What Determines Bitcoin Order Imbalance?

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ABSTRACT

This study examines the relationship between bitcoin order imbalance and returns using BitMEX trading and quote data from April 2017 to July 2018. The analysis shows that order imbalances are negatively correlated with lagged returns, implying that bitcoin investors are contrarian during the sample period. This pattern is more salient when bitcoin returns decline than when the returns rise. The subperiod analysis is more nuanced. In period 1 (25 April 2017 to 15 September 2017), investors have a strong tendency to buy when returns decline. After period 1 (16 September 2017 to 12 July 2018) in which volatility is high, such tendency becomes weakened. If we normalize order imbalance with the number of transactions, investors are contrarians in period 1 and period 4 (8 February 2018 to 12 July 2018). The hourly analysis finds that order imbalances are particularly high from 11:00 to 12:00 and 21:00 to 22:00 (KST).

KEYWORDS: bitcoin, cryptocurrency, order book, order imbalance, market microstructure

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INTRODUCTION

Order imbalance has been an important topic in finance. Order imbalance in the US equity markets exhibits weekly regularities (Gibbons & Hess 1981; Chordia et al 2001). For example, order imbalance in stock market is high on Wednesday (Chordia et al. 2001). How about the order imbalances in bitcoin? Bitcoin market trades 24 hours a day, seven days a week, in contrast to stock market. This can result in the patterns in bitcoin order imbalance different from those in stock markets.

This paper examines whether past bitcoin returns explain order imbalance after controlling for weekly and hourly regularities, and past order imbalance. Specifically, we regress order imbalance on day-of-the-week dummies, hourly dummies, lagged up-return, lagged down-return, and lagged order imbalance value. We repeat the analysis at four sub-periods.

The main results are as follows. Investors act as contrarians in response to previous bitcoin returns in whole sample period. Bitcoin investors sell if bitcoin returns advance and buy if bitcoin returns decline. The sub-period analysis shows richer results. In period 1 (25 April 2017 to 15 September 2017), investors have a strong tendency to buy (sell) when returns decline (rise). When we normalize order imbalance with the number of transaction, the contrarian pattern becomes more salient even in other periods. However, market volatility tends to weaken the contrarian activities.

We organize this paper as follows. First, we explain the data and the variables. Second, we show relationships between order imbalance and preceding market returns and prior order imbalance value with weekly or hourly regularities. The final section concludes.

DATA AND VARIABLES

Table 1: Variable Definitions

We measure all variables per minute. OIBNUM, OIBBIT, and OIBDOL measure order imbalance in the number of trades, bitcoin, and dollars. QSPR is a quoted spread averaged across all trades. NUMTRANS and TVOL are the total number of transactions and the total number of dollar volume,

respectively. PRICE is the closing price of bitcoin in dollar and RETURN represents a log return of bitcoin price.

Concepts	Definitions
OIBNUM	Number of buyer-initiated trades less the number of seller-initiated trades
OIBBIT	Buyer-initiated bitcoins purchased less the seller-initiated bitcoins sold
OIBDOL	Buyer-initiated dollars paid less the seller-initiated dollars received
QSPR	Quoted bid-ask spread averaged across all trades
NUMTRANS	Total number of transactions
TVOL	Total dollar volume
PRICE	Closing price of bitcoin at each minute
RETURN	Log return of bitcoin price over a minute

Periods	
Period 1	25 April 2017 to 15 September 2017 (144 days)
Period 2	16 September 2017 to 17 December 2017 (93 days)
Period 3	18 December 2017 to 7 February (52 days)
Period 4	8 February 2018 to 12 July 2018 (155 days)

This paper uses trade and quote data of bitcoin/US Dollar perpetual swap contract[6] traded in BitMEX, a leading exchange for trading bitcoin futures and swaps. According to CoinMarketCap's statistics, BitMEX is the largest bitcoin exchange in the world. Table 1 defines variables. The following variables are measured at one minute intervals. OIBNUM is the number of buyer-initiated trades less the number of seller-initiated trades. OIBBIT is the buyer-initiated bitcoins purchased less seller-initiated bitcoins sold. OIBDOL is the buyer-initiated dollars paid less seller-initiated dollars received. OIBNUM, OIBBIT, and OIBDOL are related to trading intensity possibly associated with private information (Kyle, 1985, Chan and Fong, 2000). Positive numbers indicate buying pressure and negative numbers indicate selling pressure. QSPR is the quoted bid-ask spread averaged across all trades. NUMTRANS is the total number of transactions. TVOL is the total dollar volume. QSPR, NUMTRANS, and TVOL are related to asset liquidity. Order imbalances tend to be negatively correlated with liquidity in stock markets (Chordia et al, 2002, Chordia et al, 2008). PRICE is the closing price of bitcoin at each minute. RETURN is the log return of bitcoin over the one minute interval.

[6] The swap contract symbol is XBTUSD. Each contract represents the dollar value of one bitcoin. This contract does not have an expiration date, and provides a way for investors to speculate or hedge on the future value of bitcoin.

Our data indicates whether a trade is buyer-initiated or seller-initiated. Hence, instead of using the Lee and Ready (1991) algorithm, we are capable of using accurate trade direction when computing order imbalance measures. Therefore, our measures are less subject to measurement errors, compared to the measures calculated using typical US equity transaction data, such as the NYSE TAQ.

WHAT CAUSES ORDER IMBALANCE?

Table 2: Weekdays dummy

Dependent variables are order imbalance measured in the number of order imbalance on each minute (OIBNUM), the number of transactions (NUMTRANS) and OIBNUM/NUMTRANS, where NUMTRANS is the total number of transactions. They are regressed on day-of-the week dummies , and past positive and negative parts of bitcoin returns. Minute index is denoted by t. We used market data are from 25th April, 2017 to 12th July, 2018 inclusive. Each day, high frequency quote data is downsampled to the minute-level data of 1440 observations per day (444 days, t-statistics in parentheses).

	Dependent variables:		
	OIBNUM	NUMTRANS	OIBNUM / NUMTRANS
Monday	-0.047	1.24	0.003
	(-0.062)	(1.221)	(1.184)
Tuesday	-0.816	6.073***	-0.001
	(-1.080)	(6.002)	(-0.479)
Wednesday	-0.385	11.744***	0.000
	(-0.511)	(11.644)	(-0.032)
Thursday	-0.139	13.228***	-0.007***
	(-0.185)	(13.100)	(-2.764)
Friday	-0.122	10.584***	0.002
	(-0.161)	(10.453)	(0.790)
Saturday	0.853	-5.589***	-0.001
	(1.130)	(-5.526)	(-0.488)
$Max(0, R_{t-1})$	421.259*	379.442***	6.808***
	(1.854)	(24.655)	(9.256)
$Max(0, R_{t-2})$	-171.095	155.871***	-2.599***
	(-0.748)	(50.895)	(-3.511)
$Max(0, R_{t-3})$	-851.062***	97.391***	-3.588***
	(-3.726)	(31.826)	(-4.848)
$Max(0, R_{t-4})$	-510.619**	75.491***	-2.310***
	(-2.248)	(24.809)	(-3.138)
$Max(0, R_{t-5})$	-375.195*	67.593***	-1.246*
	(-1.686)	(22.672)	(-1.727)
$Min(0, R_{t-1})$	-1,041.142***	-377.832***	2.160***
	(-4.703)	(-127.399)	(3.014)
$Min(0, R_{t-2})$	-1,327.877***	-143.552***	-4.667***

	(-5.903)	(-47.640)	(-6.409)
Min(0, R_{t-3})	-1,082.970***	-76.307***	-3.552***
	(-4.788)	(-25.184)	(-4.850)
Min(0, R_{t-4})	-193.502	-47.868***	-1.961***
	(-0.855)	(-15.788)	(-2.675)
Min(0, R_{t-5})	-623.250***	-29.276***	-2.091***
	(-2.781)	(-9.750)	(-2.879)
$OIBNUM_{t-1}$	0.221***	-0.048***	0.0003***
	(44.252)	(-23.492)	(61.385)
$OIBNUM_{t-2}$	0.001	-0.020***	-0.00002***
	(0.707)	(-9.375)	(-3.018)
$OIBNUM_{t-3}$	0.016***	-0.019***	0.000
	(9.963)	(-9.121)	(-0.484)
$OIBNUM_{t-4}$	0.003*	-0.023***	-0.00002***
	(1.665)	(-11.058)	(-3.089)
$OIBNUM_{t-5}$	0.010***	-0.025***	-0.00001***
	(6.551)	(-12.491)	(-2.662)
Constant	-1.409**	117.278***	0.007***
	(-2.481)	(154.159)	(3.902)
Observations	634,419	634,419	618,525
Adjusted R^2	0.048	0.12	0.011
Residual Std. Error	160.521	215.031	0.518
	(df = 634397)	(df=634397)	(df = 618503)
F Statistic	1,535.949***	4,111.6439***	339.103***
	(df = 21; 634397)	(df = 21; 634397)	(df = 21; 618503)

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

Table 2 reports the regression in which dependent variables are order imbalance measures (OIBNUM, NUMTRANS, OIBNUM/NUMTRANS) and independent variables are day-of-the week dummies, and past positive and negative parts of bitcoin returns. The results are as follows. The larger the past returns, the lower OIBNUM except one-minute lag. This pattern becomes clearer when past returns are negative, i.e. negative past returns make the negative relationship between past returns and OIBNUM stronger than positive returns do. Note that our data distinguish buyer-initiated from seller initiated trades. Therefore, we can reason bitcoin investors contrarian symmetrically, i.e. bitcoin investors tend to sell after bitcoin return advances and buy more strongly after bitcoin price decreases except one-minute. At one minute, they are momentum traders at positive return, but contrarian at negative return.

To check whether the results are driven by trading activity per se instead of overall trading sentiment, we scale the dependent variable (OIBNUM) by the total number of transactions (NUMTRANS). The result after such normalization strengthens our claim that investors

behave against the previous returns. The contrarian behavior of investors occurs from two minute to five minutes regardless of the direction of the returns. According to the previous working paper[7], the autocorrelation of both order imbalance measures and bitcoin returns are negligible, and the correlation between OIBNUM and past bitcoin return is strongly positive. In this working paper, we additionally finds that the order imbalance responds to past bitcoin returns.

Table 2 little shows day of the week effect. We cannot find significant regularities, but after dividing the number of order imbalance (OIBNUM) for the trading activity (NUMTRANS), we observe that Thursday has a lower normalized order imbalance compared to Sunday.

Table 3: Hourly dummy

Dependent variables are order imbalance measured in the number of order imbalance on each minute (OIBNUM), the number of transactions(NUMTRANS) and OIBNUM/NUMTRANS, which is the total number of transactions. They are regressed on dummies for hours of the day, past positive and negative parts of bitcoin returns, and lagged order imbalance measured in the number of transactions. Minute index is denoted by t. We used market data are from 25th April, 2017 to 12th July, 2018 inclusive. Each day, high frequency quote data is downsampled to the minute-level data of 1440 observations per day (444 days, t-statistics in parentheses).

	Dependent variable:		
	OIBNUM	NUMTRANS	OIBNUM / NUMTRANS
00	-1.049	8.224***	-0.005
	(-0.751)	(4.400)	(-1.019)
01	0.047	1.004	0.001
	(0.034)	(0.537)	(0.135)
02	-0.461	-1.856	0.0004
	(-0.330)	(-0.993)	(0.086)
03	-0.309	-12.850***	0.0005
	(-0.221)	(-6.874)	(0.105)
04	0.355	-5.739***	-0.004
	(0.254)	(-3.073)	(-0.901)
05	-0.262	-13.585***	0.004
	(-0.188)	(-7.274)	(0.810)
06	1.211	-0.404	0.005
	(0.868)	(-0.216)	(1.018)
07	1.514	2.851	0.008*
	(1.084)	(1.526)	(1.829)
08	2.068	11.932***	0.008*
	(1.481)	(6.389)	(1.784)
09	-0.814	3.991**	0.008*
	(-0.584)	(2.138)	(1.817)
10	0.879	13.253***	0.003
	(0.630)	(7.099)	(0.607)
11	2.649*	13.207***	0.012***

[7] https://www.entropy-trading.com/academic-research - workingpaper 1-1

	(1.898)	(7.072)	(2.623)
12	1.073	28.953***	0.005
	(0.768)	(15.506)	(1.164)
13	0.236	29.123***	-0.001
	(0.169)	(15.594)	(-0.186)
14	-1.075	34.113***	-0.0001
	(-0.769)	(18.251)	(-0.024)
15	1.327	17.183***	0.010**
	(0.951)	(9.204)	(2.150)
16	1.418	21.431***	0.007
	(1.016)	(11.482)	(1.636)
17	0.037	3.119*	0.004
	(0.027)	(1.672)	(0.836)
18	0.086	-6.181***	-0.001
	(0.061)	(-3.311)	(-0.204)
19	1.92	-12.395***	0.009*
	(1.375)	(-6.637)	(1.949)
20	0.892	-2.795	0.008*
	(0.639)	(-1.497)	(1.728)
21	1.553	-14.952***	0.015***
	(1.110)	(-7.992)	(3.229)
22	1.179	1.858	0.008*
	(0.844)	(0.994)	(1.725)
$Max(0, R_{t-1})$	420.206*	379.255***	6.798***
	(1.849)	(124.782)	(9.243)
$Max(0, R_{t-2})$	-172.063	155.727***	-2.610***
	(-0.753)	(50.924)	(-3.525)
$Max(0, R_{t-3})$	-851.812***	97.262***	-3.597***
	(-3.729)	(31.832)	(-4.860)
$Max(0, R_{t-4})$	-511.151**	75.370***	-2.317***
	(-2.250)	(24.806)	(-3.148)
$Max(0, R_{t-5})$	-374.879*	67.495***	-1.248*
	(-1.684)	(22.674)	(-1.731)
$Min(0, R_{t-1})$	-1,039.694***	-377.619***	2.164***
	(-4.696)	(-127.519)	(3.020)
$Min(0, R_{t-2})$	-1,327.087***	-143.393***	-4.664***
	(-5.900)	(-47.660)	(-6.405)
$Min(0, R_{t-3})$	-1,082.144***	-76.212***	-3.548***
	(-4.784)	(-25.191)	(-4.845)
$Min(0, R_{t-4})$	-192.495	-47.792***	-1.958***
	(-0.850)	(-15.786)	(-2.670)
$Min(0, R_{t-5})$	-622.059***	-29.224***	-2.088***
	(-2.775)	(-9.748)	(-2.875)
$OIBNUM_{t-1}$	0.221***	-0.048***	0.0003***
	(44.230)	(-23.578)	(61.362)
$OIBNUM_{t-2}$	0.001	-0.020***	-0.00002***
	(0.695)	(-9.439)	(-3.031)
$OIBNUM_{t-3}$	0.016***	-0.019***	0
	(9.949)	(-9.182)	(-0.498)
$OIBNUM_{t-4}$	0.003*	-0.023***	-0.00002***
	(1.653)	(-11.123)	(-3.103)
$OIBNUM_{t-5}$	0.010***	-0.026***	-0.00001***
	(6.532)	(-12.571)	(-2.684)
Constant	-2.103**	117.712***	0.002

	(-2.084)	(87.232)	(0.700)
Observations	634,419	634,419	618,525
Adjusted R^2	0.048	0.122	0.011
Residual Std. Error	160.520 (df = 634380)	214.705(df=634380)	0.518 (df = 618486)
F Statistic	849.318*** (df = 38; 634380)	2,330.384*** (df = 38; 634380)	188.387*** (df = 38; 618486)

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

Table 3 reports the regression in which dependent variables are order imbalance measures (OIBNUM, NUMTRANS, OIBNUM/NUMTRANS) and independent variables are hourly dummies, and past positive and negative parts of bitcoin returns. The results for variables other than hourly dummies are consistent with the results of Table 2. After normalizing the order imbalance by the total number of transactions, we find significant hourly regularities in order imbalance. From 11:00 to 12:00 and from 21:00 to 22:00 in Korea Standard Time (KST), order imbalances are high, suggesting seasonality, especially compared to the period from 23:00 to 24:00.

To detail the results, we divide the period into four sub-periods based on the trading regime. The four sub-periods are in Appendix Figure 1 and as follows.

- Period 1 (Gradual rising): 25 April 2017 to 15 September 2017 (144 days)
- Period 2 (Sharp rising): 16 September 2017 to 17 December 2017 (93 days)
- Period 3 (Sharp decreasing): 18 December 2017 to 7 February (52 days)
- Period 4 (Stagnant): 8 February 2018 to 12 July 2018 (155 days)

In Period 1 (25 April 2017 to 15 September 2017), we observe the development of bitcoin market and the rise of its price albeit low volume. In Period 2 (16 September 2017 to 17 December 2017), the bitcoin market surged with much investor attention. In Period 3 (18 December 2017 to 7 February), bitcoin price plunged. In Period 4 (8 February 2018 to 12 July 2018), bitcoin price was relatively stable.

Table 4: Time dummy at each period

Dependent variables are order imbalance measured in the number of order imbalance on minute (OIBNUM), the number of transactions(NUMTRANS) and OIBNUM/NUMTRANS, which is total number of transactions. They are regressed on dummies for hours of the day, past positive and negative parts of bitcoin returns and lagged order imbalance measured in number of transactions.

Minute index is denoted by t. We used market data are from 25th April, 2017 to 12th July, 2018 inclusive. Each day, high frequency quote data is downsampled to the minute-level data of 1440 observations per day (444 days, t-statistics in parentheses).

	Dependent variable:							
	Period 1		Period 2		Period 3		Period 4	
	OIBNUM	OIBNUM /NUMTRANS	OIBNUM	OIBNUM /NUMTRANS	OIBNUM	OIBNUM /NUMTRANS	OIBNUM	OIBNUM /NUMTRANS
00	0.167	0.005	0.944	-0.0004	-7.346***	-0.022**	-1.568	-0.013*
	(0.272)	(0.609)	(0.468)	(-0.043)	(-2.672)	(-2.122)	(-0.427)	(-1.652)
01	1.018*	0.017*	-0.702	-0.005	-4.619*	-0.011	0.648	-0.011
	(1.663)	(1.877)	(-0.347)	(-0.580)	(-1.681)	(-1.095)	(0.176)	(-1.420)
02	0.755	0.018**	-1.025	-0.008	-4.980*	-0.017	-0.236	-0.009
	(1.233)	(2.046)	(-0.507)	(-0.862)	(-1.812)	(-1.632)	(-0.064)	(-1.161)
03	0.858	0.018**	-0.948	-0.017*	-5.354*	-0.021**	0.028	-0.003
	(1.399)	(1.983)	(-0.470)	(-1.839)	(-1.948)	(-2.014)	(0.008)	(-0.416)
04	0.88	0.007	0.022	-0.007	-2.141	-0.016	0.264	-0.015*
	(1.439)	(0.796)	(0.011)	(-0.746)	(-0.779)	(-1.551)	(0.072)	(-1.949)
05	1.891***	0.028***	-1.569	-0.006	-5.867**	-0.025**	-0.697	-0.014*
	(3.092)	(3.134)	(-0.777)	(-0.648)	(-2.135)	(-2.401)	(-0.190)	(-1.756)
06	2.061***	0.020**	-0.38	-0.013	-2.571	-0.017	1.572	-0.004
	(3.371)	(2.207)	(-0.188)	(-1.477)	(-0.936)	(-1.598)	(0.428)	(-0.523)
07	1.960***	0.030***	2.371	0.001	-6.675**	-0.022**	2.211	-0.01
	(3.203)	(3.343)	(1.174)	(0.131)	(-2.428)	(-2.146)	(0.602)	(-1.219)
08	2.570***	0.028***	-0.757	-0.011	-5.818**	-0.016	4.748	-0.005
	(4.203)	(3.106)	(-0.375)	(-1.217)	(-2.117)	(-1.519)	(1.292)	(-0.626)
09	2.112***	0.023***	-0.132	-0.012	-6.860**	-0.020*	-3.328	-0.002
	(3.459)	(2.621)	(-0.066)	(-1.358)	(-2.496)	(-1.893)	(-0.906)	(-0.234)
10	1.518**	0.01	0.78	-0.003	-4.235	-0.009	1.227	-0.008
	(2.486)	(1.147)	(0.386)	(-0.378)	(-1.541)	(-0.868)	(0.334)	(-1.048)
11	2.689***	0.033***	-1.513	-0.013	-2.539	-0.012	5.562	-0.001
	(4.398)	(3.799)	(-0.749)	(-1.398)	(-0.924)	(-1.191)	(1.514)	(-0.098)
12	1.870***	0.025***	0.623	-0.013	-3.042	-0.016	0.996	-0.008
	(3.059)	(2.891)	(0.309)	(-1.469)	(-1.107)	(-1.576)	(0.271)	(-1.009)
13	0.271	0.007	1.296	-0.002	-6.592**	-0.020*	1.301	-0.008
	(0.444)	(0.845)	(0.642)	(-0.182)	(-2.398)	(-1.916)	(0.354)	(-0.959)
14	1.407**	0.021**	0.15	-0.013	-2.115	-0.001	-4.5	-0.022***
	(2.296)	(2.404)	(0.074)	(-1.408)	(-0.769)	(-0.087)	(-1.225)	(-2.766)
15	1.517**	0.030***	0.289	-0.008	-3.505	-0.01	2.748	-0.001
	(2.481)	(3.476)	(0.143)	(-0.883)	(-1.275)	(-0.999)	(0.749)	(-0.083)
16	1.453**	0.028***	-3.318	-0.019**	-2.058	-0.003	4.515	-0.003
	(2.379)	(3.203)	(-1.643)	(-2.090)	(-0.749)	(-0.268)	(1.230)	(-0.380)
17	1.042*	0.020**	-1.229	-0.014	-6.098**	-0.020*	1.245	-0.001
	(1.709)	(2.307)	(-0.609)	(-1.543)	(-2.219)	(-1.900)	(0.339)	(-0.117)
18	0.757	0.01	-1.829	-0.014	-3.68	-0.008	1.299	-0.004
	(1.241)	(1.093)	(-0.905)	(-1.596)	(-1.339)	(-0.812)	(0.354)	(-0.538)
19	0.802	0.013	1.085	0.002	-2.37	0.005	4.261	0.001
	(1.315)	(1.511)	(0.535)	(0.210)	(-0.863)	(0.486)	(1.160)	(0.091)
20	2.019***	0.035***	-1.764	-0.021**	-2.14	-0.001	1.381	-0.011
	(3.308)	(3.942)	(-0.871)	(-2.271)	(-0.779)	(-0.070)	(0.376)	(-1.389)
21	1.611***	0.037***	0.138	-0.008	-2.753	-0.004	3.124	0.005
	(2.632)	(4.214)	(0.068)	(-0.906)	(-1.002)	(-0.351)	(0.848)	(0.630)
22	1.498**	0.022**	-0.351	-0.001	-3.297	-0.009	2.502	-0.003
	(2.454)	(2.483)	(-0.173)	(-0.076)	(-1.200)	(-0.894)	(0.679)	(-0.398)
$Max(0, R_{t-1})$	-1,939.15***	-16.235***	1,857.62***	-3.234*	3,793.79***	4.673***	2,300.26***	-21.340***
	(17.215)	(10.303)	(4.849)	(-1.886)	(11.110)	(3.619)	(2.694)	(11.714)
$Max(0, R_{t-2})$	-724.16***	-11.19***	1,082.69***	-3.52**	44.61	-0.98	-171.88	-11.63***
	(-6.388)	(-7.045)	(2.824)	(-2.049)	(0.130)	(-0.755)	(-0.198)	(-6.277)
$Max(0, R_{t-3})$	-805.499***	-12.229***	-642.963*	-4.028**	-271.517	-1.929	-464.645	-4.443**
	(-7.125)	(-7.714)	(-1.678)	(-2.347)	(-0.791)	(-1.486)	(-0.535)	(-2.397)

$Max(0, R_{t-4})$	-1,033.60***	-12.151***	-744.60**	-3.565**	588.669*	1.164	-1068.239	-2.768
	(-9.206)	(-7.717)	(-1.962)	(-2.097)	(1.721)	(0.899)	(-1.232)	(-1.496)
$Max(0, R_{t-5})$	-753.282***	-11.498***	-766.935**	-2.585	-626.145*	-2.142*	-352.178	1.546
	(-6.827)	(-7.430)	(-2.088)	(-1.571)	(-1.873)	(-1.693)	(-0.423)	(0.870)
$Min(0, R_{t-1})$	-2,443.29***	-21.329***	182.486	-7.517***	2,042.35***	-0.261	646.024	-28.81***
	(22.710)	(14.179)	(0.526)	(-4.841)	(5.761)	(-0.195)	(0.729)	(15.232)
$Min(0, R_{t-2})$	-1,265.10***	-13.19***	-905.41**	-5.10***	-974.75***	-3.54***	-1442.30	-13.83***
	(11.590)	(-8.63105)	(-2.557)	(-3.214)	(-2.736)	(-2.626)	(-1.594)	(-7.166)
$Min(0, R_{t-3})$	-1,092.84***	-10.524***	-1,267.44***	-4.312***	-337.38	-1.365	-317.58	-5.52***
	(-9.950)	(-6.844)	(-3.560)	(-2.705)	(-0.945)	(-1.011)	(-0.351)	(-2.854)
$Min(0, R_{t-4})$	-791.566***	-8.558***	-967.192***	-4.075**	291.783	-0.795	1103.749	-0.563
	(-7.196)	(-5.555)	(-2.714)	(-2.553)	(0.818)	(-0.589)	(1.220)	(-0.292)
$Min(0, R_{t-5})$	-1,030.8***	-11.886***	386.26	-0.424	-828.421**	-3.580***	-2,537.3***	-2.193
	(-9.441)	(-7.767)	(1.095)	(-0.268)	(-2.366)	(-2.701)	(-2.904)	(-1.177)
$OIBNUM_{t-1}$	0.309***	0.003***	0.191***	0.001***	0.113***	0.0003***	0.216***	0.0004***
	(10.947)	(67.188)	(41.533)	(26.763)	(16.374)	(12.079)	(66.259)	(51.218)
$OIBNUM_{t-2}$	0.063***	0.001***	-0.015***	-0.0001***	-0.003	-0.0001***	0.002	-0.00001**
	(21.732)	(14.283)	(-3.303)	(-4.024)	(-0.391)	(-2.836)	(0.649)	(-2.029)
$OIBNUM_{t-3}$	0.047***	0.0005***	-0.005	-0.0001***	-0.001	-0.00002	0.015***	-0.00002**
	(16.123)	(11.379)	(-1.047)	(-2.689)	(-0.097)	(-0.951)	(4.459)	(-2.203)
$OIBNUM_{t-4}$	0.034***	0.0004***	-0.001	-0.00002	-0.005	-0.00003	0.001	-0.00003***
	(11.619)	(9.728)	(-0.155)	(-0.896)	(-0.726)	(-1.228)	(0.423)	(-4.418)
$OIBNUM_{t-5}$	0.044***	0.0005***	0.007	0.00001	0.021***	0.0001**	0.012***	-0.00004***
	(15.667)	(12.266)	(1.620)	(0.340)	(3.136)	(2.029)	(3.879)	(-5.700)
Constant	-1.680***	-0.006	0.525	0.022***	1.083	0.008	-4.15	0.004
	(-3.798)	(-0.943)	(0.358)	(3.297)	(0.538)	(0.984)	(-1.560)	(0.765)
Observations	205,850	190,868	133,534	133,138	74,880	74,738	220,155	219,781
Adjusted R^2	0.099	0.044	0.042	0.013	0.032	0.01	0.05	0.017
Residual Std. Error	40.091 (df = 205811)	0.557 (df = 190829)	106.371 (df = 133495)	0.476 (df = 133099)	108.52 (df = 74841)	0.410 (df = 74699)	248.635 (df = 220116)	0.530 (df = 219742)
F Statistic	597.947*** (df = 38; 205811)	234.378*** (df = 38; 190829)	155.772*** (df = 38; 133495)	46.800*** (df = 38; 133099)	66.850*** (df = 38; 74841)	21.790*** (df = 38; 74699)	302.936*** (df = 38; 220116)	102.630*** (df = 38; 219742)

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

Table 4 shows the results on the sub-periods. Figure 1 and Figure 2 describe the results. In period 1, investors act as contrarians at any past return. They buy after bitcoin returns decline and sell after returns advance. The behavior persists from one to five minutes in both positive and negative returns. Also, there are many hourly regularities. In the time zones from 05:00 to 13:00, from 14:00 to 18:00 and from 20:00 to 23:00, there are statistically significant hourly seasonalities in order imbalance. Those periods exhibit higher order imbalances compared to the period from 23:00 to 24:00. After normalizing the order imbalance by the total number of transactions (NUMTRANS), the results remain robust: the evidence for contrarians and the pattern of hourly regularity.

In period 2, investors act along the returns at the lags of one and two minutes (i.e. short-term momentum) after the bitcoin return advances, but behave as contrarian in other cases. No significant hourly regularities exist. After normalizing the order imbalance with the number

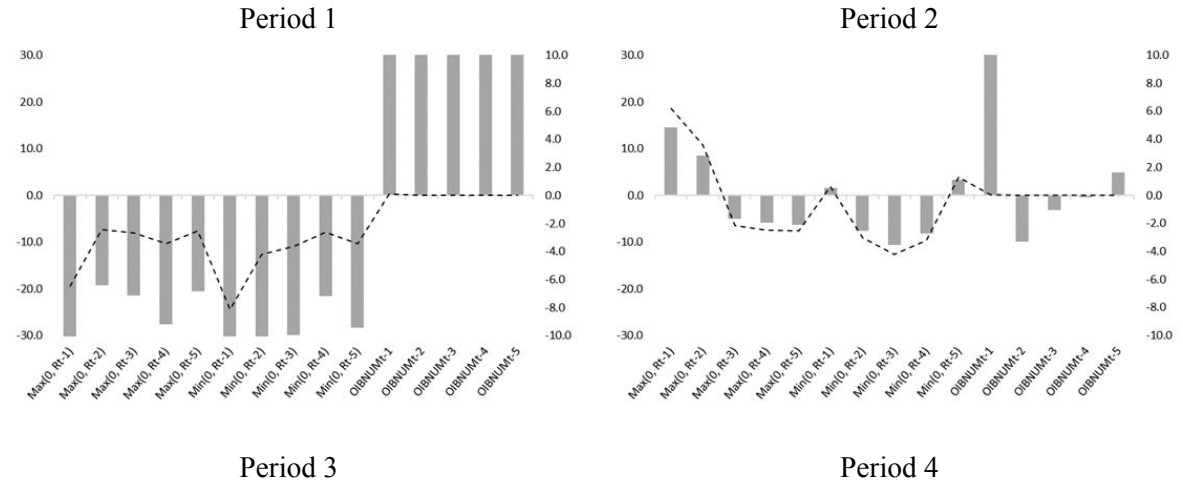
of transactions, the contrarian pattern exist from two to five minutes. At one minute before, momentum pattern exists.

In period 3, investors also act along the returns at the lag of one minute. Investors act as contrarians in negative returns at the lag of two minute. In the time period from 07:00 to 10:00, order imbalance are lower than that of the time zone from 23:00 to 24:00. However, after adjusting order imbalance by trading activity, the hourly seasonalities become insignificant.

In period 4, investors behave similarly in terms of raw order imbalance. However, after normalizing the order imbalance by trading activity, contrarian patterns emerge and remain so for three minutes after bitcoin returns advance. When bitcoin return declines, investors are contrarian to the returns at the lags of three minutes for normalized order imbalance.

Figure 1 : Coefficient and T-statistics at each period

This figure describes the results at Table 4. We adjust coefficient value of independent variables related with bitcoin returns to scale the range of graph. X-axis denote independent variables which are past positive and negative parts of bitcoin returns, and past order imbalance. Y-axis denote the value of coefficients and t-values. The dependent variable is OIBNUM. Line graph shows the coefficients of independent variables and bar graph presents t-values.



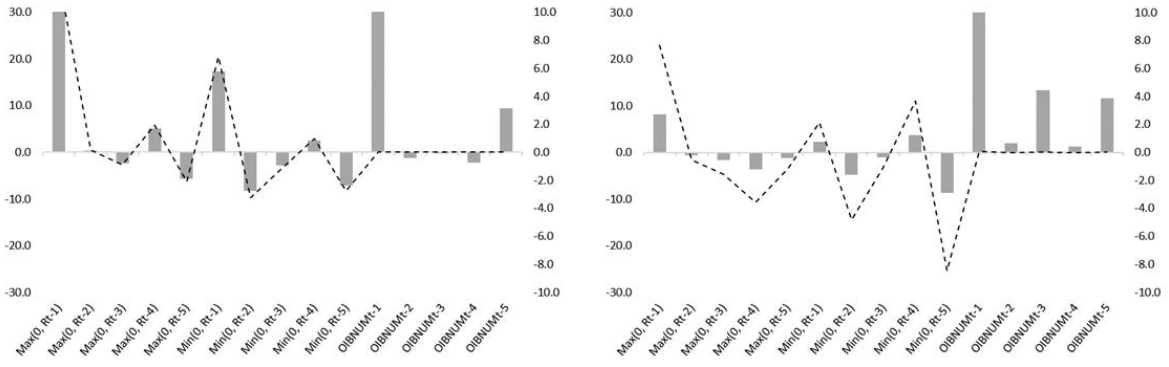
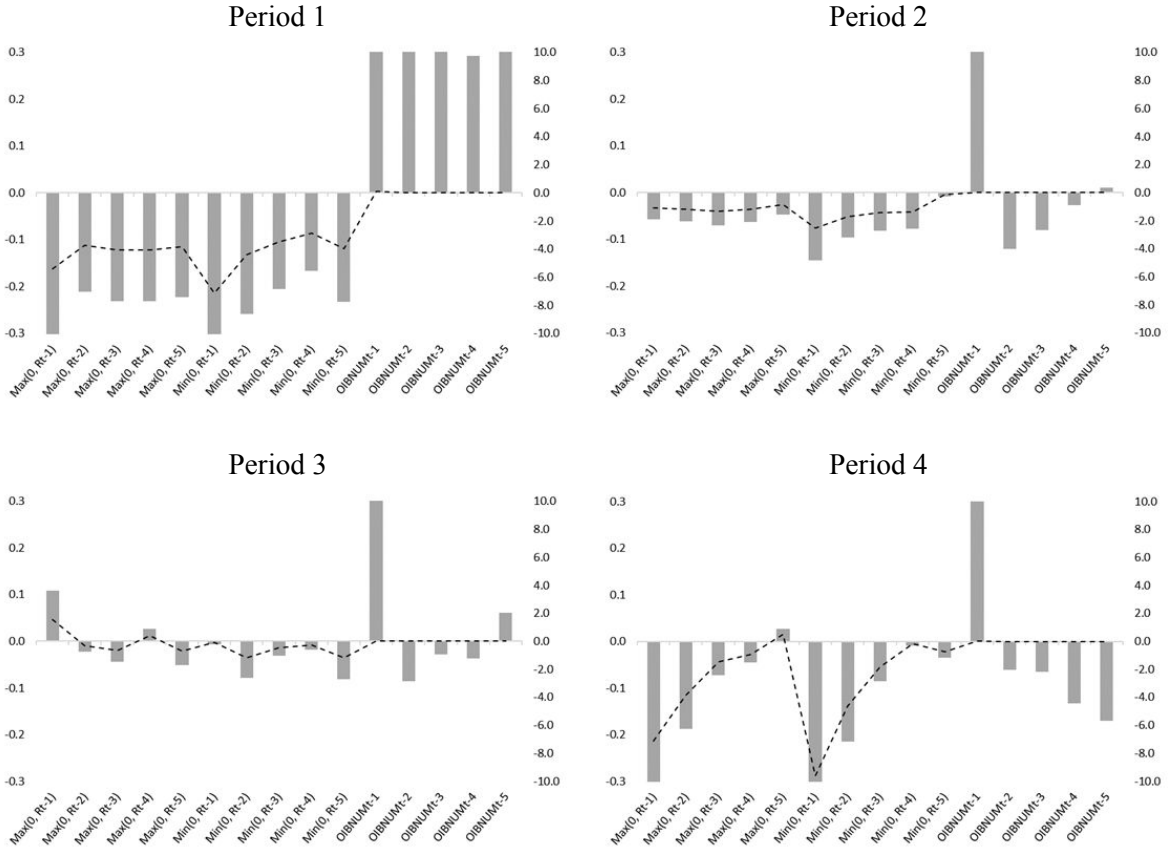


Figure 2 : Coefficient and T-statistics at each period

This figure describes the results at Table 4. We adjust coefficient value of independent variables related with bitcoin returns to scale the range of graph. The dependent variable is OIBNUM/NUMTRNAS. X-axis denote independent variables which are past positive and negative parts of bitcoin returns, and past order imbalance. Y-axis denote the value of coefficients and t-values. Line graph shows the coefficients of independent variables and bar graph presents t-values.



CONCLUSION

This paper examines the relationship between bitcoin order imbalance and returns. Order imbalances are negatively correlated with lagged returns. Bitcoin investors are contrarian during the sample period. The lower the bitcoin returns, the stronger the contrarian patterns. However, when bitcoin market is volatile (e.g. 16 September 2017 to 7 February 2018), investors become less contrarian.

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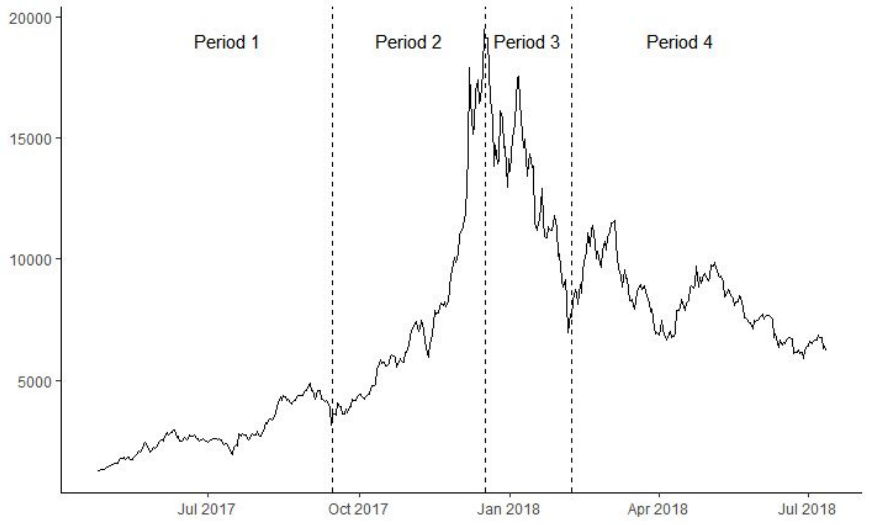
APPENDIX

Appendix Figure 1 : Behavior of bitcoin Price and Subperiods

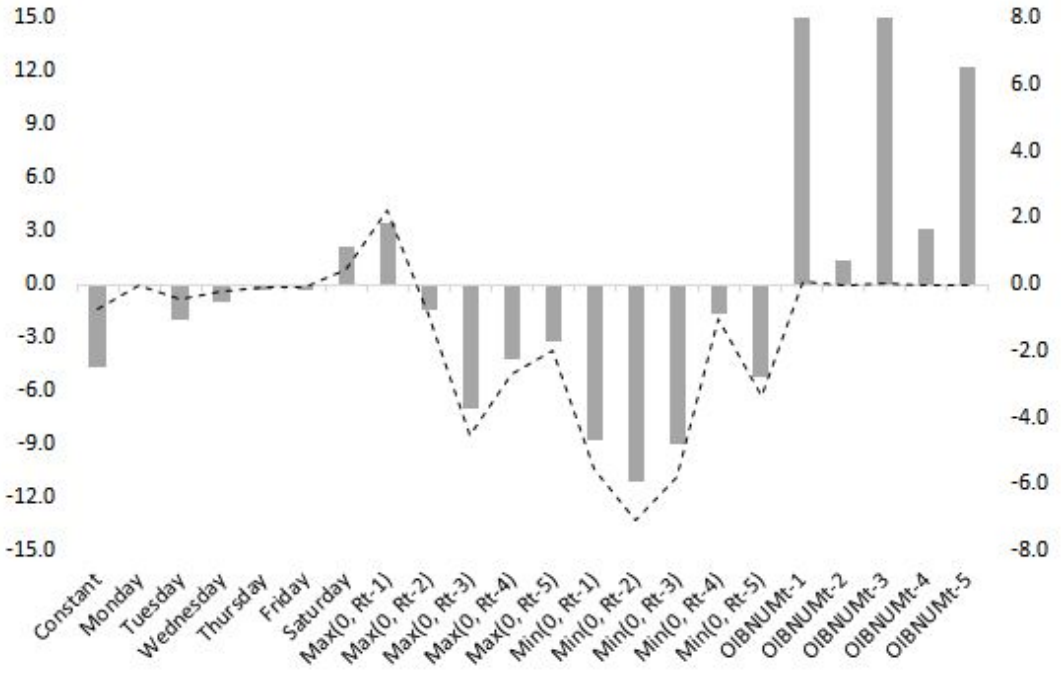
X-axis are date(25th, April, 2017 - 12th, July, 2018). Y-axis are price of bitcoin(dollar).



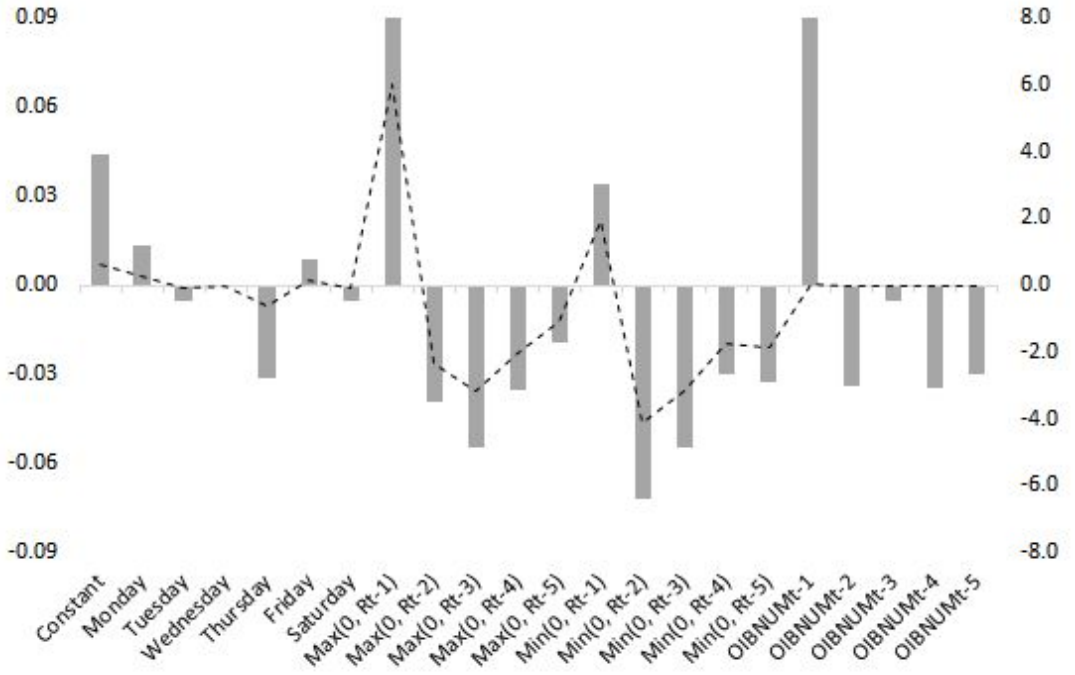
Appendix Figure 2 : Coefficient and T-statistics in Table1

We adjust independent variables related with bitcoin returns to scale the range of graph. The dependent variable is OIBNUM (Panel A) or OIBNUM/NUMTRANS (Panel B). Line graph shows the coefficients of independent variables and bar graph presents t-values.

Panel A: Dependent variable (OIBNUM)



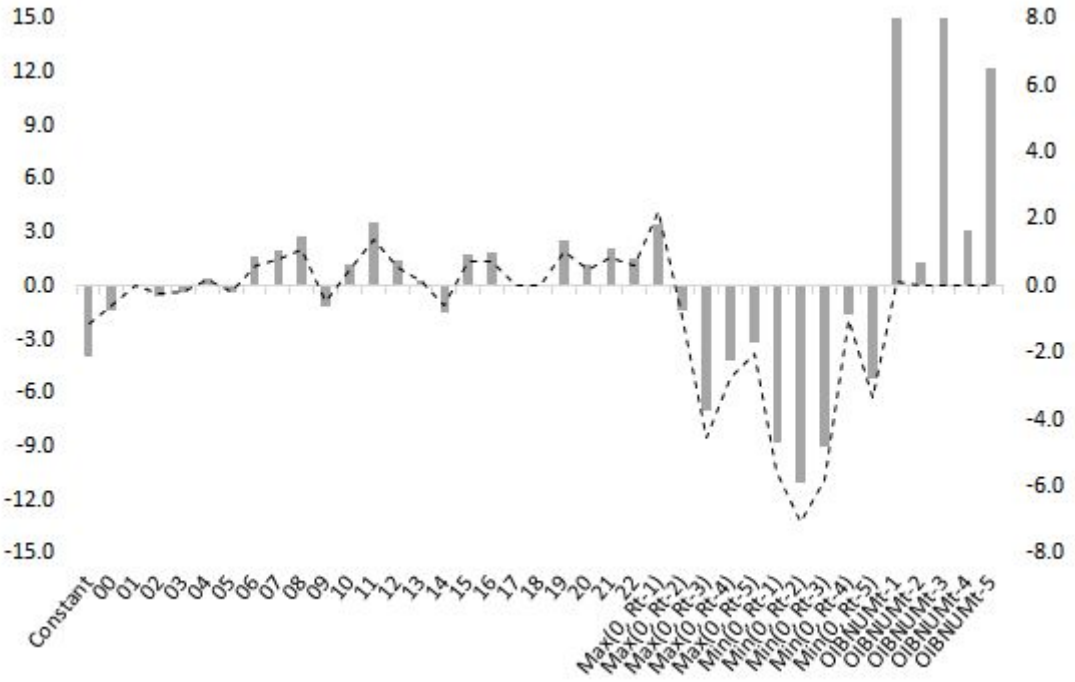
Panel B: Dependent variable (OIBNUM/NUMTRANS)



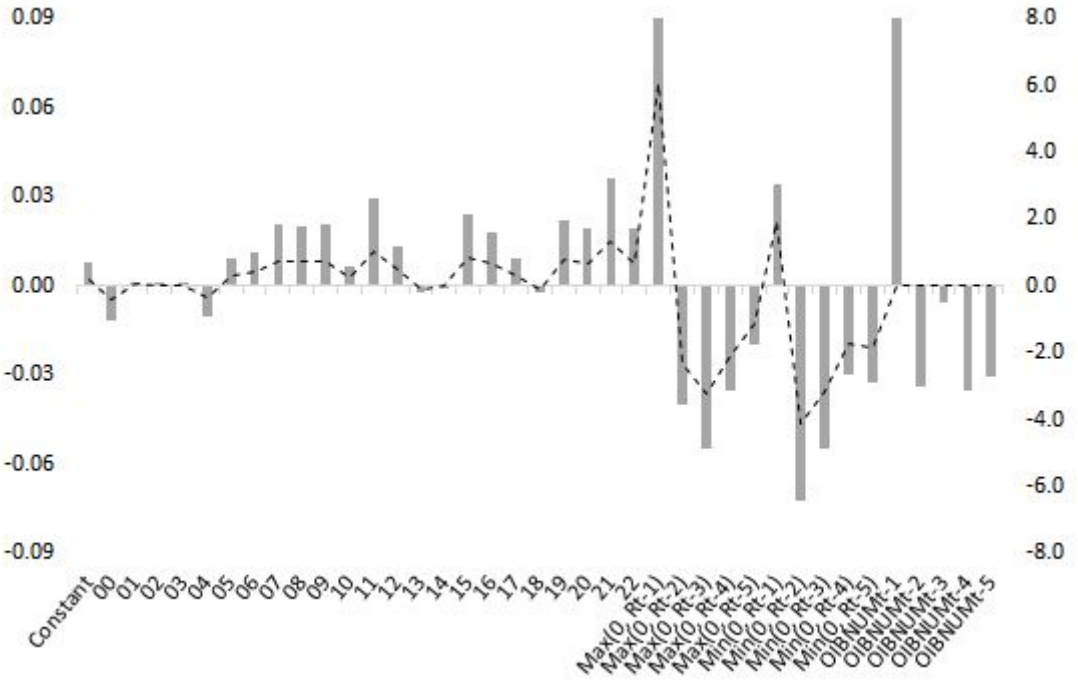
Appendix Figure 3 : Coefficient and T-statistics in Table 2

This figure presents coefficients and t-values visually. We adjust independent variables related with bitcoin returns to scale the range of graph. The dependant variable is OIBNUM (Panel A) or OIBNUM/NUMTRANS (Panel B). Line graph shows the coefficients of independent variables and bar graph presents t-values.

Panel A: Dependent variable (OIBNUM)



Panel B: Dependent variable (OIBNUM/NUMTRANS)



SUPPLEMENT

Table: Marketwide order imbalance - what causes marketwide order imbalance?

Dependent variables are the daily order imbalance measured in number of transactions, $OIBNUM_t$, on trading day t and $OIBNUM_t/NUMTRANS_t$, where NUMTRANS is total number of transactions. Both are value-weighted averages for NYSE stocks in the S&P500. The value weights are proportional to market capitalization at the end of the previous calendar year. They are regressed on day-of-the-week dummies and past positive and negative parts of S&P500 returns. R_t denotes the S&P500 index return on day t. The Cochrane/Orcutt procedure was applied to adjust for first-order serial dependence in the residuals. Data are from 1988–1998 inclusive (2779 observations, t-statistics in parentheses).

Dependent variable →	$OIBNUM_t$	$\frac{OIBNUM_t}{NUMTRANS_t}$
Explanatory variable	Coefficient (t-statistic)	
Intercept	−0.992	0.544
	(−0.43)	(1.68)
Monday	−1.80	−0.372
	(−0.70)	(−1.06)
Tuesday	6.60	0.161
	(2.64)	(0.47)
Wednesday	5.85	0.605
	(2.33)	(1.76)
Thursday	0.020	−0.345
	(0.01)	(−1.00)
Min(0, R_{t-1})	−30.06	−2.319
	(−17.70)	(−9.58)
Min(0, R_{t-2})	−2.80	−1.225
	(−1.59)	(−5.05)
Min(0, R_{t-3})	−6.25	−0.535
	(−3.52)	(−2.17)
Min(0, R_{t-4})	−1.92	−0.546
	(−1.08)	(−2.22)
Min(0, R_{t-5})	−1.16	0.828
	(−0.66)	(−3.43)
Max(0, R_{t-1})	−8.93	−1.750
	(−4.94)	(−7.04)
Max(0, R_{t-2})	0.465	−0.369
	(0.26)	(−1.46)
Max(0, R_{t-3})	−6.75	−0.877
	(−3.71)	(−3.48)
Max(0, R_{t-4})	−2.47	−0.449
	(−1.36)	(−1.79)
Max(0, R_{t-5})	−1.57	−0.530
	(−0.88)	(−2.14)
$OIBNUM_{t-1}$	0.464	0.387
	(20.18)	(15.99)
$OIBNUM_{t-2}$	0.047	0.121
	(1.83)	(4.67)
$OIBNUM_{t-3}$	0.178	0.120
	(7.04)	(4.63)
$OIBNUM_{t-4}$	0.067	0.093
	(2.62)	(3.59)
$OIBNUM_{t-5}$	0.064	0.120
	(2.85)	(4.96)
Durbin-Watson	2.01	2.01
Adjusted R^2	0.477	0.408