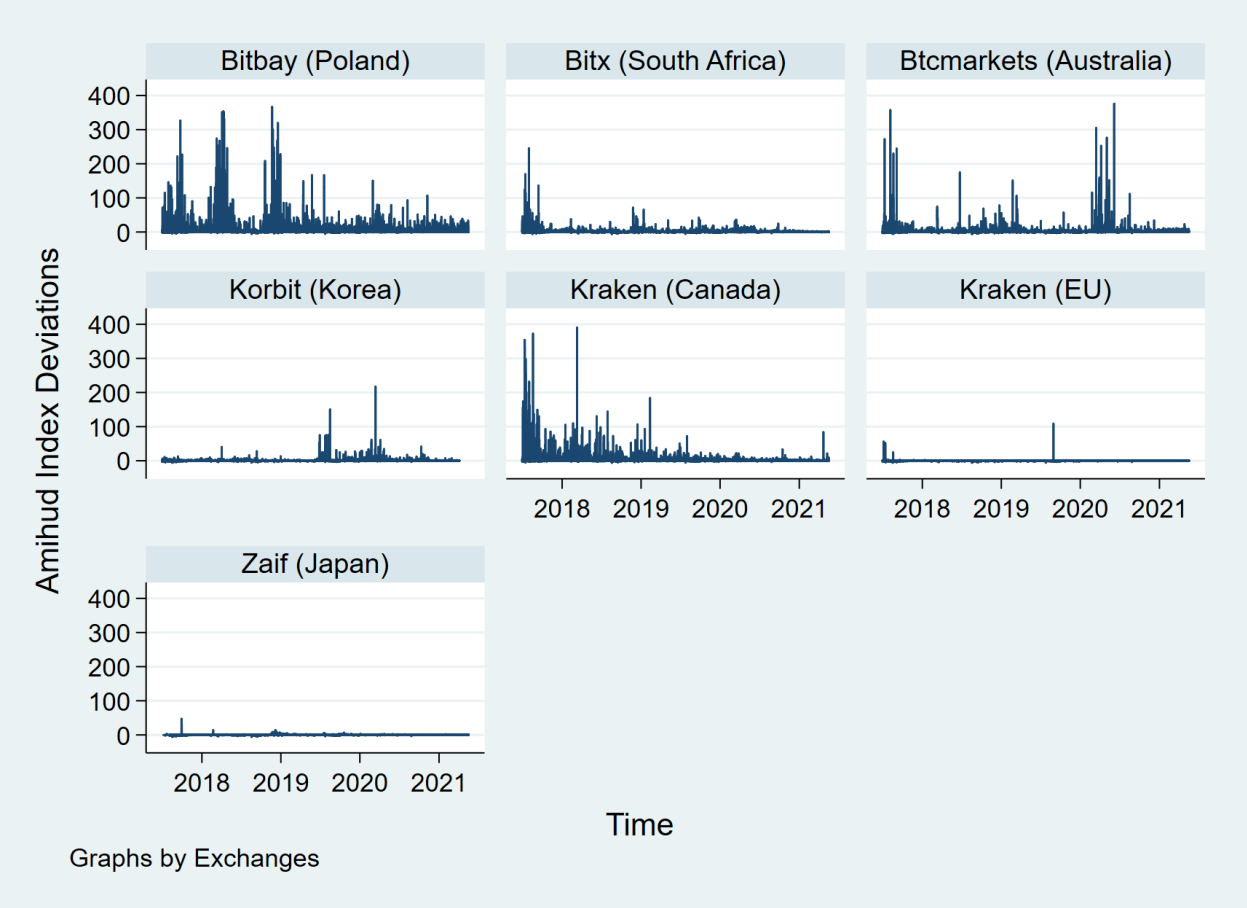

Figure 8: Amihud Index Deviations

Figure 9 displays that price deviations between exchanges. The deviations vary across exchanges. For example, the price deviations between Bitstamp (USA) and Kraken (EU) are minor overall. In contrast, the price deviations between the Bitstamp (USA) and the Korbit (Korea) are more volatile. Moreover, the price differences in a certain period are more prominent. This pattern exists in all exchanges: the price deviations around January 2018 and 2021 are more eminent than other periods. We will discuss the relationship between the price deviations and liquidity deviations further in the empirical study part.

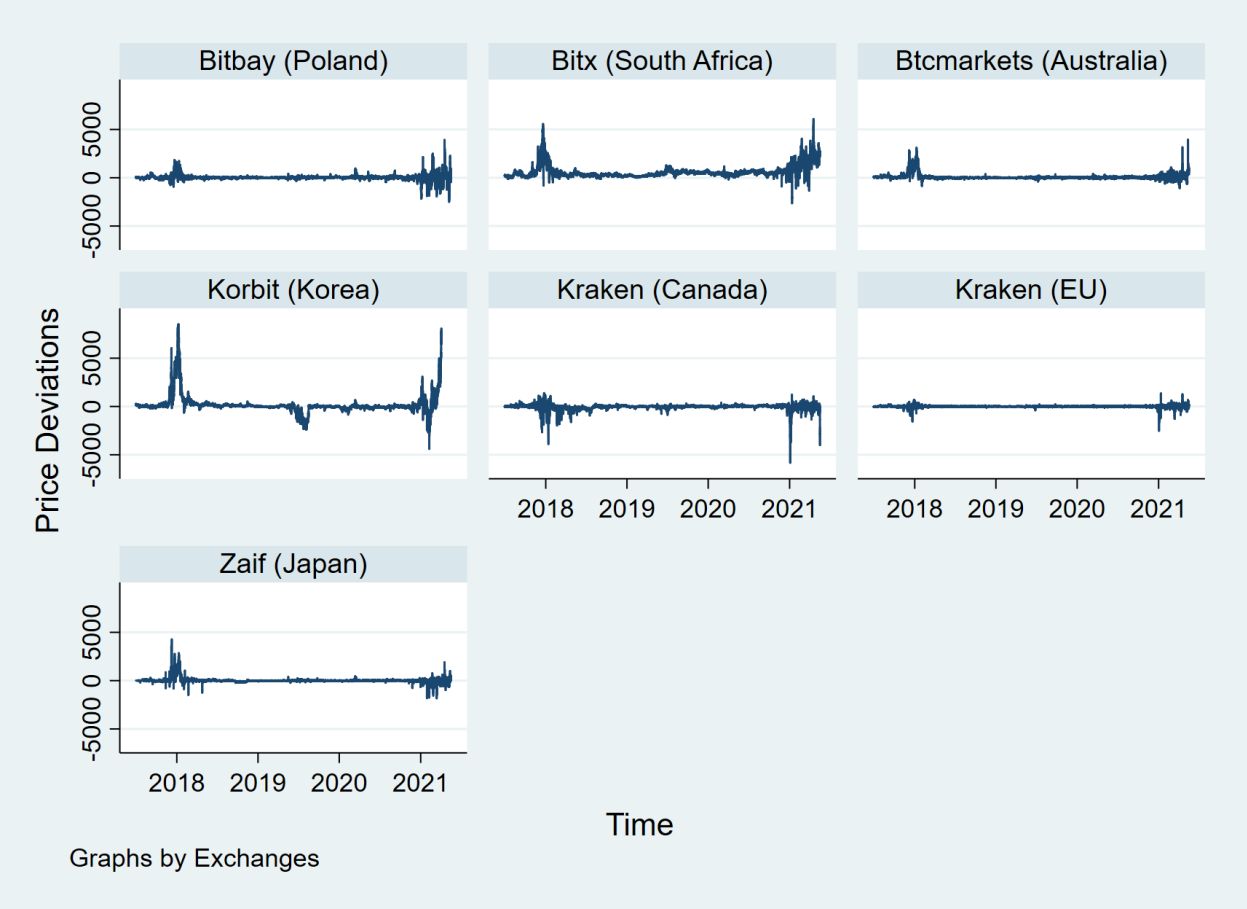

Figure 9: Price Deviations

3.4 Descriptive statistics

I now document the main statistical properties of time series for the return, price, and liquidity measures of Bitcoin in different exchanges.

Figure 10 presents the price of Bitcoin in different exchanges. Bitcoin in different countries is traded in local currency. All prices are transferred to the US dollar by applying the daily spot exchange rates. Bitcoin price at the beginning of 2018 and 2021 is more volatile comparing to another period. Especially in 2021, Bitcoin price has increased by more than 40,000 in less than two months. In another period, like in 2019, Bitcoin price is relatively stable. Combining with figure 9, the price deviations between exchanges are more considerable when Bitcoin price volatility is larger. Even though the price deviations and liquidity

level deviations exist between exchanges, Bitcoin prices in different exchanges have the same trend overall.

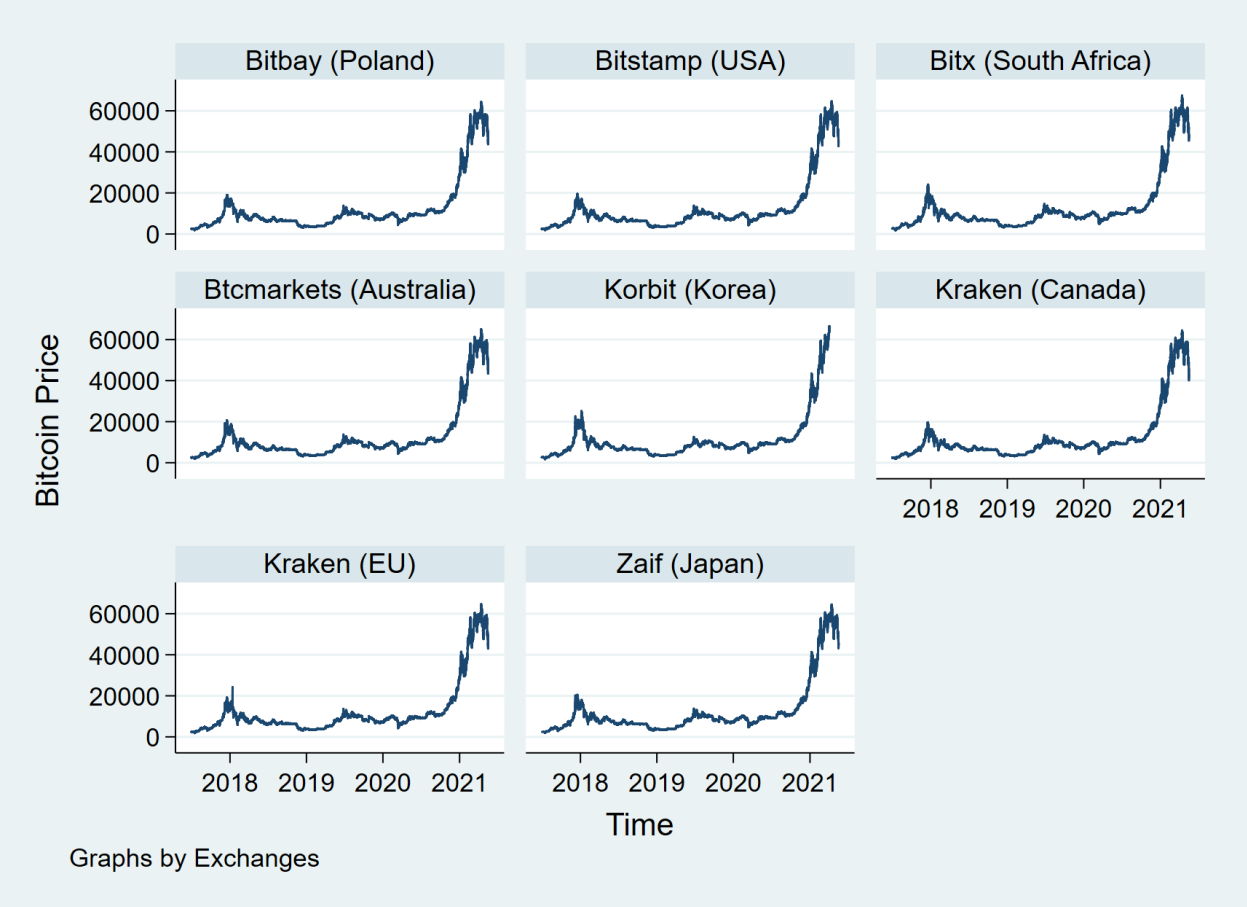

Figure 10: Bitcoin Price

Table 2 shows the Bitcoin daily return summary statistics. The average Bitcoin daily returns vary in different periods. For the period from July 2017 to July 2018, the average daily return is around 0.3%. While from July 2019 to July 2020, the average daily return is much smaller, around 0.05%. Moreover, the average daily returns from July 2020 to May 2021 are the highest since July 2017. Comparing the daily returns in different exchanges, they are not the same overall. For example, from July 2020 to May 2021, the highest average daily return is 0.72% at Korbit (Korea), and the lowest average daily return is 0.49% at Btcmarkets (Australia). The standard deviation of Bitcoin is larger in the early stage. For the period July 2017 to July 2018, exchanges have a higher standard deviation. The standard deviation at Zaif (Japan) is 6.11%, and most exchanges had a standard deviation of more

than 5%. The standard deviation is around 4% for the more recent period, which indicates that Bitcoin's daily return is less volatile as time goes by. Bitcoin daily return is positively skewed in most exchanges. However, from July 2019 to July 2020, all the exchanges are negatively skewed. Moreover, in this period, the kurtosis is much larger comparing to other periods. For the percentage of positive daily return, all periods, except July 2019 to July 2020, are larger than 50%. Especially for July 2020 to May 2021, the positive daily return percentage is the highest. It is 61.37% at Korbit (Korea).

Figure 11 presents the Bitcoin daily return frequency distributions. The distributions across exchanges are similar. The daily return is concentrated to 0 overall.

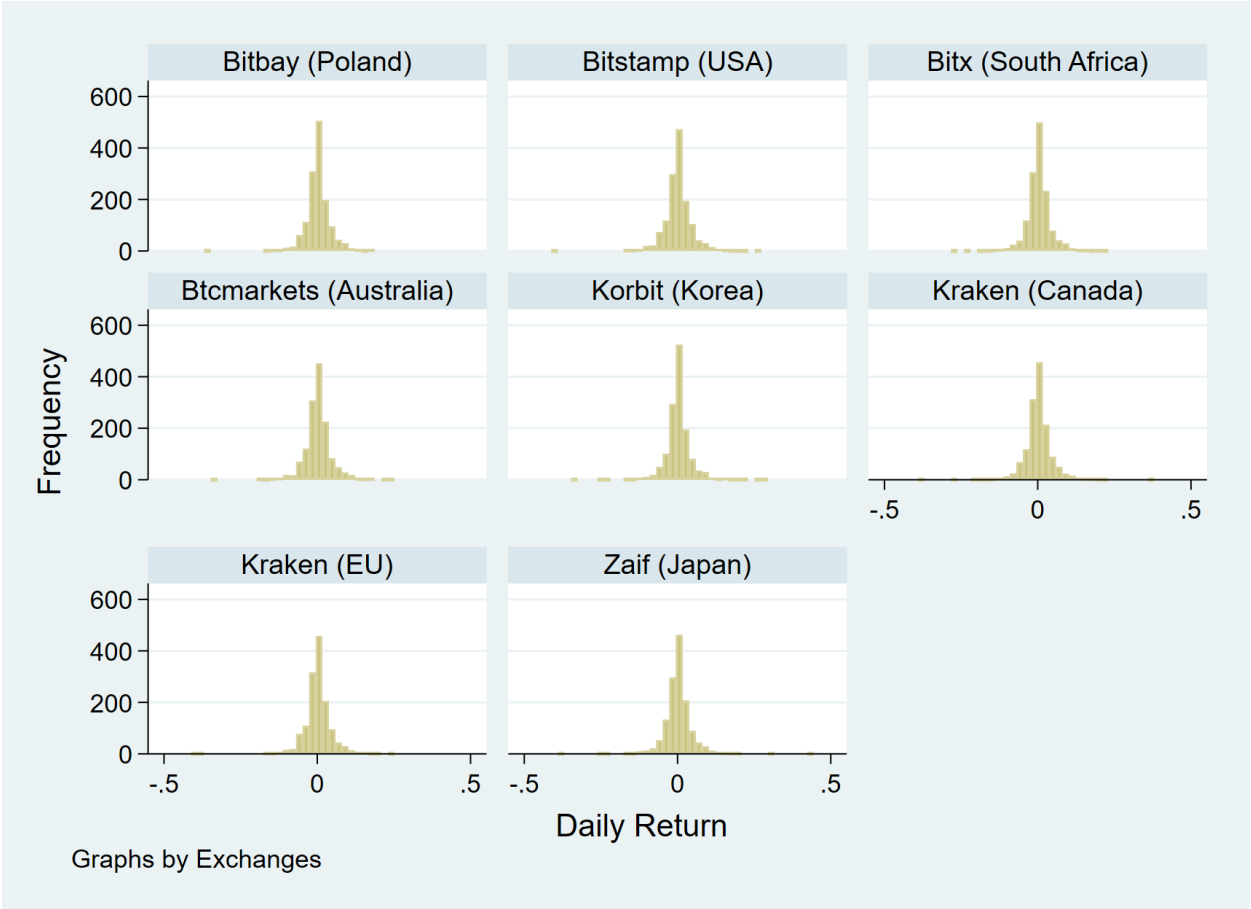

Figure 11: Bitcoin Daily Return Distribution

Figure 12 documents the Bitcoin hourly return frequency distributions. The distributions across exchanges are similar. From the distribution, it is evident that most hourly returns are around 0. The distribution is more centralized comparing with the daily return.

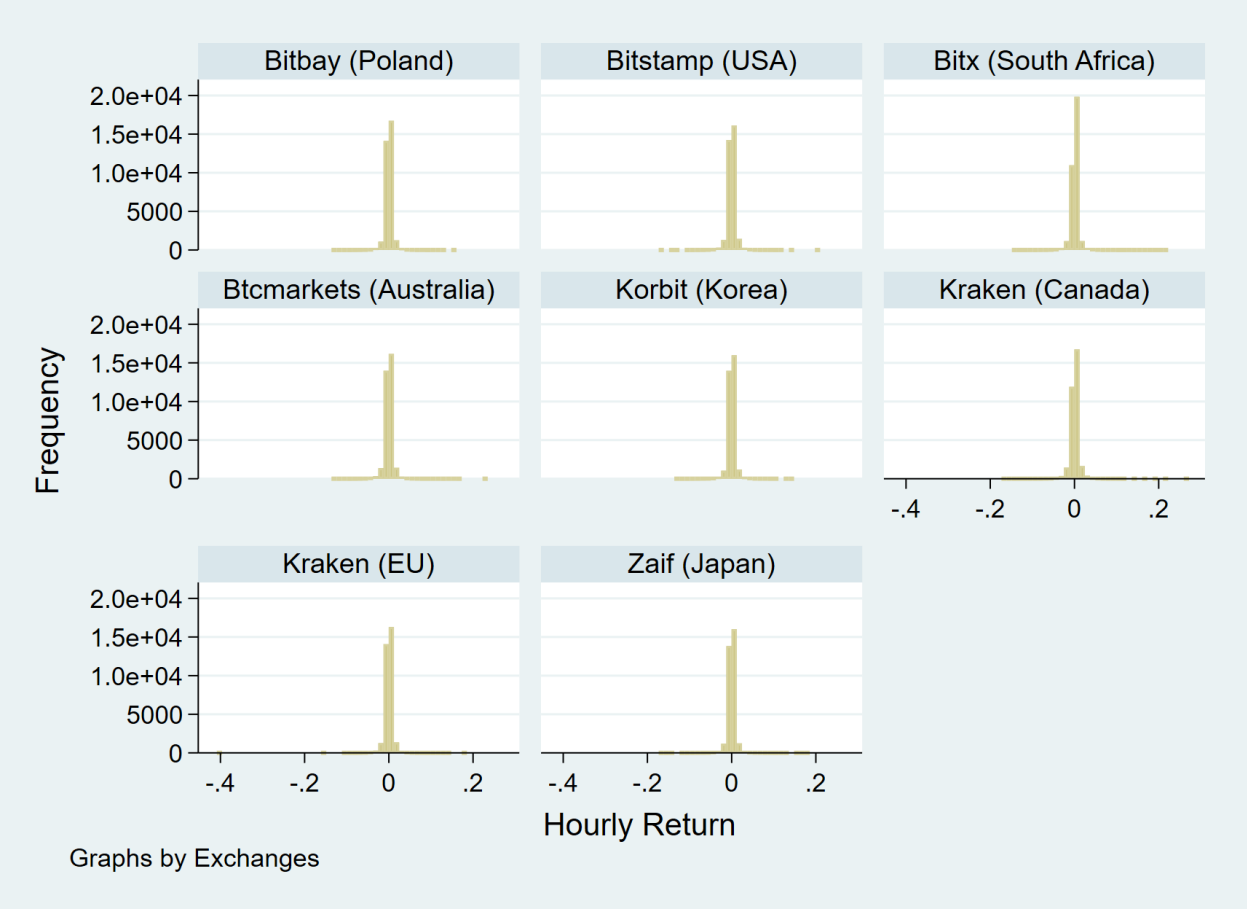

Figure 12: Bitcoin Hourly Return Distribution

Table 3 displays the Bitcoin hourly return summary statistics. The average Bitcoin daily returns are around 0.01% for most exchanges and periods. Except for July 2019 to July 2020, the hourly return is smaller compared with other periods. For the most recent period, the average hourly returns are the highest. For example, from July 2020 to May 2021, the highest average hourly return is 0.05% at Kraken (Canada). And the average hourly return at five exchanges is 0.02%. The standard deviation of the hourly return is smaller than the daily return. Overall, the standard deviation of hourly return and daily return share the same time series trend: it becomes less volatile as time goes by. The standard deviation is larger in the early period. It is more than 1.2% from July 2017 to July 2018. While from July 2020 to May 2020, it is around 0.8%. The hourly return is positively skewed in most exchanges before July 2020. However, for the period from July 2020 to May 2021, most

Table 2: Bitcoin Daily Returns Summary Statistics

Exchanges	Mean (%)	SD (%)	Median (%)	Skewness	Kurtosis	Return >0 (%)
July 1, 2017 - July 1, 2018						
Bitbay (Poland)	0.36	4.83	0.25	0.14	4.94	52.19
Bitstamp (USA)	0.41	5.43	0.29	0.48	5.39	52.46
Bitx (South Africa)	0.38	5.22	0.37	0.02	5.85	53.83
Btcmarkets (Australia)	0.35	5.56	0.36	0.45	5.62	53.28
Korbit (Korea)	0.37	5.71	0.21	0.44	8.28	52.73
Kraken (Canada)	0.43	5.97	0.28	0.56	8.90	53.70
Kraken (EU)	0.26	5.80	0.30	-0.69	10.73	51.65
Zaif (Japan)	0.42	6.11	0.32	1.08	13.36	52.45
July 1, 2018 - July 1, 2019						
Bitbay (Poland)	0.20	3.47	0.21	0.19	7.41	54.25
Bitstamp (USA)	0.21	3.69	0.15	0.27	7.27	53.97
Bitx (South Africa)	0.21	3.48	0.14	0.14	8.31	54.25
Btcmarkets (Australia)	0.21	3.60	0.10	0.21	7.56	53.85
Korbit (Korea)	0.17	3.06	0.15	0.52	7.80	54.25
Kraken (Canada)	0.24	3.53	0.16	0.36	7.41	53.02
Kraken (EU)	0.20	3.59	0.21	0.17	7.56	54.40
Zaif (Japan)	0.20	3.58	0.14	0.28	7.62	52.62
July 1, 2019 - July 1, 2020						
Bitbay (Poland)	0.06	3.96	-0.10	-1.27	21.54	48.49
Bitstamp (USA)	0.01	4.24	-0.14	-1.71	23.63	48.49
Bitx (South Africa)	0.07	3.54	0.00	-0.50	14.57	49.59
Btcmarkets (Australia)	0.03	4.01	-0.10	-1.34	19.00	48.49
Korbit (Korea)	0.01	3.67	-0.20	-1.58	24.49	45.75
Kraken (Canada)	0.06	4.03	-0.17	-1.75	24.96	46.85
Kraken (EU)	0.04	4.19	-0.07	-1.45	22.36	48.49
Zaif (Japan)	0.01	4.23	-0.19	-1.27	20.87	47.80
July 1, 2020 - May 17, 2021						
Bitbay (Poland)	0.56	3.30	0.38	0.27	5.85	56.88
Bitstamp (USA)	0.53	3.73	0.38	0.33	6.09	56.25
Bitx (South Africa)	0.50	3.39	0.33	-0.01	6.89	57.81
Btcmarkets (Australia)	0.49	3.55	0.26	0.33	6.18	55.00
Korbit (Korea)	0.72	3.21	0.45	0.30	6.68	61.37
Kraken (Canada)	0.57	3.68	0.55	0.47	7.09	59.69
Kraken (EU)	0.51	3.59	0.32	0.35	6.47	56.25
Zaif (Japan)	0.55	3.61	0.40	0.44	6.31	55.31

Table 3: Bitcoin Hourly Returns Summary Statistics

Exchanges	Mean (%)	SD (%)	Median (%)	Skewness	Kurtosis	Return >0 (%)
July 1, 2017 - July 1, 2018						
Bitbay (Poland)	0.01	1.11	0.00	0.77	21.13	50.18
Bitstamp (USA)	0.02	1.21	0.02	0.23	11.45	51.56
Bitx (South Africa)	0.02	1.39	0.00	1.66	38.10	48.85
Btcmarkets (Australia)	0.01	1.32	0.00	1.04	21.84	49.66
Korbit (Korea)	0.01	1.23	0.02	0.09	18.46	51.17
Kraken (Canada)	0.02	1.67	0.00	0.52	24.77	43.26
Kraken (EU)	0.01	1.23	0.02	0.45	14.72	51.36
Zaif (Japan)	0.01	1.31	0.01	0.43	31.36	50.82
July 1, 2018 - July 1, 2019						
Bitbay (Poland)	0.02	0.71	0.01	0.43	25.76	50.97
Bitstamp (USA)	0.01	0.73	0.01	0.41	31.31	51.14
Bitx (South Africa)	0.01	0.69	0.00	0.08	27.65	41.80
Btcmarkets (Australia)	0.00	0.72	0.00	0.29	27.06	49.26
Korbit (Korea)	0.00	0.63	0.01	0.33	25.76	50.35
Kraken (Canada)	0.02	0.82	0.00	0.69	23.18	47.97
Kraken (EU)	0.01	0.73	0.01	0.43	28.98	51.38
Zaif (Japan)	0.01	0.70	0.01	0.39	30.27	51.53
July 1, 2019 - July 1, 2020						
Bitbay (Poland)	0.00	0.83	0.00	0.38	51.33	49.31
Bitstamp (USA)	0.00	0.86	0.00	0.44	86.61	50.05
Bitx (South Africa)	0.00	0.75	0.00	2.28	94.87	44.89
Btcmarkets (Australia)	-0.01	0.85	0.00	1.72	94.57	48.76
Korbit (Korea)	0.00	0.75	0.00	0.31	48.77	48.32
Kraken (Canada)	0.00	0.85	0.00	-0.08	85.87	48.31
Kraken (EU)	0.00	0.85	0.00	0.02	79.97	50.35
Zaif (Japan)	0.00	0.81	0.00	-0.62	57.18	49.99
July 1, 2020 - May 17, 2021						
Bitbay (Poland)	0.02	0.77	0.00	-0.11	15.89	50.96
Bitstamp (USA)	0.01	0.82	0.01	0.14	18.99	51.04
Bitx (South Africa)	0.02	0.78	0.00	-0.19	28.42	50.06
Btcmarkets (Australia)	0.00	0.81	0.00	0.05	18.58	49.24
Korbit (Korea)	0.02	0.73	0.00	-0.47	16.29	50.30
Kraken (Canada)	0.05	0.85	0.04	-0.07	29.55	53.11
Kraken (EU)	0.01	0.82	0.01	-0.35	36.91	51.02
Zaif (Japan)	0.02	0.77	0.01	-0.20	13.42	51.21

Table 4: Average Value of Bitcoin Liquidity Measures

Exchanges	TX	$Vol	Amihud	KO	AR	Roll
July 1, 2017 - July 1, 2018						
Bitbay (Poland)	6.65	8.41	5.14	27.33	9.22	22.72
Bitstamp (USA)	26.38	78.87	0.21	12.28	9.79	11.30
Bitx (South Africa)	8.77	5.23	1.37	18.57	5.56	12.28
Btcmarkets (Australia)	3.28	4.95	1.09	64.94	9.69	44.55
Korbit (Korea)	8.54	24.73	0.37	22.67	9.36	17.43
Kraken (Canada)	2.69	2.41	3.81	165.18	20.54	112.80
Kraken (EU)	25.24	48.84	0.13	11.09	7.70	10.10
Zaif (Japan)	107.69	58.64	0.05	9.02	6.81	7.36
July 1, 2018 - July 1, 2019						
Bitbay (Poland)	4.89	10.59	5.08	26.79	5.81	19.59
Bitstamp (USA)	12.96	35.13	0.21	9.96	3.87	5.80
Bitx (South Africa)	3.78	2.19	0.58	11.87	1.60	4.79
Btcmarkets (Australia)	2.18	2.52	0.70	47.46	3.12	16.86
Korbit (Korea)	3.98	4.50	0.32	22.02	3.67	10.99
Kraken (Canada)	2.43	1.56	1.40	89.76	9.10	46.96
Kraken (EU)	15.41	22.56	0.36	8.13	2.78	3.79
Zaif (Japan)	38.22	15.32	0.55	6.36	3.24	4.13
July 1, 2019 - July 1, 2020						
Bitbay (Poland)	5.26	21.87	2.88	24.83	6.23	18.91
Bitstamp (USA)	14.50	52.29	0.32	10.88	6.55	8.31
Bitx (South Africa)	3.68	2.78	0.67	14.35	1.77	5.83
Btcmarkets (Australia)	2.01	2.83	1.11	51.86	3.58	18.86
Korbit (Korea)	3.91	2.82	0.94	49.35	5.16	845.45
Kraken (Canada)	2.19	1.87	0.67	74.06	4.82	29.48
Kraken (EU)	18.93	34.48	0.12	8.15	2.54	3.10
Zaif (Japan)	21.44	6.41	0.48	8.50	4.02	5.58
July 1, 2020 - May 17, 2021						
Bitbay (Poland)	6.13	39.14	1.98	24.61	7.65	20.37
Bitstamp (USA)	25.16	144.49	0.07	8.73	4.56	5.57
Bitx (South Africa)	13.62	11.42	0.34	11.16	5.37	8.27
Btcmarkets (Australia)	2.94	6.16	0.90	35.60	4.56	16.45
Korbit (Korea)	6.59	6.36	0.34	17.27	3.95	7.67
Kraken (Canada)	3.06	4.03	0.48	41.21	5.02	20.83
Kraken (EU)	34.21	112.21	0.04	7.02	2.71	2.98
Zaif (Japan)	18.10	10.29	0.31	10.23	3.35	4.61

Table 5: Average Value of Price Deviations and Liquidity Deviations

Exchanges	ΔPrice	ΔTX	Δ$Vol	ΔAmihud	ΔKO	ΔAR	ΔRoll
July 1, 2017 - July 1, 2018							
Bitbay (Poland)	65.89	-19.74	-70.46	4.94	15.06	-0.58	11.41
Bitx (South Africa)	633.78	-17.61	-73.63	1.17	6.30	-4.24	0.98
Btcmarkets (Australia)	224.78	-23.11	-74.01	0.89	52.67	-0.12	33.26
Korbit (Korea)	641.30	-17.84	-54.16	0.17	10.40	-0.44	6.14
Kraken (Canada)	-79.02	-24.12	-78.46	3.61	152.84	10.45	101.46
Kraken (EU)	8.02	-1.05	-29.80	-0.08	-1.19	-2.07	-1.18
Zaif (Japan)	154.75	79.94	-25.41	-0.13	-2.88	-2.99	-3.82
July 1, 2018 - July 1, 2019							
Bitbay (Poland)	7.59	-8.08	-24.55	4.88	16.84	1.94	13.79
Bitx (South Africa)	275.43	-9.19	-32.94	0.37	1.92	-2.27	-1.01
Btcmarkets (Australia)	4.09	-10.78	-32.69	0.50	37.49	-0.78	11.05
Korbit (Korea)	8.33	-8.98	-30.62	0.11	12.07	-0.20	5.20
Kraken (Canada)	-27.61	-10.60	-34.10	1.20	79.76	5.18	41.15
Kraken (EU)	3.50	2.47	-12.59	0.15	-1.83	-1.09	-2.01
Zaif (Japan)	-19.12	25.26	-19.86	0.34	-3.61	-0.63	-1.68
July 1, 2019 - July 1, 2020							
Bitbay (Poland)	42.48	-9.25	-30.44	2.56	13.95	-0.32	10.59
Bitx (South Africa)	517.42	-10.82	-49.50	0.35	3.47	-4.78	-2.48
Btcmarkets (Australia)	24.50	-12.50	-49.52	0.79	40.97	-2.99	10.54
Korbit (Korea)	-213.91	-10.56	-49.36	0.62	38.49	-1.38	837.54
Kraken (Canada)	6.93	-12.37	-50.73	0.36	63.19	-1.77	21.16
Kraken (EU)	7.77	4.44	-17.73	-0.20	-2.72	-4.01	-5.20
Zaif (Japan)	7.23	6.95	-45.90	0.16	-2.39	-2.52	-2.73
July 1, 2020 - May 17, 2021							
Bitbay (Poland)	10.12	-19.03	-105.34	1.91	15.88	3.08	14.80
Bitx (South Africa)	1005.13	-11.54	-133.07	0.27	2.43	0.81	2.71
Btcmarkets (Australia)	92.14	-22.22	-138.35	0.82	26.87	-0.01	10.88
Korbit (Korea)	249.60	-17.99	-131.17	0.25	8.56	-0.62	2.09
Kraken (Canada)	-31.84	-22.13	-140.57	0.41	32.46	0.45	15.24
Kraken (EU)	5.78	9.05	-32.25	-0.03	-1.72	-1.86	-2.59
Zaif (Japan)	-41.44	-7.06	-134.20	0.24	1.49	-1.21	-0.96

exchanges are negatively skewed. The kurtosis shares a similar pattern as the daily return: the kurtosis is higher from July 2019 to July 2020. For the percentage of positive hourly return, it is around 50% percent.

Table 4 documents the average value of the liquidity measurements across exchanges. The TX index and the $Vol index measure the liquidity level of the market. The larger the average value, the more liquid the market. The Amihud index, the KO index, the AR index, and the Roll index describe the illiquidity level of the trading platform. The larger the average value, the more illiquid the market. Bitstamp (USA), Kraken (EU), and Zaif (Japan) have high average TX value and $Vol value, low average Amihud value, KO value, AR value, and Roll value. They are liquid exchanges since July 2017. However, the average liquidity measures show that Bitbay (Poland) and Kraken (Canada) are illiquid since July 2017. The liquidity momentum exists at Bitcoin trading platforms. Moreover, the average value of Bitcoin liquidity measures presents that Bitcoin trading was very active from July 2017 to July 2018. After that, the market liquidity level decreased overall. Then it started to be booming again after July 2020.

Table 5 reports the average price deviations and average liquidity level deviations across exchanges. Bitstamp (USA) is used as the benchmark. The price gap between different exchanges is vast. From July 2020 t0 May 2021, the average price deviations between Bitx (South Africa) and Bitstamp (USA) is 1005.13 US dollars. For the liquidity level deviations, as Bitstamp (USA) is one of the most liquid exchanges, the larger the absolute value of the differences, the more illiquid the exchange. Overall, Kraken (EU) and Zaif (Japan) have lower liquidity deviations.

4 Empirical Study

4.1 Price and liquidity difference

I visualize the relationship between the absolute value of price deviations and the absolute value of liquidity level deviations across exchanges by controlling the time fixed effect and exchange fixed effect. For the regression, daily data is used. The α_t is the time fixed effect,

and the α_i is the exchange fixed effect.

$$|\Delta Price_{it}| \ = \ \alpha_t \ + \ \alpha_i \ + \ \beta_1 Momentum_{it} \ + \ \beta_2 |\Delta Liquidity \ Measures_{it}|$$

The $Momentum_{it}$ is the price momentum. It is calculated by: $Momentum_{i,t} = price_{i,t} - price_{i,t-3}$. Use the price to subtract the price three days before.

Table 6: Price Differences and Liquidity Differences

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	$\|\Delta Price\|$	$\|\Delta Price\|$	$\|\Delta Price\|$	$\|\Delta Price\|$	$\|\Delta Price\|$	$\|\Delta Price\|$
Momentum	0.296***	0.295***	0.295***	0.294***	0.283***	0.299***
	(0.0124)	(0.0124)	(0.0124)	(0.0124)	(0.0125)	(0.0124)
$\|\Delta TX\|$	0.668***					
	(0.240)					
$\|\Delta \$Vol\|$		7.272***				
		(0.830)				
$\|\Delta Amihud\|$			0.0398			
			(0.168)			
$\|\Delta KO\|$				0.304***		
				(0.0694)		
$\|\Delta AR\|$					1.860***	
					(0.268)	
$\|\Delta Roll\|$						0.979***
						(0.131)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Exchange FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	11,241	11,241	11,241	11,241	11,199	11,241
R-squared	0.390	0.394	0.390	0.391	0.393	0.393

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6 presents the regression results after controlling the fixed effects and price momentum. The price deviations are highly correlated with the liquidity deviations. For both the price deviations and the liquidity deviations, the absolute value is applied. Most of the β_2 coefficients are significant and positive. The absolute value of liquidity deviations is positively correlated with the absolute value of the price deviations between exchanges. It might

be explained by the trading costs. If a price error exists in one trading platform, arbitrage should happen except for the existence of trading cost. Higher trading costs will lead to less trading and more liquidity deviations between exchanges. As a result, the price error is highly correlated with the liquidity deviations.

4.2 Liquidity factors

The liquidity of the Bitcoin market is highly correlated with the amount of public attention put on this emerging market. As website searching technology develops, the Google search index can be viewed as public attention to particular objects. When the public is interested in it, the search index surges. As a result, the Google search index can be used as a factor to predict Bitcoin market liquidity level.

$$Liquidity_{it} = \alpha_t + \alpha_i + \beta_1 Liquidity\ Momentum_{it} + \beta_2\ Google\ Search\ Index_{it} + \epsilon_{it}$$

The liquidity momentum refers to the differences between the liquidity level and liquidity level three days before. It can be calculated by:

$$Liquidity\ Momentum_{i,t} = Liquidity_{i,t} - Liquidity_{i,t-3}$$

After controlling the time fixed effect and exchange fixed effect, this model applies the liquidity momentum and google search index to predict the liquidity level.

Table 7 documents the results of the liquidity factors model. As for the TX and the $Vol, the higher their value, the more liquid the market. Since the coefficients are positive, it means that the market becomes more liquid when more people search on Google about Bitcoin. The other four measurements are illiquidity measures. The larger the value of them, the less liquid the market. And except for the AR index, other coefficients are all negative and significant, which means that the market is more liquid as the public puts more attention on it. For the momentum, the coefficients are all significant and positive. It indicates that the more liquid Bitcoin market tends to stay high liquidity and the less liquid market is more likely to be illiquid.

Table 7: Liquidity Factors Model

VARIABLES	(1) TX	(2) $Vol	(3) Amihud	(4) KO	(5) AR	(6) Roll
Google search Index	0.811***	1,227***	-0.0138**	-0.333***	-0.000472	-0.253***
	(0.0252)	(60.15)	(0.00591)	(0.0465)	(0.0132)	(0.0379)
TX Momentum	0.499***					
	(0.0128)					
$Vol Momentum		0.501***				
		(0.00778)				
Amihud Momentum			0.500***			
			(0.00531)			
KO Momentum				0.494***		
				(0.00720)		
AR Momentum					0.501***	
					(0.00587)	
Roll Momentum						0.498***
						(0.00717)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Exchange FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	11,241	11,241	11,241	11,240	11,163	11,241
R-squared	0.625	0.604	0.558	0.629	0.584	0.591

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5 Tesla Event Study

In 2021, Tesla has been in the spotlight of the Bitcoin market. On February 8, 2021, it has announced that 1.5 billion US dollars worth of bitcoin has been purchased. According to Tesla's 2020 10k filing, it declared that the bitcoin investment is for further diversification and maximization returns on the cash. Furthermore, it planned to accept Bitcoin as a form of payment for its products.

On March 24, 2021, Elon Musk, the CEO of Tesla, announced that Tesla would accept Bitcoin as a payment in the USA. The market responded to it simultaneously: the price of Bitcoin has increased by 2,000 US dollars in 3 hours.

On May 12, 2021, Tesla decided to stop accepting bitcoin as a payment method. Elon Musk also shared the news through Twitter, indicating that due to fossil fuel use for bitcoin mining, they will stop accepting bitcoin. The price of Bitcoin dropped dramatically after the announcement.

5.1 First Announcement

The first announcement is on February 8, 2021, and the bitcoin price surged after Tesla issued their 10k file. According to figure 13, exchanges in different regions all reacted to this news swiftly. For the Bitcoin price in Bitstamp (USD), the price of bitcoin before this news was less than 40,000 US dollars. Within two hours, it surged to 44,000. The market is extremely sensitive to such news.

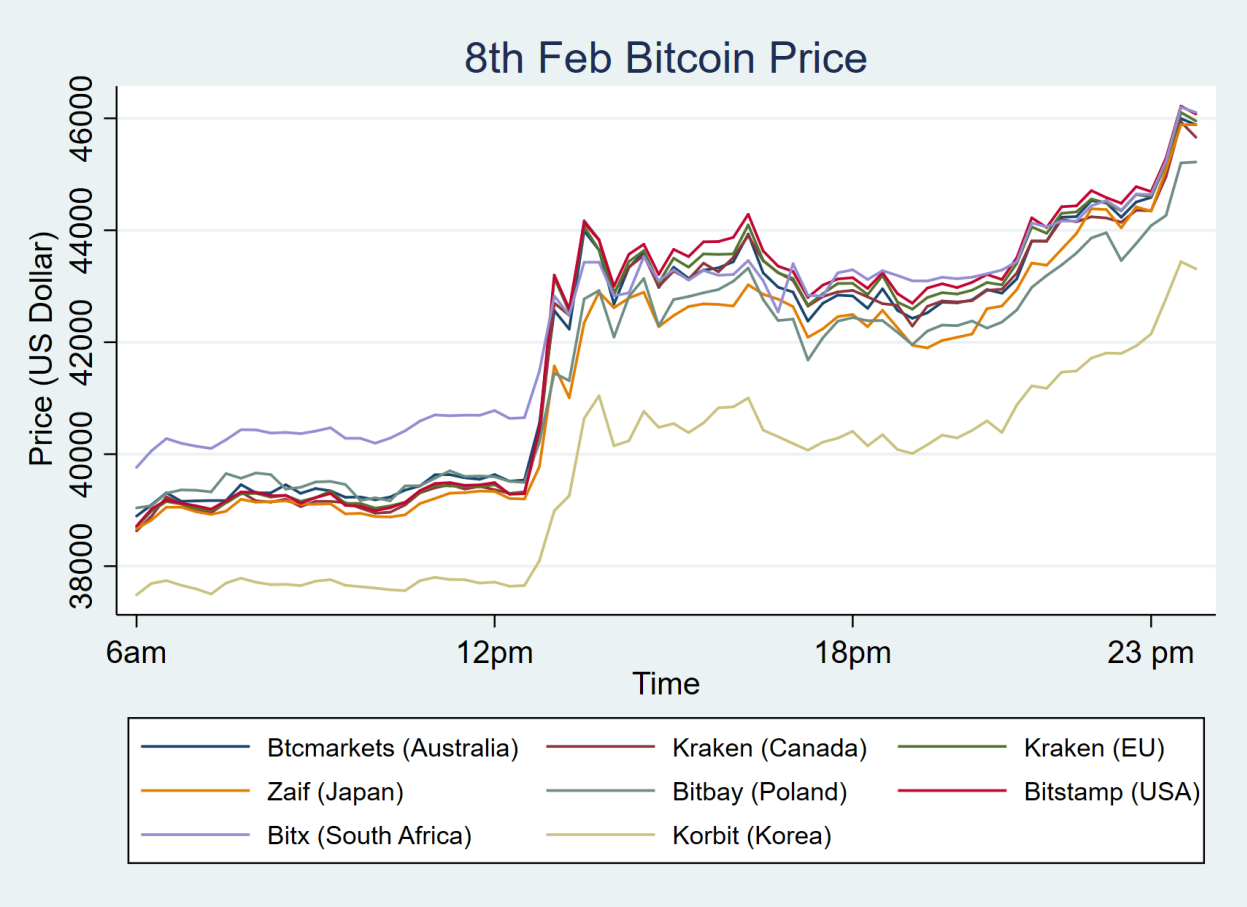

Figure 13: Tesla 1st Announcement Bitcoin Price

The market start-reacting time is defined as the first minute with a minute level return

of more than 0.1%. Also, it should be followed with more than 5 minutes with a return of more than 0.1% in the next 10-minute interval. For instance, if the minute-return for 12:25 is 0.13%. And in the period 12:25 - 12:35, more than five minute-returns, such as 12:26, 12:28, 12:31, 12:33, and 12:34, are larger than 0.1%. Then 12:25 is the start reacting time.

Under this definition, the market start reaction time for all these nine exchanges is around 12:42. For the first announcement, I apply the hourly trading data and set the event time as 12 pm on February 8, 2021.

In order to estimate the abnormal liquidity level, I set the event window as 2 hours before and 5 hours later the event time. For the estimation window, it is 24 hours before and 48 hours later the event window.

$$Liquidity_{it} = \alpha_t + \alpha_i + \sum_{j=-2}^{j=5} \beta_{0j} I(event_{it} = j) + \beta_1 Momentum_{it} + \beta_2\ Google\ Trend_{it} + \epsilon_{it}$$

Table 8 shows the abnormal liquidity rate at Bitstamp (USA). The liquidity level increased during the event period. The abnormal Amihud, abnormal KO, and abnormal Roll are all negative. It indicates that the values of these measures are smaller at the event window than usual. In other words, the market became more liquid. For the abnormal TX and the abnormal $Vol, they are positive. Moreover, the largest abnormal value happens in 1 hour after the announcement. For example, the abnormal TX at period 1 is 65.27, and abnormal $Vol at period 1 is 1261.11. For the abnormal KO, it is -9.65 at period 0 and -12.78 at period 1.

Table 8: First Announcement Abnormal Liquidity at Bitstamp (USA)

Time	Abnormal TX	Abnormal $Vol	Abnormal Amihud	Abnormal KO	Abnormal Roll
-2	2.98	64.06	-0.54	-7.01	-9.35
-1	5.44	73.87	-0.34	-7.06	-7.58
0	38.43	557.04	-0.50	-9.65	-8.02
1	65.27	1261.11	-0.34	-12.78	-3.56
2	22.46	528.21	-0.25	-7.09	-12.27
3	20.58	335.66	-0.46	-7.04	-9.51
4	22.35	371.78	-0.47	-10.55	-9.18
5	13.20	219.37	-0.54	-6.88	-14.07
t value	3.35	3.14	-11.33	-10.78	-8.28

The Bitstamp (USD) is one of the most liquid Bitcoin exchanges in the world. Table

9 presents the abnormal liquidity at Kraken (Canada), a less liquid trading platform. The abnormal TX and the abnormal $Vol at Kraken (Canada) are negative. However, the abnormal KO and abnormal Roll are positive. At period 1, the abnormal TX is -59.76, and the abnormal $Vol is -383.5. It shows opposite results to table 8: during the announcement, the liquidity level at Kraken (Canada) is smaller than usual.

Table 9: First Announcement Abnormal Liquidity at Kraken (Canada)

Time	Abnormal TX	Abnormal $Vol	Abnormal Amihud	Abnormal KO	Abnormal Roll
-2	-10.19	-35.92	-0.19	17.17	10.51
-1	-10.81	-36.92	0.31	20.94	5.73
0	-34.06	-192.91	-0.37	16.88	7.68
1	-59.76	-383.50	-0.04	12.65	3.69
2	-28.39	-150.94	0.23	14.54	27.70
3	-19.58	-93.80	0.54	14.29	6.87
4	-19.24	-95.33	-0.09	13.76	13.64
5	-16.65	-68.25	-0.34	17.09	16.24
t value	-4.32	-3.25	0.05	17.02	4.20

Comparing the results in table 8 and table 9, it shows that the liquidity level for more liquid exchanges is higher than usual, while the less liquid exchanges are more illiquid during the announcement period. One explanation might be that the capital tends to flow into the more liquid market when the market is hit by big news.

5.2 Second Announcement

Elon Musk released the second announcement at 07:02:40, March 24, 2021. It declared that Tesla would accept Bitcoin as a payment method in the USA. Tesla has already mentioned in its 10-k filing that it was considering accepting bitcoin as a payment method on February 8, 2021. Figure 14 shows that the price of bitcoin increased by more than 2,500 dollars shortly after the second announcement. Even though price deviations exist across exchanges, the price still moved in similar trends.

For the second announcement, the same event study framework is used. The event time is the announcement time: 7 am March 24, 2021.

$$Liquidity_{it} = \alpha_t + \alpha_i + \sum_{j=-2}^{j=5} \beta_{0j} I(event_{it} = j) + \beta_1 Momentum_{it} + \beta_2\ Google\ Trend_{it} + \epsilon_{it}$$

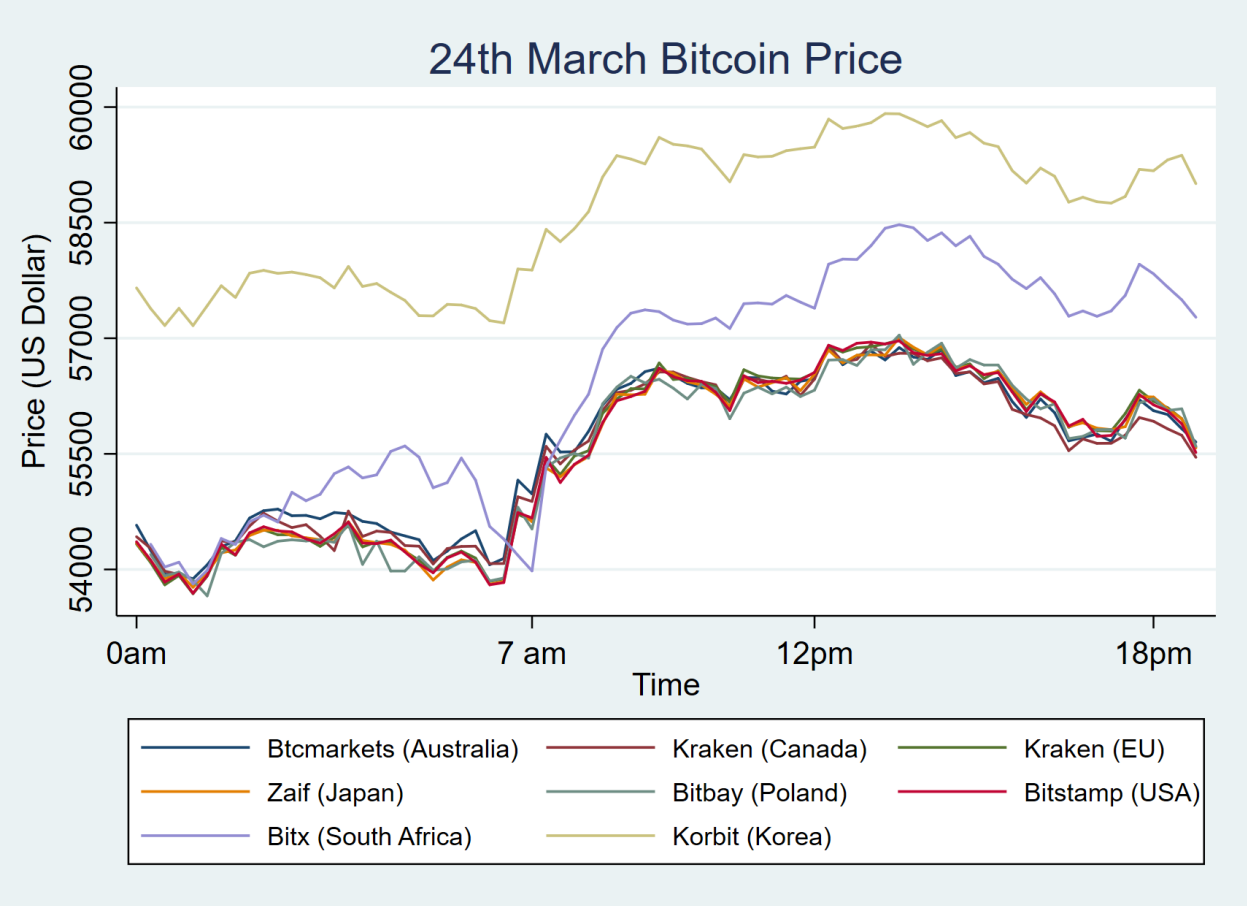

Figure 14: Tesla 2nd Announcement Bitcoin Price

Table 10 documents the abnormal liquidity level at Bitstamp (USA) during the second announcement period. It is similar to the abnormal liquidity during the first announcement. The abnormal Amihud, abnormal KO, and abnormal Roll are negative. And the abnormal TX and abnormal $Vol are positive. Other abnormal liquidity measures are negative. All the results indicate that the market is more liquid than usual. One explanation is that once the news was released, investors have more tendency to trade. After period 0, the abnormal TX and abnormal $Vol surged. The abnormal TX value at period 0 and period 1 are 17.79 and 21.48. And the abnormal $Vol is 213.78 in the first period. Even though the change is not as dramatic as the first announcements, the results are still significant. The reason why the price changing in the second announcement is not as steep as the first one is that Tesla has already mentioned that they might accept Bitcoin as a payment method before. As a result, the second announcement is not breaking news to the public as the first announcement.

Table 11 shows the abnormal liquidity at Kraken (Canada) during the second announce-

Table 10: Second Announcement Abnormal Liquidity at Bitstamp (USA)

Time	Abnormal TX	Abnormal $Vol	Abnormal Amihud	Abnormal KO	Abnormal Roll
-2	15.03	132.69	-0.67	-10.17	-5.63
-1	9.98	77.66	-0.83	-9.76	-7.25
0	17.79	199.16	-0.88	-10.49	-5.42
1	21.48	213.78	-0.56	-9.12	6.08
2	6.07	101.62	-0.49	-8.69	-3.66
3	13.24	111.66	-1.10	-9.71	-4.57
4	7.06	67.79	-0.36	-9.40	-6.91
5	18.16	170.58	-0.45	-9.66	-9.67
t value	6.94	6.93	-7.50	-47.98	-2.79

ment. The abnormal TX and the abnormal $Vol at Kraken (Canada) are negative, consistent with the results in the first announcement. When the market was influenced by the big news, the trading at Kraken (Canada) is less active than the predicted level.

Table 11: Second Announcement Abnormal Liquidity at Kraken (Canada)

Time	Abnormal TX	Abnormal $Vol	Abnormal Amihud	Abnormal KO	Abnormal Roll
-2	-6.19	-37.83	-0.54	16.65	2.06
-1	-10.03	-54.67	-0.69	20.49	8.13
0	-16.17	-68.00	1.31	28.47	7.42
1	-17.29	-74.93	-0.05	22.86	-3.96
2	-13.18	-57.46	0.32	26.85	3.54
3	-9.44	-38.68	-0.93	22.49	11.31
4	-7.75	-10.47	-0.28	15.48	12.44
5	-12.70	-45.00	-0.21	19.48	-6.86
t value	-8.35	-6.76	-0.53	13.43	1.73

5.3 Third Announcement

In the third announcement, Tesla decided to stop accepting bitcoin as a payment method. As it announced on March 24th that they would accept Bitcoin as a payment in the USA and continually accept it as a payment method in other countries, the market did not expect the reverse. The information was released by Elon Musk's Twitter at 22:06:14, May 12, 2021. Figure 15 shows the price changes of Bitcoin in different exchanges. After the announcement, the Bitcoin price fell from 55,000 to 48,000 in around 2 hours. Even though the price started to bound up later, stop accepting bitcoin as a payment still had a significant adverse effect on Bitcoin price.

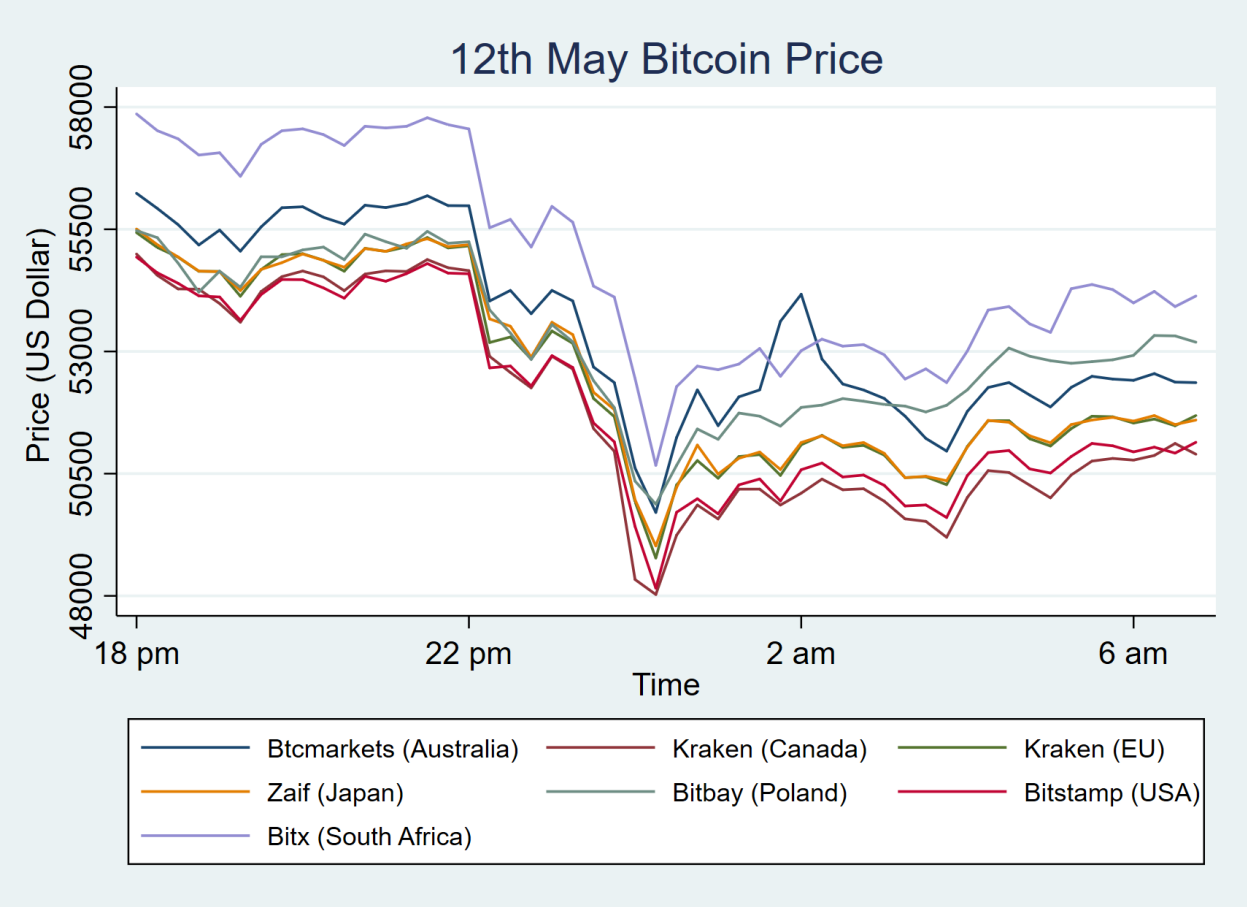

Figure 15: Tesla 3rd Announcement Bitcoin Price

Table 12 presents the abnormal liquidity at Bitstamp (USA). Even though the third announcement is negative news to the market, the abnormal liquidity shares the same characteristics as the two announcements before. The abnormal TX and abnormal $Vol are all positive. And the abnormal Amihud, abnormal KO, and abnormal Roll are negative after the announcement. The abnormal TX and abnormal $Vol are 27.28 and 267.9 at period 0. It is more volatile than the second announcement.

Table 13 shows the abnormal liquidity at Kraken (EU). The abnormal TX and abnormal $Vol are all negative. At period 0, the abnormal TX is -34.16, and the abnormal $Vol is -158.63. The abnormal KO and abnormal Roll are primarily positive. Kraken (Canada) is less liquid during the third announcement period. As a result, the abnormal liquidity in these three announcements shares the same characteristics. The liquidity level becomes

higher for the liquid market, while the illiquid market tends to have more illiquid.

Table 12: Third Announcement Abnormal Liquidity at Bitstamp (USA)

Time	Abnormal TX	Abnormal $Vol	Abnormal Amihud	Abnormal KO	Abnormal Roll
-2	9.46	81.83	-1.08	-8.04	-13.62
-1	5.80	49.54	-1.42	-10.76	-3.49
0	27.28	367.90	-0.99	-9.21	-8.83
1	30.85	353.64	-1.29	-9.01	-12.11
2	47.43	628.49	-0.92	-11.57	4.28
3	20.54	187.62	-0.84	-13.07	-9.69
4	19.89	203.66	-1.04	-12.62	-21.52
5	19.25	143.46	-1.09	-7.85	-9.96
t value	4.91	3.74	-16.13	-14.31	-3.53

Table 13: Third Announcement Abnormal Liquidity at Kraken (Canada)

Time	Abnormal TX	Abnormal $Vol	Abnormal Amihud	Abnormal KO	Abnormal Roll
-2	-11.64	-45.31	-0.87	15.13	11.78
-1	-9.65	-24.23	-1.27	19.84	12.23
0	-34.16	-158.63	-0.89	24.92	3.20
1	-31.31	-140.53	-1.20	21.56	10.06
2	-42.04	-250.52	-0.60	18.81	24.07
3	-17.92	-113.55	-0.28	7.77	2.28
4	-13.83	-88.00	-0.93	14.29	-2.19
5	-17.98	-88.74	-0.82	10.10	14.63
t value	-5.29	-4.52	-7.67	8.05	3.25

6 Conclusion

This paper studies the Bitcoin market liquidity and price deviations. Six hourly liquidity measures, the number of transactions (TX), the trading dollar volume ($Vol), the Amihud ratio (Amihud), the Kyle and Obizhaeva ratio (KO), the Abdi and Ranaldo ratio (AR), and the Roll serial covariance ratio (Roll), are introduced to describe liquidity level across exchanges. Persistent liquidity deviations and price gaps exist across exchanges. Moreover, the liquidity level in exchange does not show a time series increasing or decreasing trend overall. The liquid market keeps to be liquid, and the illiquid market tends to be illiquid. The global liquidity index is constructed by applying the Paasche index, which combines the liquidity measures at eight exchanges with the dollar trading volume. It shows that the

liquidity level of the whole Bitcoin market was active back in 2017. In contrast, the market became less liquid in 2018 and 2019. Until 2021, it became booming again.

After controlling the time fixed effect, exchange fixed effect, and the price momentum, the price gaps are still positively correlated with the liquidity deviations. Exchanges with larger liquidity level deviations are more likely to have higher price deviations.

Use the Google search index to simulate the public attention; the liquidity factors model shows the correlation between liquidity level and Google search index. The liquidity level is positively correlated to the Google search index. When the Google search index is high, Bitcoin markets tend to be more liquid. Furthermore, these results hold for five liquidity measures except for the AR index.

The Tesla announcements event study examines the effects of exogenous shocks on the Bitcoin market's liquidity level. Use the liquidity factors model to be the liquidity benchmark. It shows that different stories happened in liquid and illiquid Bitcoin exchanges when Tesla announcements were released. For liquid Bitcoin exchange, Tesla announcements had a positive effect on its liquidity level. While for the illiquid Bitcoin exchange, its liquidity level is negatively influenced by Tesla announcements. It was even more illiquid comparing to the case without the announcements. When the market is hit by big news, capital will have more incentive to flow into the more liquid exchanges than the illiquid ones.

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