On the day-of-the-week effects of Bitcoin markets: international evidence

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Abstract

Purpose – The purpose of this paper is to examine the day-of-the-week effects of Bitcoin (BTC) markets on the exchange level from January 2014 to September 2018.
Design/methodology/approach – The in-depth study on the day-of-the-week effects is conducted by using data consisting of Bitcoin prices denominated in 20 fiat currencies from 23 Bitcoin trading exchanges through the method of rolling sample for calendar effect proposed by Zhang *et al.* (2017).
Findings – It is shown by the empirical results that different patterns of the day-of-the-week effects are observed on Bitcoin denominated in various fiat currencies by referring to the price data collected from exchanges. Furthermore, the patterns of the day-of-the-week effects are also available after adjusting Bitcoin prices denominated in domestic currencies into USD.
Research limitations/implications – Because of the discontinuity of data for some daily return series, estimation with dynamic variance is not applicable. It is assumed that the error item follows normal distribution with constant variance.
Originality/value – The day-of-the-week effects are wide-spread in Bitcoin markets, and they are not mainly caused by movements of foreign exchange rates. Actually, empirical findings in this study provide evidence for inefficiency of Bitcoin markets.

Keywords Day-of-the-week effect, Bitcoin return, Currencies, Rolling window

Paper type Research paper

1. Introduction

Because of the features of decentralization and scarcity, there are differences between Bitcoin and other assets in financial markets. On one hand, Bitcoin has emerged as a new financial asset which attracts attention from not only investors but also media since its being introduced by Nakamoto (2008). It indeed provides an alternative choice for both investment optimization and risk management when the investors are confronted with the rises in price and market capitalization. Benefiting from the decentralization of the blockchain, Bitcoin is also employed as a channel for capital flight and money laundering which is quite conductive to illegal economic activities. On the other hand, Bitcoin, which has no fundamental value, is much more volatile compared with traditional financial assets, and therefore investment on Bitcoin could be very risky. In addition, as both pricing factors and pricing mechanism of this crypto currency have not been clear enough so far, further studies on the financial asset properties of Bitcoin remain to be conducted.

The day-of-the-week effect, which is known as one of the calendar anomalies in financial markets, refers to the fact that returns are different on specific weekdays. According to the efficient market hypothesis (EMH), it can be concluded that investors could not obtain abnormal returns on the basis of public information collected. Under this premise, expected returns in the efficient market on each weekday should be almost identical. However, it is

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found through previous researches that weekend effects or day-of-the week effects are available in both stock markets and foreign exchange markets. In the meanwhile, the existence of the day-of-the-week effect provides evidence for the inefficiency of financial markets. Since Bitcoin exchanges are open all round the clock every day without holidays and weekends, relevant information released should be incorporated into price immediately, and the continuous generation of Bitcoin returns are accessible. In other words, the distribution of Bitcoin returns should be the same in calendar time.

There are large amounts of literature on the day-of-the-week effects presented in the stock markets. Cross (1973) reported the significant difference shown between returns on Friday and Monday, according to the daily return data obtained from S&P Composite Stock Index. French (1980) found the existence of negative mean returns on Monday obtained from S&P Composite Stock Index. Gibbons and Hess (1981) discovered negative mean returns on Monday based on the statistics collected from 30 stocks of Dow Jones. Researches (Keim and Stambaugh, 1984; Rogalski, 1984; Smirlock and Starks, 1986, etc.) confirmed the abnormally low returns on Monday and high returns on Friday existing in the US stock markets. Further, day-of-the-week effects were also available in other equity markets. It was reported by Jaffe and Westerfield (1985) that the weekend effect on returns can also be found in UK, Japan, Canada and Australia. However, the lowest mean returns were found on Tuesday in both Japanese and Australian stock markets. Moreover, subsequent studies (Dubois and Louvet, 1996; Choudhry, 2000; Brooks and Persand, 2001; Basher and Sadorsky, 2006; Yalcin and Yucel, 2006; Zhang *et al.*, 2017) found different patterns of the day-of-the-week effects in both developed and emerging stock markets.

In addition to stock markets, the day-of-the-week effects can also be found in other markets. McFarland *et al.* (1982) first recorded the day-of-the-week effects on foreign exchanges that returns of currency prices denominated in USD were high on Mondays and Wednesdays, but low on Thursdays and Fridays. Hsieh (1988) further proposed that return distributions on each day of the week may be different for British Pound, Canadian Dollar and Deutsche Mark, as well as Japanese Yen. Aydoğan and Booth (2003) put forward the day-of-the-week effect in the Turkish foreign exchange markets from 1986 to 1994. Yamori and Kurihara (2004) came to the conclusion that the day-of-the-week effects existed in some currencies during the 1980s in the foreign exchange market in New York, but the day-of-the-week effects shown by all currencies disappeared during the 1990s. Moreover, studies conducted for the day-of-the-week effects on foreign currencies were also carried by Corhay *et al.* (1995), Berument *et al.* (2007), Ke *et al.* (2007). Additionally, the day-of-the-week effects or weekend effects were also available in gold market (Ma, 1986; Aydoğan and Booth, 2003), future market of foreign currency (Cornett *et al.*, 1995), crude oil market (Yu and Shih, 2011) and so on.

Presently, the day-of-the-week effect on Bitcoin return is still under exploration. Kurihara and Fukushima (2017) discovered the day-of-the-week effect on Bitcoin return with the data spanning from July 17, 2010 to December 29, 2016 which was downloaded from www.bitcoinaverage.com, and further found that Bitcoin market is becoming increasingly efficient. And Décourt *et al.* (2017) also discovered that the average return on Monday is significantly higher by studying in detail daily returns of Bitcoin Price Index (BPI) from Coindesk. Caporale and Plastun (2018) found abnormally positive returns on Monday in Bitcoin market after analyzing the day-of-the-week effect in several crypto currencies according to the data obtained from CoinMarketCap. However, Baur *et al.* (2017) found no consistent day-of-the-week effect patterns via heat maps after the analysis conducted for daily returns on exchange level of Bitcoin traded in USD (Bitstamp, BTCE, Coinbase, Kraken), CNY (BTCN), JPY (Coincheck) and EUR (Kraken) from December 31, 2010 to October 20, 2017.

It can be concluded that in-depth studies on the day-of-the-week effect in Bitcoin market are still rare to be seen. Therefore the rolling window analysis of calendar effect proposed by

Zhang *et al.* (2017) is conducted to study on the day-of-the-week effects of Bitcoin traded in 20 different fiat currencies from 23 Bitcoin exchanges.

This study aims to examine the day-of-the-week effects in Bitcoin markets, including BPI from Coindesk, and Bitcoin denominated in 20 fiat currencies from 23 exchanges. Top nine fiat currencies, including CNY, USD, EUR, JPY, GBP, KRW, PLN, CAD and AUD, which used to possess a high proportion of Bitcoin spot trading volume, and play an important part in the evolution of Bitcoin price, are mainly focused on. In addition, investigation on Bitcoin traded in other 11 domestic currencies is reported as well. As a result, significant Monday and Thursday effects are detected on the BPI which represents global trend, and different day-of-the-week effect patterns from Bitcoin prices on exchange level are shown as well. Furthermore, it is discovered that the day-of-the-week effects of Bitcoin markets are also available after adjusting prices denominated in domestic currencies into USD. All the above-mentioned results indicate that day-of-the-week effects of Bitcoin markets are not mainly caused by the movements of exchange rates.

The other parts of this study is organized as follows: Section 2 presents data source and sample selection; Section 3 gives the description of the methodology applied in this study; Section 4 mainly reports empirical results obtained from regressions; Section 5 provides conclusions.

2. Data

As for the data about daily prices of Bitcoin in all currencies and exchanges, they are downloaded from Bitcoincharts, which is known as a website collecting daily data of Bitcoin trading from various exchanges. This study analyzes mainly Bitcoin daily returns of 30 samples which cover a total of 20 fiat currencies from 23 different exchanges. As a consequence, the number of research samples is 31 in total, including BPI downloaded from Coindesk. For the purpose of observing common behavior, daily returns are selected on the basis of the observation carried out from January 1, 2014 to September 30, 2018. However, as shown in Table I, missing values of some samples are available. Furthermore, this study follows the time standard of Coordinated Universal Time (UTC).

Table I shows the general information related to data sources of this study. Currency codes and fiat currencies are shown in the first two columns; exchange names that Bitcoin trading occurred are displayed in the third column; the first and last dates of research samples are available in both the fourth and fifth columns; whether there are missing values from the first date to the last date is shown in the last column.

3. Method

A method that is similar to that of Zhang *et al.* (2017) is applied in this study. Zhang *et al.* (2017) used a regression with weekday dummies to study on the day-of-the-week effects on stock markets, and specified the variance as a GARCH (1, 1) process to illustrate the dynamic volatility. Afterwards, Zhang *et al.* (2017) employed a method of rolling sample to investigate the robustness for the day-of-the-week effect on stock market returns. Rolling window analysis is able to avoid data snooping because all data samples are employed when the window length is selected.

3.1 Daily return

In this study, daily return R_t is defined as the raw return:

$$R_t = (P_t - P_{t-1})/P_{t-1} \times 100, \tag{1}$$

where P_t refers to the closing price on date t. Generally, daily return of financial assets is defined as the logarithm difference in relevant studies, but there will be large bias when dramatic fluctuation exists in Bitcoin prices on the exchange level.

Code	Currency	Exchange	First	Last	Missing
BPI	USA Dollar		January 1, 2014	September 30, 2018	No
AUD	Australian Dollar	BTCMarkets	January 1, 2014	September 30, 2018	Yes
BRL	Brazilian Real	Mercado Bitcoin	January 1, 2014	September 30, 2018	No
CAD	Canadian Dollar	Kraken	March, 10 2016	September 30, 2018	Yes
CNY	Chinese Yuan	BTCChina/BTCC	January 1, 2014	September 30, 2017	Yes
CNY	Chinese Yuan	BTCtrade	January 1, 2014	September 30, 2017	No
CZK	Czech Koruna	Bitstock	January 1, 2014	September 28, 2018	Yes
EUR	EURO	bitcoin.de	January 1, 2014	September 30, 2018	No
EUR	EURO	BTC-e	January 1, 2014	July 25, 2017	Yes
EUR	EURO	itBit	March 1, 2014	September 30, 2018	Yes
EUR	EURO	The Rock Trading	January 1, 2014	September 30, 2018	Yes
GBP	Pound Sterling	Coinfloor	January 1, 2014	September 30, 2018	Yes
IDR	Indonesian Rupiah	BitX/Luno	February 2, 2016	September 30, 2018	No
IDR	Indonesian Rupiah	Indodax	February 2, 2014	September 30, 2018	No
ILS	Israeli Shekel	Bit2C	January 1, 2014	September 30, 2018	Yes
JPY	Japanese Yen	BTCBOX	October 4, 2014	September 30, 2018	Yes
JPY	Japanese Yen	Coincheck	November 1, 2014	September 30, 2018	No
KRW	South Korean Won	Korbit	January 1, 2014	September 30, 2018	No
MYR	Malaysian Ringgit	BitX/Luno	October 9, 2014	September 30, 2018	Yes
NGN	Nigerian Naira	BitX/Luno	September 9, 2015	September 30, 2018	Yes
PLN	Polish Zloty	BitBay	March 30, 2014	September 30, 2018	No
RUB	Russian Ruble	BTC-e	January 1, 2014	July 25, 2017	Yes
SGD	Singapore Dollar	itBit	January 1, 2014	May 18, 2018	Yes
USD	USA Dollar	bitKonan	January 1, 2014	September 30, 2018	Yes
USD	USA Dollar	BitStamp	January 1, 2014	September 30, 2018	Yes
USD	USA Dollar	CEX.IO	July 19, 2014	September 30, 2018	Yes
USD	USA Dollar	itBit	January 1, 2014	September 30, 2018	Yes
USD	USA Dollar	Kraken	January 8, 2014	September 30, 2018	Yes
VEF	Venezuelan Bolvar	SurBitcoin	August 16, 2014	September 9, 2017	Yes
VND	Vietnamese Dong	VBTC	September 10, 2015	September 30, 2018	Yes
ZAR	South African Rand	BitX/Luno	January 1, 2014	September 30, 2018	Yes

Table I.
Bitcoin exchange list

3.2 Linear regression with dummies

For the purpose of examining the existence of the day-of-the-week effects on the Bitcoin returns, a linear regression model with weekday dummies is conducted in this study:

$$R_t = \sum_{i=1}^{7} \beta_i D_{it} + \epsilon_t, \tag{2}$$

where D_{it} is the dummy variable of weekday i, β_i the expected return on weekday i. If the t-value of β_i is larger than 1.96 or lower than −1.96, then it can be acknowledged that β_i is statistically different from zero at the 5 percent significance level. Subsequently, the detection of a day-of-the-week effect is carried out on weekday i. Moreover, ϵ_t is the error item. Because of the discontinuity of data for some daily return series, GARCH(1,1) model used by Zhang *et al.* (2017) is not applicable, and it is assumed that the error item here follows normal distribution with constant variance.

3.3 Rolling window analysis

In order to analyze the robustness or significance of the day-of-the-week effects existing in Bitcoin markets, a method of rolling window regression, which is similar to that of Zhang *et al.* (2017), is adopted in this study. In addition, the measurement q for the performance of calendar effect proposed by Zhang *et al.* (2017) is also utilized here:

$$q_i = \frac{m_i}{M} \times 100\%, \tag{3}$$

where i is a weekday, m_i the number of t statistic which is either larger than 1.96 or lower than −1.96 in all rolling regressions, M the total number of rolling regressions with a selected rolling window length. Moreover, q_+ is used to denote q with positive t-values, and q_- is employed to represent q with negative t-values in empirical analysis later. In the study, larger q value means that higher frequency of specified t-values is obtained, and higher significance of the day-of-the-week effect is observed on a specific weekday.

4. Empirical results

4.1 Descriptive statistics

Table II shows summary statistics of daily returns obtained from Bitcoin. The column named as "Obs" shows in detail the total number of observations carried out for each sample. In addition, the forth column lists the average return obtained from every sample. It is observed that the highest mean return (2.1849) comes from the SurBitcoin exchange providing BTC/VEF trading, while the lowest mean return (0.1626) is available in the BTC/EUR trading which comes from the BTC-e exchange. The fifth column of the table presents the standard deviation (Std. Dev.) of mean return. Moreover, the sixth and seventh columns show the minimum and maximum daily returns obtained from each sample, respectively. It is further concluded that the return ranges of BTC/CZK from Bitstock and BTC/EUR from bitcoin.de are all very large, and it is also suggested by corresponding standard deviations that large volatility exists in the daily returns from the two exchanges. The last two columns

Code	Exchange	Obs	Mean	SD	Min.	Max.	Skew	Kurt
BPI		1,734	0.2026	3.9370	−21.8962	25.4093	0.0785	5.1984
AUD	BTCMarkets	1,730	0.2253	4.1668	−18.7377	23.7327	0.2532	4.8406
BRL	Mercado Bitcoin	1,734	0.2226	3.7138	−22.3915	42.9639	0.5855	14.5724
CAD	Kraken	931	0.3745	4.3275	−26.2830	22.4501	−0.1486	4.5046
CNY	BTCChina	1,300	0.2152	3.8716	−28.0039	19.7242	−0.3979	7.7084
CNY	BTCtrade	1,369	0.2030	3.8905	−27.3451	24.3569	−0.1788	8.4658
CZK	Bitstock	1,532	0.3301	7.5974	−65.2888	190.5429	10.0545	260.0643
EUR	bitcoin.de	1,734	0.2651	5.2233	−49.6105	95.3846	3.5186	74.2716
EUR	BTC-e	1,290	0.1626	3.4405	−22.6418	21.2427	−0.1858	7.5075
EUR	itBit	1,549	0.2121	4.5866	−96.7181	24.2392	−6.0968	129.3600
EUR	The Rock Trading	1,719	0.2131	3.8532	−18.6791	24.2662	0.0688	4.5610
GBP	Coinfloor	1,632	0.2774	4.2279	−22.0949	46.3000	0.8882	11.9519
IDR	BitX	958	0.3835	4.0027	−27.5898	37.2618	0.5493	14.8290
IDR	Indodax	1,694	0.2134	3.7154	−27.9742	33.3936	0.1229	12.2858
ILS	Bit2C	1,732	0.2313	4.4972	−23.0769	25.8960	0.1105	4.5096
JPY	BTCBOX	1,633	0.2589	4.2990	−29.1835	41.2170	0.5196	12.5610
JPY	Coincheck	1,430	0.3004	4.2774	−27.3049	42.3619	0.6639	14.2445
KRW	Korbit	1,734	0.2126	4.0584	−25.2085	28.1478	0.2089	8.9954
MYR	BitX	1,416	0.3477	5.0377	−33.3333	50.0000	1.3611	16.1317
NGN	BitX	932	0.4151	4.9194	−29.2408	34.0595	0.4750	8.7193
PLN	BitBay	1,646	0.1878	3.8972	−60.2273	27.8195	−2.1156	38.9270
RUB	BTC-e	1,228	0.2048	3.1602	−19.6383	15.8629	−0.2240	5.6528
SGD	itBit	1,514	0.1636	4.0831	−22.7226	25.9534	−0.0469	5.4873
USD	bitKonan	1,681	0.3040	5.5713	−33.6918	60.5406	0.9720	12.7742
USD	BitStamp	1,730	0.2028	3.9777	−24.4890	26.9211	0.1233	5.7645
USD	CEX.IO	1,533	0.2243	3.7194	−20.0166	22.7218	−0.0254	5.7257
USD	itBit	1,688	0.2140	3.9464	−20.3098	25.8599	0.1442	5.1049
USD	Kraken	1,667	0.2044	4.1566	−25.2881	26.6024	0.0850	4.8746
VEF	SurBitcoin	1,064	2.1849	22.1242	−90.0000	430.0000	10.5432	171.8739
VBTC	VND	1,065	0.4560	4.7075	−24.9017	36.7024	0.8980	9.4440
ZAR	BitX	1,476	0.2108	4.3716	−29.4872	25.8701	−0.1501	6.4724

Table II.
Descriptive statistics

list Skewness and excess Kurtosis of each sample, respectively. It is shown by excess Kurtosis that daily returns of all samples are heavy-tailed.

4.2 Preliminary results

Table III shows all estimates of linear regressions and corresponding significance levels which are marked with asterisks. According to the asterisks, a Monday effect is quite significant in Bitcoin markets. It can be observed that estimated coefficients for Monday which represent the expected returns are positive for all linear regressions. In addition, among all the 31 regressions, estimated coefficients for Monday in 26 samples, including the BPI, are statistically different from zero at the 5 percent significance level, and those of three samples are statistically different from zero at the 10 percent significance level. However, the estimated coefficients for Monday are insignificant only for BTC/CAD and BTC/ZAR. In terms of Tuesday, estimated coefficients for all samples, except for BTC/GBP, are not statistically different from zero. As for Wednesday, only estimated coefficient for BTC/EUR from itBit is statistically different from zero at the 5 percent significance level. Besides, it is found that a positive and significant Thursday effect is accessible in the daily returns of BTC/CAD, BTC/EUR from itBit, BTC/JPY from Coincheck, BTC/MYR, BTC/PLN and BTC/NVD. In addition, the results show that only estimates for BTC/BRL, BTC/NGN, and BTC/ZAR are statistically different from zero at the 5 percent significance level on Friday. Moreover, mean return obtained from BTC/ZAR on Saturday is statistically different from

Code	Exchange	Mon	Tue	Wed	Thu	Fri	Sat	Sun
BPI		0.5495**	0.2245	−0.1600	0.2270	0.1784	0.3951	0.0050
AUD	BTCMarkets	1.0282***	0.3464	−0.2608	0.0694	0.2760	−0.1225	0.2462
BRL	Mercado Bitcoin	0.9740***	0.3357	−0.0265	0.3158	0.4999**	−0.0554	−0.4818**
CAD	Kraken	0.3904	0.4704	−0.0334	0.7673**	0.3108	0.4545	0.2594
CNY	BTCChina	0.6475**	0.2382	0.1140	−0.0288	0.1923	0.2771	0.0655
CNY	BTCtrade	0.5841**	0.2472	0.0523	−0.0765	0.2085	0.3492	0.0574
CZK	Bitstock	0.9744*	0.2836	0.0112	0.6609	0.6539	0.1190	−0.4909
EUR	bitcoin.de	0.6666**	−0.0277	0.2296	0.5258	0.0926	0.2248	0.1441
EUR	BTC-e	0.5531**	0.2396	−0.1134	0.1667	0.1295	0.1378	0.0256
EUR	itBit	0.5756*	0.3894	−0.7495**	0.6691**	0.4531	0.1116	0.0481
EUR	The Rock Trading	0.7916***	0.1755	−0.1839	0.3294	0.3404	0.1392	−0.0983
GBP	Coinfloor	0.8462***	0.5524**	−0.3942	0.4131	0.2831	0.1448	0.1049
IDR	BitX	0.5929*	0.3728	0.2378	0.5786*	0.2707	0.4576	0.1753
IDR	Indodax	0.5480**	0.3096	0.0252	0.2990	0.2490	0.1333	−0.0703
ILS	Bit2C	0.6338**	0.1091	−0.1558	0.2043	0.0060	0.4397	0.3808
JPY	BTCBOX	0.8125***	0.1900	0.0391	0.2242	0.3664	0.2299	−0.0502
JPY	Coincheck	0.8602***	0.0014	−0.1270	0.6827**	0.3429	0.3484	−0.0044
KRW	Korbit	0.7204***	0.1021	−0.1619	0.3014	0.2035	0.2461	0.0785
MYR	BitX	0.9869***	0.2851	−0.1818	1.0315***	0.2668	0.3168	−0.2752
NGN	BitX	1.0034**	0.1379	0.2284	0.0623	0.9814**	0.2817	0.2360
PLN	BitBay	0.6148**	0.2751	−0.2570	0.5831**	0.3240	0.0006	−0.2238
RUB	BTC-e	0.6175***	0.3659	−0.2175	0.0187	0.4399*	0.2447	−0.0349
SGD	itBit	0.6267**	0.1080	−0.1484	−0.0263	0.4445	0.0374	0.1049
USD	bitKonan	1.8969***	0.3458	−0.0459	0.4219	0.1538	0.0338	−0.6716*
USD	BitStamp	0.5829**	0.2440	−0.2009	0.2951	0.2083	0.2858	0.0053
USD	CEX.IO	0.5911**	0.1840	−0.2272	0.4008	0.1459	0.4063	0.0692
USD	itBit	0.7297***	0.1074	−0.0299	0.2441	0.1787	0.2522	0.0181
USD	Kraken	0.7281**	0.2169	−0.2160	0.3262	0.1433	0.2671	−0.0354
VEF	SurBitcoin	4.6215**	2.5837	0.5903	2.7476	2.1387	−0.5213	3.2782*
VBTC	VND	1.1100***	0.2774	0.1543	1.4318***	0.2024	0.4444	−0.4568
ZAR	BitX	0.1005	0.3139	−0.4134	0.2808	0.7662**	0.6814**	−0.2535

Notes: *,**,***Significant at 10, 5 and 1 percent levels, respectively

Table III.
Regression with dummies

zero at the 5 percent significance level, and a negative effect on Sunday is observed from the daily returns of BTC/BRL trading. Another finding from Table III shows that most estimated coefficients for Wednesday are negative, which suggests the general level of low mean returns on Wednesdays.

4.3 Rolling window analysis

In rolling window analysis, Bitcoin priced in CNY, USD, EUR, JPY, GBP, KRW, PLN, CAD and AUD are mainly focused on, and they were known as top nine fiat currencies used in exchange trading during the period of overall sample, according to the statistics from Bitcoinity.org (accessed on October 25, 2018). In addition, these top nine fiat currencies used to account for more than 90 percent of the volume for global Bitcoin spot trading.

Moreover, all the values of q on seven weekdays are reported. Besides, the highest values obtained from q_+ or q_- which are larger than 10 percent are marked in italic face. In addition, time series of t-values on each weekday are also displayed with a selected window length of 500 or 1,000 days during which Bitcoin is traded in the top nine fiat currencies. Furthermore, the date existing in each plot actually represents the last date of a rolling window period. Last, two black dash lines in each plot refer to t-value = 1.96 (upper) or t-value = −1.96 (lower).

All samples from exchanges are roughly divided into three groups based on the prominent day-of-the-week effect presented with long window length in each sample, including Monday, Thursday and all other cases. Moreover, in every group, only one table and one figure are explained in detail. All other tables and figures are shown in Appendices.

4.3.1 Day-of-the-week effect on BPI. Table IV and Figure 1 report the test results obtained from the day-of-the-week effect on BPI from Coindesk. Table IV shows that both Monday and Thursday effects are significant when the rolling window lasts for 500 or 1,000 days. Specifically, it shows that the Monday effect appears to be significant since August 2017 with

Length	q	Monday (%)	Tuesday (%)	Wednesday (%)	Thursday (%)	Friday (%)	Saturday (%)	Sunday (%)
500	q_+	*20.40*	3.16	0.08	16.36	0.00	1.70	0.00
500	q_-	0.00	0.00	1.05	0.00	0.00	0.00	0.00
1,000	q_+	*64.76*	0.00	0.00	48.71	0.00	25.58	0.00
1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table IV. q-values for BPI

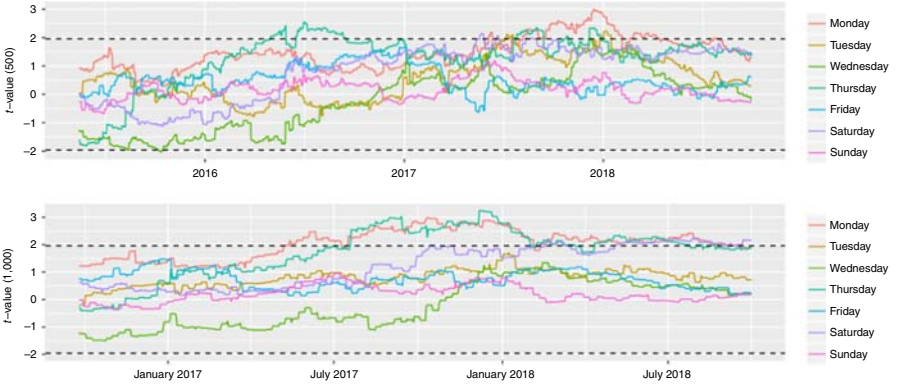

Figure 1. t-values of BPI

rolling window lasting for 500 days, and from May 2017 with rolling window lasting for 1,000 days. In the meantime, difference is found in the Thursday effect. When the rolling window has the length of 500 days, Thursday effect is observed during the periods from May 2016 to 2017, and from July 2017 to 2018, respectively. When the length of rolling window is 1,000 days, then the Thursday effect from July 2017 begins to be significant. Additionally, it is observed that a Saturday effect is available from February 2018. Outstanding Monday effect detected in BPI returns here is in line with the findings from the studies conducted by Décourt *et al.* (2017) and Caporale and Plastun (2018).

The cause of the weekday anomaly on Bitcoin return is still under exploration. Aharon and Qadan (2018) proposed that high mean return on Monday has close association with high volatility. Ma and Tanizaki (2019) also reported higher volatilities on Monday and Thursday. It is obtained that the significant Monday and Thursday effects on BPI return are possibly originated from high volatilities.

4.3.2 Prominent Monday effects. Tables V and AI in Appendix 1 show all q-values of time series with prominent Monday effects in the long run, including BTC/CNY (BTCChina and BTCtrade), BTC/USD (bitKonan, BitStamp, CEX.IO, itBit and Kraken), BTC/EUR (bitcoin.de, BTC-e and The Rock Trading), BTC/JPY (BTCBOX and Coincheck), BTC/GBP (Coinfloor), BTC/KRW (Korbit), BTC/AUD (BTCMarkets), BTC/BRL (Mercado Bitcoin), BTC/IDR (BitX), BTC/ILS (Bit2C), BTC/NGN (BitX), BTC/RUB (BTC-e), BTC/SGD (itBit) and BTC/VND (VBTC). Apart from BTC/USD from itBit, figures for t-values from other samples are presented in Appendix 1.

Table V and Figure 2 show the test results of the day-of-the-week effect of BTC/USD obtained from itBit. It is shown that followed by Thursday effect, Monday effect is significant when both rolling window lengths are available. In addition, when the length of rolling window is 500 days, the values of q_+ obtained from Monday and Thursday are 38.02

Table V. q-values for BTC/USD from itBit

Length	q	Monday (%)	Tuesday (%)	Wednesday (%)	Thursday (%)	Friday (%)	Saturday (%)	Sunday (%)
500	q_+	*38.02*	0.00	0.59	21.87	0.00	0.00	0.00
500	q_-	0.00	0.00	0.08	0.00	0.00	0.00	0.00
1,000	q_+	*75.56*	0.00	0.00	58.78	0.00	0.00	0.00
1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00

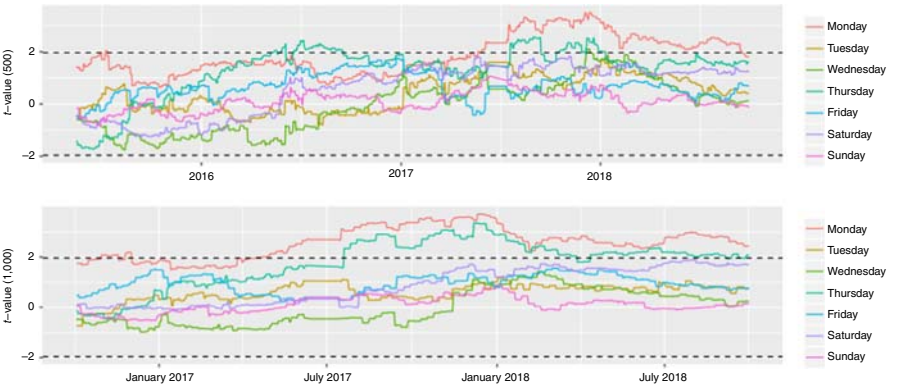

Figure 2. t-values of Bitcoin priced in USD from itBit

and 21.87 percent, respectively. When the length of rolling window increases, the values of q_+ are 75.56 and 58.78 percent, respectively. Figure 2 shows that Monday effect starts from May 2017 when there is a rolling window period of 500 days. In terms of long length of rolling window, Monday effect starts from April 2017, and Thursday effect starts from July 2017.

4.3.3 Prominent Thursday effects. Tables VI and AII show all q-values of five time series with prominent Thursday effects in long run, including BTC/EUR (itBit), BTC/PLN (BitBay), BTC/IDR (Indodax), BTC/MYR (BitX) and BTC/VEF (SurBitcoin). Apart from BTC/EUR from itBit, figures for t-values of other samples are also presented in Appendix 2.

Table VI and Figure 3 show the test results of the day-of-the-week effect of BTC/EUR obtained from itBit. Instead of prominent Monday effect in BTC/USD trading from the same exchange, Thursday effect is more robust with both rolling window length when Bitcoin is denominated in EURO. The values of q_+ obtained from Thursday are 25.05 and 66.73 percent, respectively, whereas the values of q_+ obtained from Monday are 10.10 and 48.55 percent, respectively. Figure 3 shows that Thursday effect is more robust after October 2017 when the window length of a long period is available, and t-values on Wednesday are low. Additionally, the sharp decline of t-values on Wednesday mainly caused by dramatically low closing price in itBit on January 24, 2018.

4.3.4 Prominent effects on other weekdays. Table VII shows q-values obtained from three time series with prominent effects on other weekdays, including Tuesday effect on BTC/CAD (Kraken), Friday effects on BTC/CZK (Bitstock) and BTC/ZAR (BitX). As data of BTC/CAD collected from Kraken is not sufficient enough, only the analysis on a window length of 500 days is carried out. As shown in Table VII, a Tuesday effect with the value of q_+ equal to 41.44 percent is prominent. Accurately, Tuesday effect can be observed before February 2018 shown in Figure 4. For BTC/CZK, robust Friday effect is detected when both the two lengths

Length	q	Monday (%)	Tuesday (%)	Wednesday (%)	Thursday (%)	Friday (%)	Saturday (%)	Sunday (%)
500	q_+	10.10	2.00	0.00	*25.05*	7.43	0.00	0.00
500	q_-	0.00	0.00	*17.33*	0.00	0.00	0.00	0.00
1,000	q_+	48.55	0.00	0.00	*66.73*	15.09	0.00	0.00
1,000	q_-	0.00	0.00	9.82	0.00	0.00	0.00	0.00

Table VI. q-values for BTC/EUR from itBit

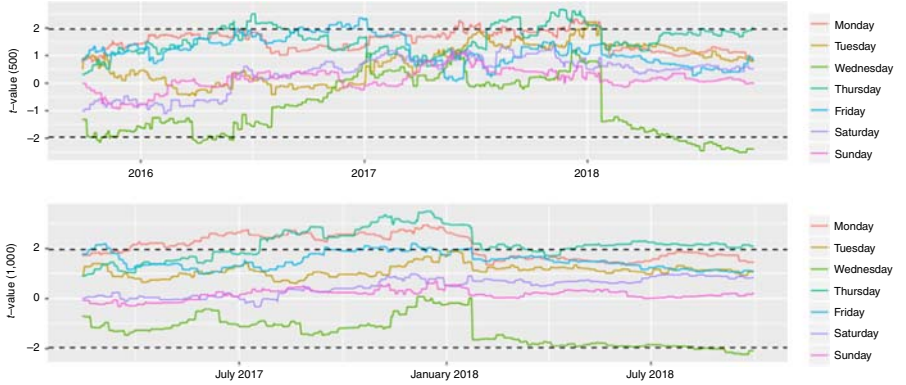

Figure 3. t-values of Bitcoin priced in EUR from itBit

Table VII.
q-values of samples with prominent effects on other weekdays

Code	Exchange	Length	q	Monday (%)	Tuesday (%)	Wednesday (%)	Thursday (%)	Friday (%)	Saturday (%)	Sunday (%)
CAD	Kraken	500	q_+	9.26	*41.44*	1.62	0.46	0.00	0.00	0.00
CAD	Kraken	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CZK	Bitstock	500	q_+	15.20	0.00	0.00	20.43	*45.79*	0.00	0.00
CZK	Bitstock	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.68
CZK	Bitstock	1,000	q_+	8.44	0.00	0.00	0.00	*69.79*	0.00	0.00
CZK	Bitstock	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ZAR	BitX	500	q_+	15.05	2.15	0.00	1.43	35.93	*45.45*	0.00
ZAR	BitX	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ZAR	BitX	1,000	q_+	0.00	0.00	0.00	0.00	*58.28*	41.93	0.00
ZAR	BitX	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 4.
t-values of Bitcoin priced in CAD from Kraken

of rolling window are available. The values of q_+ on Friday are 45.79 and 69.79 percent, respectively, with both the two lengths of rolling window, which is not revealed in regression in Table III. With respect to BTC/ZAR, significant Friday and Saturday effects are identified. The three day-of-the-week effects are different from weekday patterns obtained from previous findings. When the rolling window length is 500 days, the values of q_+ on Friday and Saturday are 35.93 and 45.45 percent, respectively, whereas the values of q_+ on Friday and Saturday with long rolling window length are 58.28 and 41.83 percent, respectively, which is consistent with significant expected returns shown in Table III.

4.4 q values for Bitcoin adjusted in USD

For the purpose of excluding the impact of exchange rate changes on domestic Bitcoin prices, Bitcoin denominated in domestic currency is then adjusted into USD through exchange rate transformation as follows:

$$\frac{BTC_t}{USD_t} = \frac{BTC_t/X_t}{USD_t/X_t} \tag{4}$$

$$R_{t+1}^{BTC/USD} = \left(\frac{BTC_{t+1}}{USD_{t+1}} - \frac{BTC_t}{USD_t}\right) \Big/ \frac{BTC_t}{USD_t} \times 100, \tag{5}$$

where X refers to the currency of interest.

Table AIII displays the values of q_+ and q_- for the Bitcoin returns after its price being denominated in USD. In addition, all related exchange rates denominated in domestic currencies are collected from the Bank of England, including USD/AUD, USD/CAD, USD/

CNY, USD/CZK, USD/EUR, USD/GBP, USD/ILS, USD/JPY, USD/KRW, USD/MYR, USD/PLN, USD/RUB, USD/SGD and USD/ZAR.

Moreover, after adjusting the prices of Bitcoin denominated in domestic currencies into USD, the day-of-the-week effects of Bitcoin are still observed, as shown in Table AIII. Besides, the patterns of day-of-the-week effect possessed by Bitcoin denominated in most fiat currencies stay relatively stable after price adjustment, which reveals the fact that the day-of-the-week effects on Bitcoin are not mainly caused by the movements of exchange rates.

4.5 Additional analysis

First, this study only focuses on the existence of the day-of-the-week effects on returns of Bitcoin markets, but does not pay attention to the causes of these effects. One possible explanation for the weekday anomaly detected from Bitcoin markets is the difference of sentiment across the weekdays. As Bitcoin is not backed by any government or central bank, its price and volatility could be possibly affected by attention or sentiment (see Bukovina and Marticek, 2016; Karalevicius *et al.*, 2018; Aharon and Qadan, 2018). Shen *et al.* (2019) further put forward that the attention to Bitcoin indexed by number of tweets has strong association with realized volatility and volume of Bitcoin on next trading day. However, as the day-of-the-week effects are not identical, further investigation on the cause of this weekday anomaly should be conducted.

Second, according to empirical results above, the day-of-the-week effects on Bitcoin returns are not platform or exchange specified. In this study, Kraken, itBit and BitX operate exchanges between Bitcoin and more than one fiat currencies. For Kraken, when the length of rolling window is 500 days, robust Tuesday effect is observed in BTC/CAD trading from July 2017 to January 2018 as shown in Figure 4. However, this phenomenon is not found in BTC/USD trading during the same period as shown in Figure A6. In terms of itBit, Monday effect is more outstanding in BTC/USD trading than that in BTC/EUR trading during the same period. With respect to BitX, patterns of the day-of-the-week effects on BTC/MYR and BTC/ZAR are totally different as displayed in Tables VII and AII. To some extent, the day-of-the-week effects of Bitcoin markets observed in this study are more relevant to fiat currencies.

5. Conclusions

This study applies the analysis method of rolling window for calendar effect proposed by Zhang *et al.* (2017) to examine the day-of-the-week effects on Bitcoin returns obtained from BPI and 30 time series of Bitcoin prices denominated in 20 fiat currencies from 23 exchanges from January 2014 to September 2018. First, with the simple linear regressions, significantly positive Monday effect was detected in daily returns of BPI and Bitcoin prices denominated in most domestic currencies. Second, it is revealed by rolling window analysis that different patterns of the day-of-the-week effects are available in Bitcoin returns on the exchange level. More specifically, prominent positive Monday effect and/or Thursday effect are observed when Bitcoin is priced in CNY, USD, EUR, JPY, GBP, KRW, PLN, AUD, BRL, IDR, ILS, MYR, NGN, RUB, SGD, VEF and VND by employing the price data collected from various exchanges; the anomaly of high mean return on Tuesday is significant when Bitcoin is traded in CAD from Kraken before February 2018; outstanding positive Friday effect is obtained when Bitcoin is priced in CZK from Bitstock; robust Saturday effect is detected when Bitcoin is traded in ZAR from BitX. Moreover, studies conducted on the Bitcoin adjusted into USD show that the day-of-the-week effects of Bitcoin markets are not mainly caused by the movements of exchange rates.

In addition, empirical findings obtained from this study provide evidence for Bitcoin market inefficiency. One potential explanation for weekend effects or day-of-the-week

effects of stock markets and foreign exchange markets is that information released will be incorporated in pricing under the influence of exchange closure and trading system. Although Bitcoin is traded online all around the clock every day, significantly high mean returns on Monday from BPI and different day-of-the-week effect patterns of various Bitcoin markets are still available. Actually, this is not in line with EMH, and it indicates that market inefficiency exists in many Bitcoin markets.

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Appendix 1. Prominent day-of-the-week effects on Monday

Day-of-the-week effect on Bitcoin priced in CNY

Test results of the day-of-the-week effects of BTC/CNY mainly employ daily data collected from BTCChina and BTCtrade, and they are reported in detail in Tables AI, Figures A1 and A2. It is shown in Table AI that the day-of-the-week effect in CNY is not very robust. It is further observed that when the length of rolling window period is 500 days, the value of q_+ obtained from Saturday in BTCtrade is 15.63 percent, which is shown during February and September in 2017 in Figure A2. In addition, when the length of the rolling window period is 1,000 days, then the values of q_+ obtained from Monday are 19.60 and 14.59 percent, respectively, which are shown from July and June 2017. Although Bitcoin trading in CNY used to account for a large proportion in the sample period, the day-of-the-week effects observed on the basis of the daily data collected from both BTCChina and BTCtrade are not so significant. In addition, the appearance of significant Monday effect in BTCChina and BTCtrade depends on sampling.

Day-of-the-week effect on Bitcoin priced in USD

Test results of the day-of-the-week effects of BTC/USD obtained from four exchanges are shown in Table AI. Figures A3–A6 display correspondingly the change of *t*-values.

By analyzing the data collected from bitKonan, BitStamp, CEX.IO and Kraken, it is observed that Monday and Thursday effects are very outstanding when Bitcoin is traded in USD. In addition, when

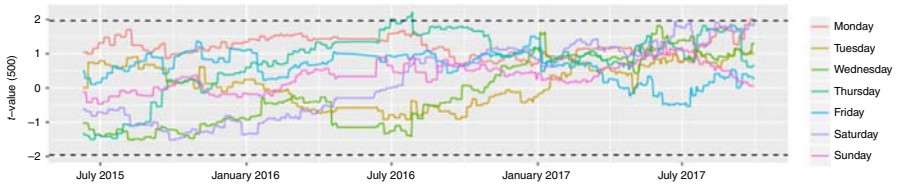
Code	Exchange	Length	q	Monday (%)	Tuesday (%)	Wednesday (%)	Thursday (%)	Friday (%)	Saturday (%)	Sunday (%)
CNY	BTCChina	500	q_+	0.75	0.00	0.00	2.37	0.00	0.00	0.00
CNY	BTCChina	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CNY	BTCChina	1,000	q_+	*19.60*	0.00	0.00	4.65	0.00	0.00	0.00
CNY	BTCChina	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CNY	BTCtrade	500	q_+	0.00	0.00	0.00	0.34	0.00	*15.63*	0.00
CNY	BTCtrade	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CNY	BTCtrade	1,000	q_+	*14.59*	0.00	0.00	7.84	0.00	0.00	0.00
CNY	BTCtrade	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
USD	bitKonan	500	q_+	*97.21*	*34.43*	0.00	36.55	0.00	0.00	0.00
USD	bitKonan	500	q_-	0.00	0.00	0.00	1.27	0.00	0.00	4.65
USD	bitKonan	1,000	q_+	*100.00*	29.91	0.00	63.34	0.00	0.00	0.00
USD	bitKonan	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.44
USD	BitStamp	500	q_+	*28.51*	*4.31*	0.00	23.15	0.00	0.08	0.00
USD	BitStamp	500	q_-	0.00	0.00	9.18	0.00	0.00	0.00	0.00
USD	BitStamp	1,000	q_+	*69.22*	0.00	0.00	60.05	0.00	0.68	0.00
USD	BitStamp	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
USD	CEX.IO	500	q_+	*34.14*	3.38	0.97	7.54	0.00	1.06	0.00
USD	CEX.IO	500	q_-	0.00	0.00	4.74	0.00	0.00	0.00	0.00
USD	CEX.IO	1,000	q_+	*94.01*	0.00	0.00	32.96	0.00	45.88	0.00
USD	CEX.IO	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
USD	Kraken	500	q_+	*45.80*	5.74	0.26	19.01	2.05	0.00	0.00
USD	Kraken	500	q_-	0.00	0.00	1.20	0.00	0.00	0.00	0.00
USD	Kraken	1,000	q_+	*89.97*	0.00	0.00	52.25	0.00	6.29	0.00
USD	Kraken	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EUR	bitcoin.de	500	q_+	*32.63*	0.00	1.30	11.42	0.00	0.00	0.00
EUR	bitcoin.de	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EUR	bitcoin.de	1,000	q_+	*49.52*	0.00	17.96	45.99	0.00	7.62	0.00
EUR	bitcoin.de	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EUR	BTC-e	500	q_+	17.07	0.00	0.00	*30.34*	0.00	0.00	0.00
EUR	BTC-e	500	q_-	0.00	0.00	4.05	0.00	0.00	0.00	0.00
EUR	BTC-e	1,000	q_+	*30.93*	0.00	0.00	10.31	0.00	0.00	0.00
EUR	BTC-e	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EUR	The Rock Trading	500	q_+	*54.10*	6.97	0.00	37.54	0.00	0.00	0.00
EUR	The Rock Trading	500	q_-	0.00	0.00	2.54	0.00	0.00	0.00	0.00
EUR	The Rock Trading	1,000	q_+	*100.00*	0.00	0.00	76.39	1.94	0.00	0.00
EUR	The Rock Trading	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JPY	BTCBOX	500	q_+	*44.18*	0.00	0.26	0.00	0.00	0.00	0.00
JPY	BTCBOX	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JPY	BTCBOX	1,000	q_+	*84.07*	0.00	0.00	4.26	1.10	0.63	0.00
JPY	BTCBOX	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JPY	Coincheck	500	q_+	*42.96*	0.00	0.00	0.97	0.00	2.26	0.00
JPY	Coincheck	500	q_-	0.00	0.00	0.32	0.00	0.00	0.00	0.00
JPY	Coincheck	1,000	q_+	*100.00*	0.00	0.00	24.13	0.00	7.89	0.00
JPY	Coincheck	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GBP	Coinfoor	500	q_+	*40.23*	6.81	0.00	5.32	18.85	0.00	0.00
GBP	Coinfoor	500	q_-	0.00	0.00	*12.30*	0.00	0.00	0.00	0.00
GBP	Coinfoor	1,000	q_+	*96.28*	0.00	0.00	29.10	6.04	0.00	0.00
GBP	Coinfoor	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KRW	Korbit	500	q_+	*39.43*	1.21	0.00	11.58	0.00	0.00	0.00
KRW	Korbit	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KRW	Korbit	1,000	q_+	*68.71*	0.00	0.00	62.59	0.00	0.00	0.00
KRW	Korbit	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AUD	BTCMarkets	500	q_+	*83.02*	4.31	0.00	0.00	6.66	0.00	3.09
AUD	BTCMarkets	500	q_-	0.00	0.00	0.00	2.19	0.00	18.93	0.00
AUD	BTCMarkets	1,000	q_+	*100.00*	0.00	0.00	0.00	0.00	0.00	17.10
AUD	BTCMarkets	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BRL	Mercado Bitcoin	500	q_+	*76.19*	0.49	0.81	20.08	6.48	0.00	0.00

Table AI.
q values of samples with prominent Monday effects

(*continued*)

Code	Exchange	Length	q	Monday (%)	Tuesday (%)	Wednesday (%)	Thursday (%)	Friday (%)	Saturday (%)	Sunday (%)
BRL	Mercado Bitcoin	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	15.38
BRL	Mercado Bitcoin	1,000	q_+	*100.00*	*2.04*	0.00	45.31	47.48	0.00	0.00
BRL	Mercado Bitcoin	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	19.05
IDR	BitX	500	q_+	*29.19*	13.29	15.90	20.92	0.00	0.00	0.00
IDR	BitX	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ILS	Bit2C	500	q_+	*31.87*	*1.14*	0.00	14.84	0.00	7.38	0.81
ILS	Bit2C	500	q_-	0.00	0.00	4.30	1.14	0.00	0.00	0.00
ILS	Bit2C	1,000	q_+	*43.79*	0.00	0.00	39.02	0.00	15.01	7.37
ILS	Bit2C	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NGN	BitX	500	q_+	*45.96*	0.00	0.00	2.31	3.00	0.00	0.00
NGN	BitX	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RUB	BTC-e	500	q_+	37.72	1.65	0.00	0.00	*53.09*	0.00	0.00
RUB	BTC-e	500	q_-	0.00	0.00	*20.85*	0.96	0.00	0.00	0.00
RUB	BTC-e	1,000	q_+	*75.98*	0.00	0.00	0.00	60.70	0.00	0.00
RUB	BTC-e	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SGD	itBit	500	q_+	*16.06*	0.00	0.00	6.21	3.05	1.38	0.00
SGD	itBit	500	q_-	0.00	0.00	4.73	0.00	0.00	0.00	0.00
SGD	itBit	1,000	q_+	*80.00*	0.00	0.00	26.41	0.00	0.00	0.00
SGD	itBit	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VND	VBTC	500	q_+	*67.84*	25.44	0.53	65.55	0.00	0.00	0.00
VND	VBTC	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table AI.



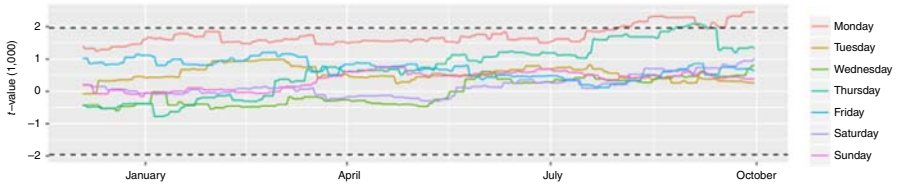


Figure A1.
t-values of Bitcoin priced in CNY from BTCChina

Figure A2.
t-values of Bitcoin priced in CNY from BTCtrade

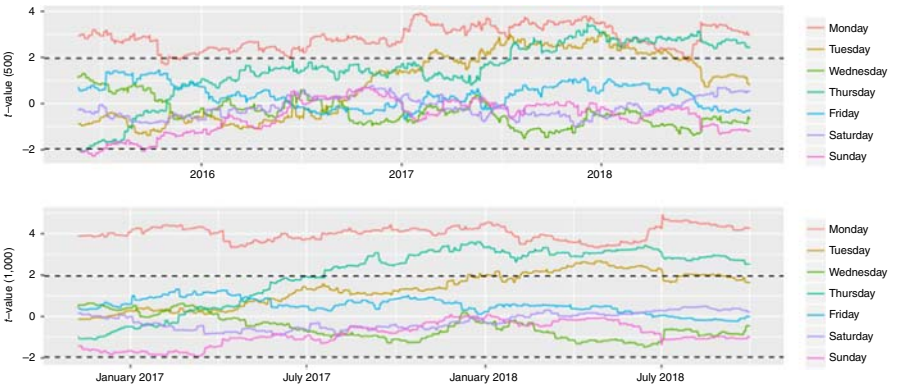


Figure A3.
t-values of Bitcoin priced in USD from bitKonan

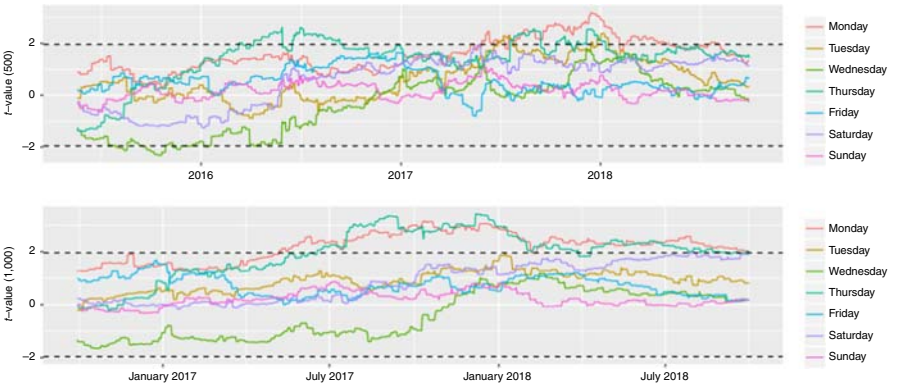


Figure A4.
t-values of Bitcoin priced in USD from BitStamp

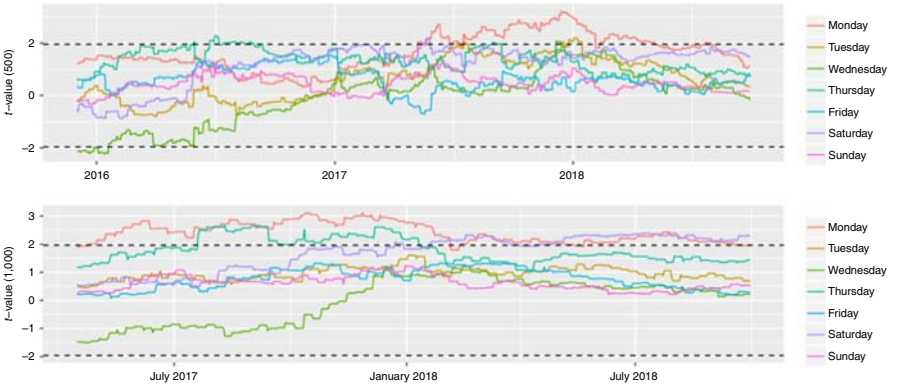


Figure A5.
t-values of Bitcoin priced in USD from CEX.IO

the length of rolling window is 500 days, the values of q_+ obtained from Monday are 97.21, 28.51, 34.14 and 45.80 percent, respectively, whereas the values of q_+ obtained from Thursday are 36.55, 23.15, 7.54 and 19.01 percent, respectively. Moreover, when the length of rolling window is 1,000 days, the values of q_+ obtained from Monday are 100, 69.22, 94.01 and 89.97 percent, respectively, while the values of q_+

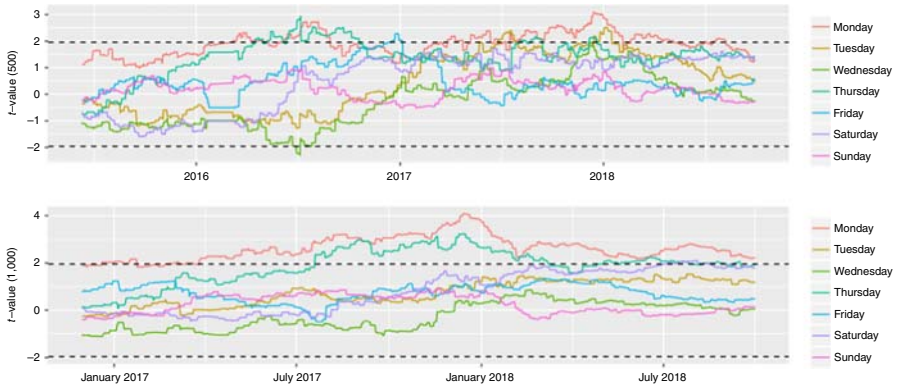


Figure A6. *t*-values of Bitcoin priced in USD from Kraken

obtained from Thursday are 63.34, 60.05, 32.96 and 52.25 percent, respectively. Consequently, Monday and Thursday effects are more significant when the length of rolling widow increases. Additionally, a Tuesday effect is discovered in bitKonan, and a prominent Saturday effect is also found in CEX.IO when the length of rolling window is 1,000 days.

Figure A3 shows that positive Thursday effect starts from July 2017, and Tuesday effect starts from February 2017 to June 2018 in bitKonan when short rolling window period is available. And the positive Tuesday effect starts from February 2018 when long rolling window period is available, except for robust Monday effect.

Figure A4 shows that Monday effect in BitStamp starts from May 2017 in both plots, and Thursday effect is more stable after the rolling window length increases to 1,000 days. Monday effect observed from BitStamp also depends on sampling.

Figure A5 shows that Monday effect in CEX.IO is significant from May 2017 when the length of rolling window is 500 days, and Saturday effect starts to be significant from January 2018 when long rolling window period is available. When the length of rolling window increases, differences in returns on weekdays also decline from 2018.

Figure A6 shows that Monday effect in Kraken is not continuous when the length of rolling window is 500 days, and Monday and Thursday effects are robust from 2017 in the lower plot. Although mean returns on Monday continue to be high, differences in returns tend to be smaller in BTC/USD trading from Kraken.

After analyzing data from above exchanges (including itBit) providing BTC/USD trading, except for bitKonan, most prominent Monday effects in four exchanges are detected from 2017. It means that abnormally higher returns on Monday in BTC/USD trading are actually derived from returns generated in recent years.

Day-of-the-week effect on Bitcoin priced in EURO

Test results of the day-of-the-week effects of BTC/EUR obtained from bticoin.de, BTC-e, and The Rock Trading are reported in Table AI. And corresponding distributions of *t*-values are shown in Figures A7–A9.

Based on the Bitcoin daily returns collected from bticoin.de, BTC-e and The Rock Trading, it is observed that both Monday and Thursday effects are prominent. When the length of rolling window is 500 days, the values of q_+ obtained from Monday are 32.63, 17.07 and 54.10 percent, respectively, while the values of q_+ obtained from Thursday are 11.42, 30.34 and 37.54 percent, respectively. If the length of rolling window period is 1,000 days, the values of q_+ obtained from on Monday are 49.52, 30.93 and 100 percent, respectively, whereas the values of q_+ obtained from Thursday are 45.99, 10.31 and 76.39 percent, respectively. According to Table AI, overall performance of Monday and Thursday effects of Bitcoin traded in EUR is similar to the situation when Bitcoin is traded in USD.

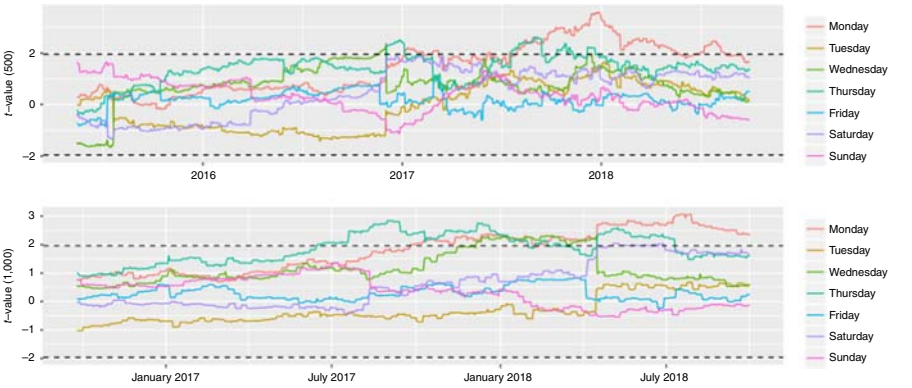
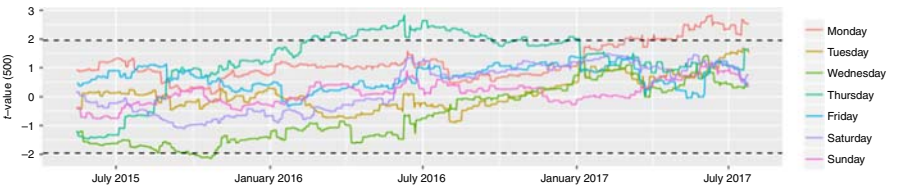


Figure A7.
t-values of Bitcoin priced in EUR from bitcoin.de



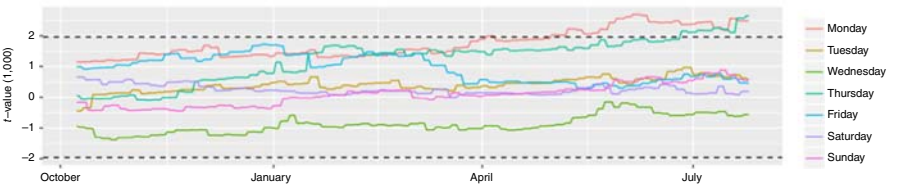


Figure A8.
t-values of Bitcoin priced in EUR from BTC-e

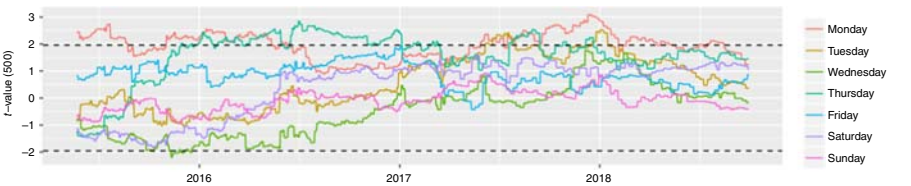


Figure A9.
t-values of Bitcoin priced in EUR from The Rock Trading

Figure A7 shows that the prominent Monday effect in bitcoin.de starts from July 2017 in the upper plot. In addition, Thursday effect starts from June 2017, and Monday effect is significant from September 2017 if the length of rolling window period is 1,000 days.

Figure A8 shows that in BTC-e, a significant Thursday effect extends from February 2016 to January 2017, and Monday effect starts from February 2017 when the length of rolling window period

is 500 days. Moreover, after the length of rolling window period is increased, Monday effect begins to appear from May 2017.

Figure A9 shows that Monday effect in The Rock Trading is significant from June 2016 to the end of May 2017 when there is a short period of rolling window, and Monday and Thursday effects are robust if the length of rolling window is 1,000 days.

Day-of-the-week effect on Bitcoin priced in JPY

Test results of the day-of-the-week effects of BTC/JPY obtained from BTCBOX and Coincheck are reported in Table AI. It is shown that Monday effect is prominent in both exchanges. When the length of rolling window is 500 days, the values of q_+ obtained from Monday are 44.18 and 42.96 percent, respectively. In addition, when the length of rolling window is 1,000 days, the values of q_+ obtained from Monday are 84.07 and 100 percent, respectively.

As shown in Figures A10 and A11, Monday effects are robust. Monday effect starts to be significant around May 2017 in BTC/JPY trading. And Monday effect also starts to be significant around May 2017 in BTCBOX, as shown in Figure A10. Moreover, the value of q_+ obtained from Thursday is 24.13 percent in Coincheck when the length of rolling window is 1,000 days, and Figure A11 shows that t-values of Coincheck obtained from Thursday are always high, and close to the upper black dash line which denotes t-value $= 1.96$.

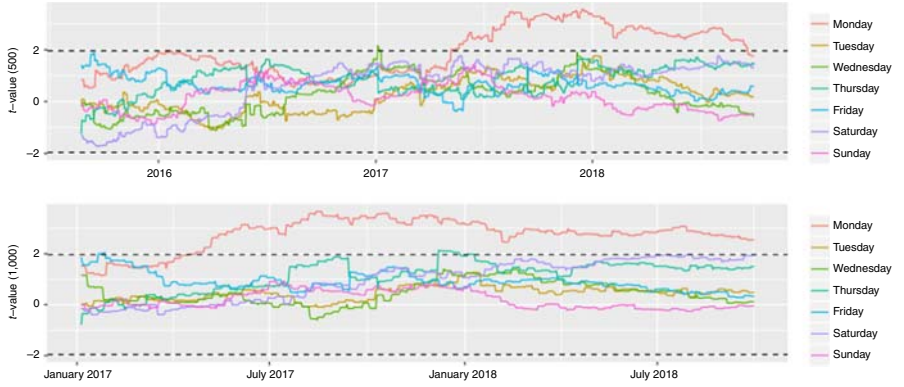


Figure A10. t-values of Bitcoin priced in JPY from BTCBOX

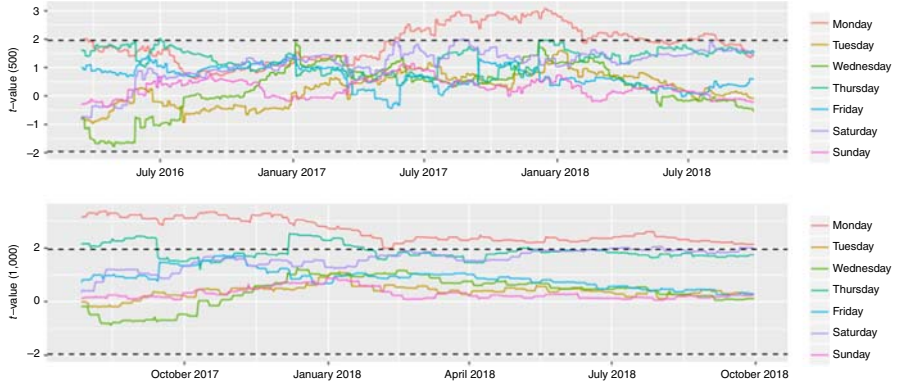


Figure A11. t-values of Bitcoin priced in JPY from Coincheck

Day-of-the-week effect on Bitcoin priced in GBP

Test results of the day-of-the-week effects of BTC/GBP obtained from Coinfloor are reported in Table AI. It is generally observed that when the length of rolling window is 500 days, both Monday and Friday effects are prominent in Coinfloor, and the values of q_+ obtained from Monday and Friday are 40.23 and 18.85 percent, respectively.

In addition, Figure A12 shows that Friday effect is significant during the period from June 2016 to May 2017, and Monday effect begins to be outstanding after June 2017, as shown in Figure A12. Furthermore, a negative Wednesday effect is found before June 2016, which is corresponding to $q_- = 12.30$ percent, as shown in Table AI. When the length of rolling window period is 1,000 days, Monday effect is always significant with a q_+ value that is equal to 96.28 percent, and Thursday effect is clearly available between July 2017 and February 2018, as shown in Figure A12. Meanwhile, differences in returns between weekdays are inclined to decrease.

Day-of-the-week effect on Bitcoin priced in KRW

Test results of the day-of-the-week effects of BTC/KRW obtained from Korbit are shown in Table AI and Figure A13. It is shown that both Monday and Thursday effects are prominent when rolling window of both periods are available. In addition, when the length of rolling window is 500 days, the values of q_+ obtained from Monday and Thursday are 39.43 and 11.58 percent, respectively.

As shown in Figure A13, the significant Monday and Thursday effects are mainly detected after June 2017. When the length of rolling window is 1,000 days, the values of q_+ obtained from Monday

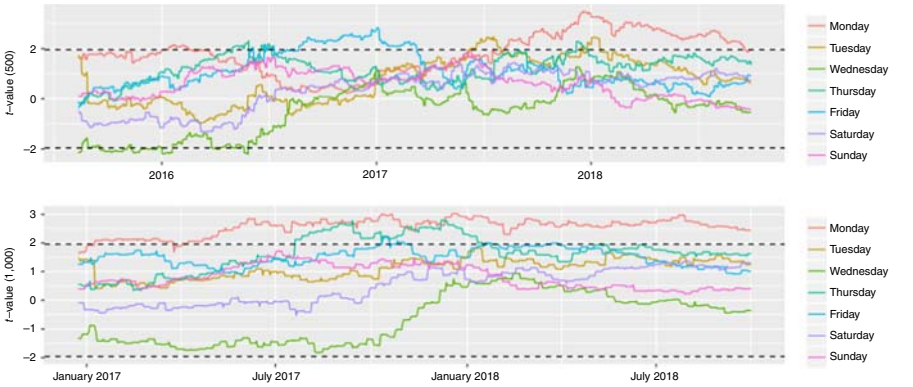


Figure A12.
t-values of Bitcoin priced in GBP from Coinfloor

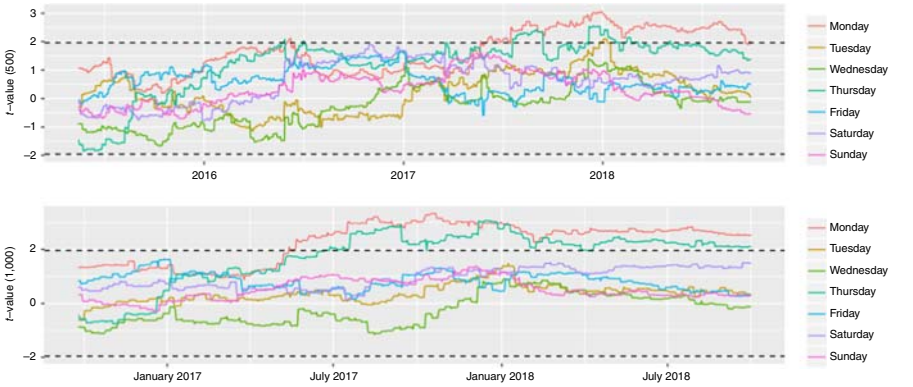


Figure A13.
t-values of Bitcoin priced in KRW from Korbit

and Thursday are 68.71 and 62.59 percent, respectively, and both effects start to be outstanding around May 2017, as shown in Figure A13.

Day-of-the-week effect on Bitcoin priced in AUD

Test results of the day-of-the-week effects of BTC/AUD obtained from BTCMarkets are reported in Table AI and Figure A14. It is shown that when the length of rolling window is 500 days, positive Monday effect with the value of q_+ equal to 83.02 percent and negative Saturday effect with the value of q_- equal to 18.93 percent are prominent. In addition, it is shown by Figure A14 that Monday effect is not significant from November 2016 to April 2017, while Saturday effect is roughly significant before January 15, 2017. When the length of rolling window is 1,000 days, the probability of significantly positive mean return obtained from Mondays is 100 percent, but a positive Sunday effect, instead of Saturday effect, is significant before July 2017.

Appendix 2. Prominent day-of-the-week effects on Thursday

Test results of the day-of-the-week effects of BTC/PLN obtained from BitBay are displayed in Table AII and Figure A15. It is shown that both Monday and Thursday effects are prominent when two different lengths of rolling window are available. In addition, it appears that Thursday effect is more significant than Monday effect based on the values of q_+ obtained from Table AII. Moreover,

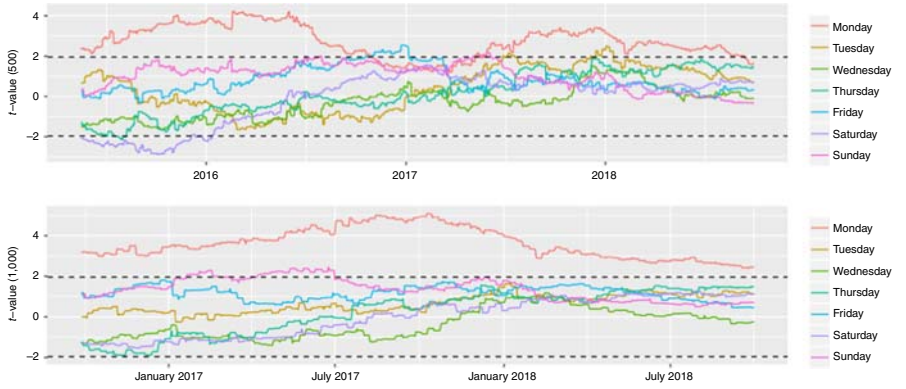


Figure A14. *t*-values of Bitcoin priced in AUD from BTCMarkets

Code	Exchange	Length	q	Monday (%)	Tuesday (%)	Wednesday (%)	Thursday (%)	Friday (%)	Saturday (%)	Sunday (%)
PLN	BitBay	500	q_+	37.75	3.31	0.87	*42.02*	2.96	0.00	0.00
PLN	BitBay	500	q_-	0.00	0.00	*15.69*	0.00	0.00	0.00	0.09
PLN	BitBay	1,000	q_+	86.55	2.01	0.00	*91.96*	0.93	0.00	0.00
PLN	BitBay	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IDR	Indodax	500	q_+	18.41	5.86	7.28	*35.65*	0.00	0.00	0.00
IDR	Indodax	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IDR	Indodax	1,000	q_+	60.14	0.00	1.01	*79.14*	0.00	0.00	0.00
IDR	Indodax	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MYR	BitX	500	q_+	37.30	7.63	21.37	*55.18*	0.00	0.00	0.00
MYR	BitX	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MYR	BitX	1,000	q_+	91.37	0.00	27.34	*100.00*	0.00	0.00	0.00
MYR	BitX	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VEF	SurBitcoin	500	q_+	12.57	38.41	12.21	*61.24*	12.92	0.00	6.55
VEF	SurBitcoin	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table AII. *q*-values of samples with prominent Thursday effects

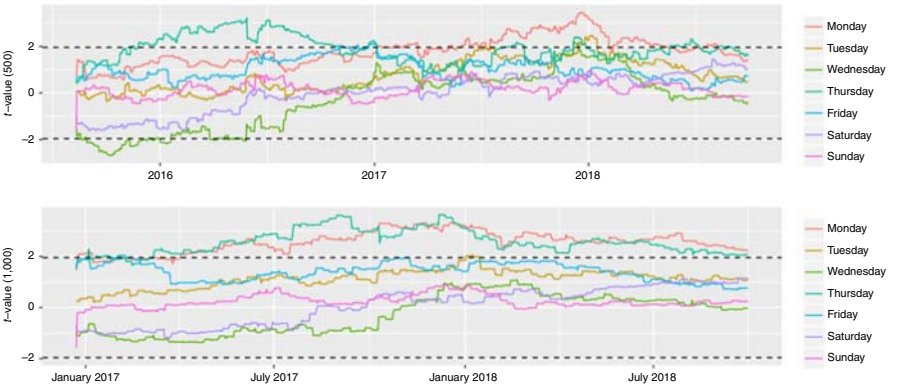


Figure A15.
t-values of Bitcoin priced in PLN from BitBay

when the length of rolling window is 500 days, Thursday effect is basically observed from October 2015 to December 2016, as shown in Figure A15. Accordingly, Monday effect is available from January 2017. Furthermore, a negative Wednesday effect is identified till June 2016. When the length of rolling window is 1,000 days, only clear Monday and Thursday effects are still obviously observed with the values q_+ equal to 86.55 percent on Monday and equal to 91.96 percent on Thursday.

Tests on the BTC/IDR, BTC/MYR and BTC/VEF are also presented in Table AII. It is quite obvious that Thursday effects are prominent during sampling period, which is followed by significant Monday effect. For BTC/IDR from Indodax, values of q_+ obtained from Thursday are 42.02 and 91.96 percent for both the two lengths of rolling window, while values of q_+ obtained from Monday are 37.75 and 86.55 percent, which is consistent with corresponding results in Table III. For BTC/MYR from BitX, values of q_+ on Thursday are 55.18 and 100 percent, followed by values of q_+ of 37.30 and 91.37 percent on Monday. Moreover, except for Saturday, significantly positive mean returns are detected on six weekdays in BTC/VEF from SurBitcoin, and the day-of-the-week effect on Thursday with q_+ of 61.24 percent is robust when the rolling window length is 500 days. However, this significant Thursday effect is not available in previous regression in Table AIII.

Appendix 3. The day-of-the-week effects of Bitcoin adjusted in USD

Exchange	Length	q	Monday (%)	Tuesday (%)	Wednesday (%)	Thursday (%)	Friday (%)	Saturday (%)	Sunday (%)
AUD									
BTCmarkets	500	q_+	*84.48*	5.69	0.00	0.00	2.76	0.00	3.74
BTCmarkets	500	q_-	0.00	0.00	0.00	3.57	0.00	*18.93*	0.00
BTCmarkets	1,000	q_+	*100.00*	0.00	0.00	0.00	0.00	0.00	17.37
BTCmarkets	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BRL									
Mercado Bitcoin	500	q_+	*57.41*	0.00	2.35	23.81	8.74	0.00	0.00
Mercado Bitcoin	500	q_-	0.00	0.00	0.24	0.00	0.00	0.00	14.49
Mercado Bitcoin	1,000	q_+	*100.00*	0.00	1.09	40.54	30.75	0.00	0.00
Mercado Bitcoin	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	16.05
CAD									
Kraken	500	q_+	9.26	*37.96*	1.62	9.26	0.00	0.00	0.00
Kraken	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CNY									
BTCChina	500	q_+	0.00	0.00	0.00	2.62	0.00	0.00	0.00
BTCChina	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BTCChina	1,000	q_+	*14.29*	0.00	0.00	6.98	0.00	0.00	0.00
BTCChina	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BTCtrade	500	q_+	0.00	0.00	0.00	0.34	0.00	*15.63*	0.00
BTCtrade	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BTCtrade	1,000	q_+	5.41	0.00	0.00	9.73	0.00	0.00	0.00
BTCtrade	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CZK									
Bitstock	500	q_+	15.00	0.00	0.00	25.07	*45.79*	0.00	0.00
Bitstock	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.68
Bitstock	1,000	q_+	8.07	0.00	0.00	0.00	*69.79*	0.00	0.00
Bitstock	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EUR									
bitcoin.de	500	q_+	*33.77*	0.00	1.21	19.11	0.00	0.00	0.00
bitcoin.de	500	q_-	0.00	2.91	0.00	0.00	0.00	0.00	0.00
bitcoin.de	1,000	q_+	49.52	0.00	17.96	*51.43*	0.00	7.62	0.00
bitcoin.de	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BTC-e	500	q_+	12.26	0.00	0.00	*40.58*	0.00	0.00	0.00
BTC-e	500	q_-	0.00	0.00	4.05	0.00	0.00	0.00	0.00
BTC-e	1,000	q_+	*30.58*	0.00	0.00	10.31	0.00	0.00	0.00
BTC-e	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
itBit	500	q_+	11.90	1.24	0.00	*34.95*	4.10	0.00	0.00
itBit	500	q_-	0.00	0.00	*20.95*	0.00	0.00	0.00	0.00
itBit	1,000	q_+	48.55	0.00	0.00	*73.09*	3.82	0.00	0.00
itBit	1,000	q_-	0.00	0.00	*15.27*	0.00	0.00	0.00	0.00
The Rock Trading	500	q_+	*55.16*	10.16	0.00	45.41	0.00	0.00	0.00
The Rock Trading	500	q_-	0.00	0.00	3.20	0.00	0.00	0.00	0.00
The Rock Trading	1,000	q_+	*100.00*	0.00	0.00	78.19	0.00	0.00	0.00
The Rock Trading	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GBP									
Coinfloor	500	q_+	*39.81*	7.86	0.00	8.47	1.24	0.00	0.00
Coinfloor	500	q_-	0.00	0.00	4.85	0.00	0.00	0.00	0.00
Coinfloor	1,000	q_+	*95.89*	0.00	0.00	37.44	0.00	0.00	0.00
Coinfloor	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(*continued*)

Table AIII. q-values for Bitcoin adjusted in USD

Exchange	Length	q	Monday (%)	Tuesday (%)	Wednesday (%)	Thursday (%)	Friday (%)	Saturday (%)	Sunday (%)
ILS									
Bit2C	500	q_+	*33.98*	1.14	0.00	20.76	0.00	7.22	0.81
Bit2C	500	q_-	0.00	0.00	5.11	0.57	0.00	0.00	0.00
Bit2C	1,000	q_+	*54.98*	0.00	0.00	45.43	0.00	15.01	7.23
Bit2C	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JPY									
BTCBOX	500	q_+	*44.62*	0.00	0.62	0.26	0.00	0.00	0.00
BTCBOX	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BTCBOX	1,000	q_+	*85.17*	0.00	0.00	6.62	0.00	0.63	0.00
BTCBOX	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coincheck	500	q_+	*44.79*	0.00	0.00	8.06	0.00	0.75	0.00
Coincheck	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coincheck	1,000	q_+	*100.00*	0.00	0.00	48.49	0.00	7.19	0.00
Coincheck	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KRW									
Korbit	500	q_+	*39.35*	1.70	0.00	22.02	0.00	0.00	0.00
Korbit	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Korbit	1,000	q_+	68.71	0.00	0.00	*68.98*	0.00	0.00	0.00
Korbit	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MYR									
BitX	500	q_+	37.19	7.74	18.65	*68.70*	0.00	0.00	0.00
BitX	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BitX	1,000	q_+	89.69	0.00	27.34	*100.00*	0.00	0.00	0.00
BitX	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PLN									
BitBay	500	q_+	39.06	5.14	0.87	*46.21*	0.61	0.00	0.00
BitBay	500	q_-	0.00	0.00	*13.16*	0.00	0.00	0.00	0.00
BitBay	1,000	q_+	86.55	0.00	0.00	*89.64*	0.00	0.00	0.00
BitBay	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RUB									
BTC-e	500	q_+	17.56	0.00	0.00	0.00	*45.27*	0.00	0.00
BTC-e	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BTC-e	1,000	q_+	*24.02*	0.00	0.00	0.00	0.00	0.00	0.00
BTC-e	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SGD									
itBit	500	q_+	8.28	0.00	0.00	*14.09*	0.00	1.38	0.00
itBit	500	q_-	0.00	0.00	3.94	0.00	0.00	0.00	0.00
itBit	1,000	q_+	*63.50*	0.00	0.00	29.13	0.00	0.00	0.00
itBit	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ZAR									
BitX	500	q_+	27.53	2.15	0.00	5.73	24.05	*44.83*	0.00
BitX	500	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BitX	1,000	q_+	0.00	0.00	0.00	27.88	34.17	*41.93*	0.00
BitX	1,000	q_-	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table AIII.

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