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**Financial Regulations and Price Inconsistencies across Bitcoin
Markets***

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Abstract

We document systematic differences in bitcoin prices across 11 different markets representing 26% of global bitcoin trade volume. These differences must — due to the identical nature of all bitcoin — result from characteristics of markets themselves. We examine differences across the markets and find that those which do not require customer identification for establishing an account are more likely to deviate from representative market prices than those which do. This implies that standard financial regulations, specifically know-your-customer regulations, can have a non-negligible impact on the bitcoin market.

JEL codes: G12, G14, K42, L86

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1 Introduction

Bitcoin is a homogeneous, virtual good that is completely identical across all the online markets in which it is sold.¹ The markets that sell bitcoin (“bitcoin exchanges”) operate 24 hours a day, 7 days a week, with pricing data available immediately and free of charge to anyone in the world with Internet access. Despite these properties, we find that bitcoin prices behave differently across markets; not all exchanges adhere to the law of one price (LOOP) — the theory that identical goods should sell for identical prices after trade costs are taken into consideration.

Should LOOP be expected of bitcoin prices? Whether bitcoin is considered a currency trading on international exchange rate markets or — as argued by Yermack (2015) — an asset trading on international financial markets, the answer is yes. Akram, Rime, and Sarno (2008) established the existence of LOOP in exchange rate markets, while Eun and Sabherwal (2003) established LOOP for internationally traded assets. Thus, if a bitcoin exchange fails to achieve LOOP, the cause must be associated with a characteristic of the exchange. We find bitcoin markets that consistently fail LOOP do not require customer identification to initiate an account, and therefore do not fully implement know-your-customer (KYC) policies. We are not aware of any other research that shows an impact by traditional financial regulations on bitcoin markets.

While there is no uniform, global regulatory framework for bitcoin—countries regulate or ignore bitcoin as they choose — most bitcoin regulations were implemented during 2013 or the beginning of 2014. The nature and extent of these regulations vary with some, such as Kaplanov (2012), debating the need for any regulation, envisioning a currency free of government intervention. The most recent bitcoin regulation announcement at the time of writing occurred on July 2014: Ecuador banned bitcoin, while the Isle of Mann merely clarified the application of existing tax rules.² Within the USA, virtual currency exchanges are regulated by the Financial Crimes Enforcement Network (FinCEN), though individual states (e.g. New York) may adopt tougher measures. In March 2013, FinCEN classified bitcoin markets as be money transmitting businesses (MTB’s), requiring exchanges to adopt anti-money-laundering (AML) and KYC policies. However, the global nature of bitcoin allows an exchange that trades bitcoin for US dollars to claim that it does not do business with the US consumers, and is therefore not subject to FinCEN’s rulings. It is also feasible for an exchange to only selectively enforce a stated AML/KYC policy. King (2016) proposes a new framework to encourage financial institutions in the USA to incorporate bitcoin-based businesses (BBBs). A key element of this framework is the expectation that financial institutions ensure that the BBBs implement *and* enforce AML/KYC. Even though the global bitcoin regulatory environment is fractured, results from this paper

¹Whether bitcoin is a currency, a good, or an asset is not relevant for this paper.

²A detailed discussion of the global regulatory environment can be found at <http://www.coindesk.com/bitcoin-legal-map/> and <http://www.coindesk.com/information/is-bitcoin-legal/>

imply that these policies may have an effect on the bitcoin market.

We provide a brief introduction to relevant bitcoin terminology and price research in Section 2. In Section 3 we summarize the behavior of bitcoin prices in US dollars across twelve price sources, and document the difference in levels both within and across exchanges depending upon which price-series is used. In Section 4, we document the failure of LOOP for several exchanges in our data. In Section 5 we examine the characteristics of each exchange, and show that all exchanges that fail LOOP do not require consumers to provide identification to establish an account. We find lower price deviations on exchanges that require identification, providing an explanation for these exchanges are more prone to LOOP failure. Section 6 concludes.

2 A Brief Review Of Bitcoin

This section provides the information needed to understand bitcoin for this paper; for a comprehensive overview of bitcoin, readers should consult [Velde \(2013\)](#). An accessible technical review of bitcoin can be found in [Böhme, Christin, Edelman, and Moore \(2015\)](#). [Brandvold, Molnár, Vagstad, and Valstad \(2015\)](#) contains a brief discussion of major events in bitcoin history, while [White \(2015\)](#) considers the market for crypto-currencies more broadly.

Bitcoin is a digital currency with no central issuing authority or physical form.³ More specifically, bitcoin is a cryptocurrency, a subset of digital currencies that use cryptography techniques to guide encryption protocols which identify ownership and verify transactions details. The bitcoin encryption protocol was outlined by the entity [Nakamoto \(2008\)](#)⁴ and uniquely identifies each bitcoin within the bitcoin economy. Nakamoto created 21 million bitcoin, but did not release these into circulation. Instead, each bitcoin must be discovered by solving mathematical algorithms in a process called mining, examined by [Kroll, Davey, and Felten \(2013\)](#). Once mined, every bitcoin—or fraction thereof—can be sold, used as payment for retail purchases, or kept as an investment to be traded later. Bitcoin is bought and sold on trading websites known as “exchanges,” each of which is independently operated and accessible 24 hours a day, 7 days a week to a global clientele.

It may seem strange that a completely virtual good could sustain a positive price. [Dwyer \(2015\)](#) showed that this phenomenon results from the limited availability and unique identification of each bitcoin. [Luther \(2016\)](#) shows that a requirement for this result is low transaction costs. [Halaburda and Gandal \(2014\)](#) show that, in its early establishment phase, the value of a cryptocurrency (of which bitcoin is but one

³Perspectives on whether bitcoin satisfies the economic definition of money can be found in [Velde \(2013\)](#), [Lo and Wang \(2014\)](#), and [Yermack \(2015\)](#), but do not impact the results of this paper.

⁴No one knows whether Nakamoto is an individual or a group, male or female, or actually Japanese.

example) is determined by competition with other cryptocurrencies. This creates volatility in its initial price, but later transitions into pricing behavior consistent with use as a financial asset. This mechanism explains why [Kristoufek \(2013\)](#) finds a cointegrating relationship between bitcoin values and search queries on Google Trends and Wikipedia (potentially indicating a speculative bubble driven by curiosity), while [Glaser, Zimmermann, Haferkorn, Weber, and Siering \(2014\)](#) find that consumers' behavior is consistent with use of bitcoin as an investment vehicle. For investment purposes, [Brière, Oosterlinck, and Szafarz \(2015\)](#) show that bitcoin is an effective diversification asset.

Bitcoin has gained links to the physical goods economy over time as retailers—including Windows, Dell, Overstock, and gift card merchants—began accepting it as a form of payment, though not all use the same method.⁵ For example, Dell accepts direct bitcoin payments, but Amazon instead provides digital gift cards which may be purchased with bitcoin and then used to purchase goods on their website. Although a growing number of vendors accept bitcoin, both [Ali, Barrdear, Clews, and Southgate \(2014\)](#) and [Greene and Shy \(2014\)](#) conclude that digital currencies such as bitcoin do not currently have enough users to act as a general purchasing alternative to fiat currencies.

3 About Bitcoin Prices

3.1 Bitcoin Data Collection

We obtain the daily data for all exchanges that post prices in US dollars for a minimum 410 of the 426 days between 1 June 2014, and 31 July 2015, from www.bitcoincharts.com.⁶ This yields data from eleven exchanges⁷ (Table 1), with price and volume statistics summarized in Table 2 and detailed exchange characteristics discussed in Section 5.1. We also collect data from Coindesk's Bitcoin Price Index, which aggregates prices from selected exchanges into a reference price-series. Linear interpolation is used in case of missing data-values.⁸

The data consist of the daily trade volume for each exchange, along with the Open, Close, High, Low, and Transaction-weighted prices. The BPI does not report Transaction-weighted price. In total we consider 59 price-series: five variants from each of the 11 exchanges, and four variants from the BPI. We examine all five variants to verify that the finding of this paper is a consistent feature of an exchange's prices. Bitcoin

⁵Websites such as [coinmap](http://coinmap.org) (<http://coinmap.org>) or [usebitcoins](http://usebitcoins.info) (usebitcoins.info) maintain lists of businesses—both online and physical—that accept bitcoin.

⁶All the studied exchanges have their bitcoin prices posted on the same aggregation website, and can therefore be simultaneously observed by all participants.

⁷One additional exchange, [Cointrader](#), satisfies this selection criterion but is not included as it subsequently declared bankruptcy due to a hack.

⁸The price-series used as reference ([BitFinex](#)) and the exchanges with the most troubled price-series ([LocalBitcoins](#) and [HitBTC](#)), have no missing data values so linear interpolation is not driving the results of this paper.

Table 1: Selected Bitcoin Exchanges

Name	Observations		Website
	Initial	Interpolated	
ANXBTC	419	426	https://anxbtc.com
BitFinex	426	426	https://www.bitfinex.com
BitKonan	423	426	https://bitkonan.com
BitStamp	423	426	https://www.bitstamp.net
BTC-e	415	426	https://btc-e.com
HitBTC	426	426	https://hitbtc.com
itBit	426	426	https://www.itbit.com
Kraken	417	426	https://www.kraken.com
LakeBTC	414	414	https://www.lakebtc.com
LocalBitcoins	426	426	https://localbitcoins.com
The Rock Trading	420	426	https://www.therocktrading.com
Bitcoin Price Index (BPI)	426	426	http://www.coindesk.com/price/

exchanges operate 24 hours a day, 7 days a week, the close is the price of the last trade prior to 23:59:59 UTC, open is the price of the first trade after 00:00:00 UTC. We obtain data on the daily total global volume of bitcoin trades from <https://blockchain.info>. The BPI does not report a trade volume associated with its index price.

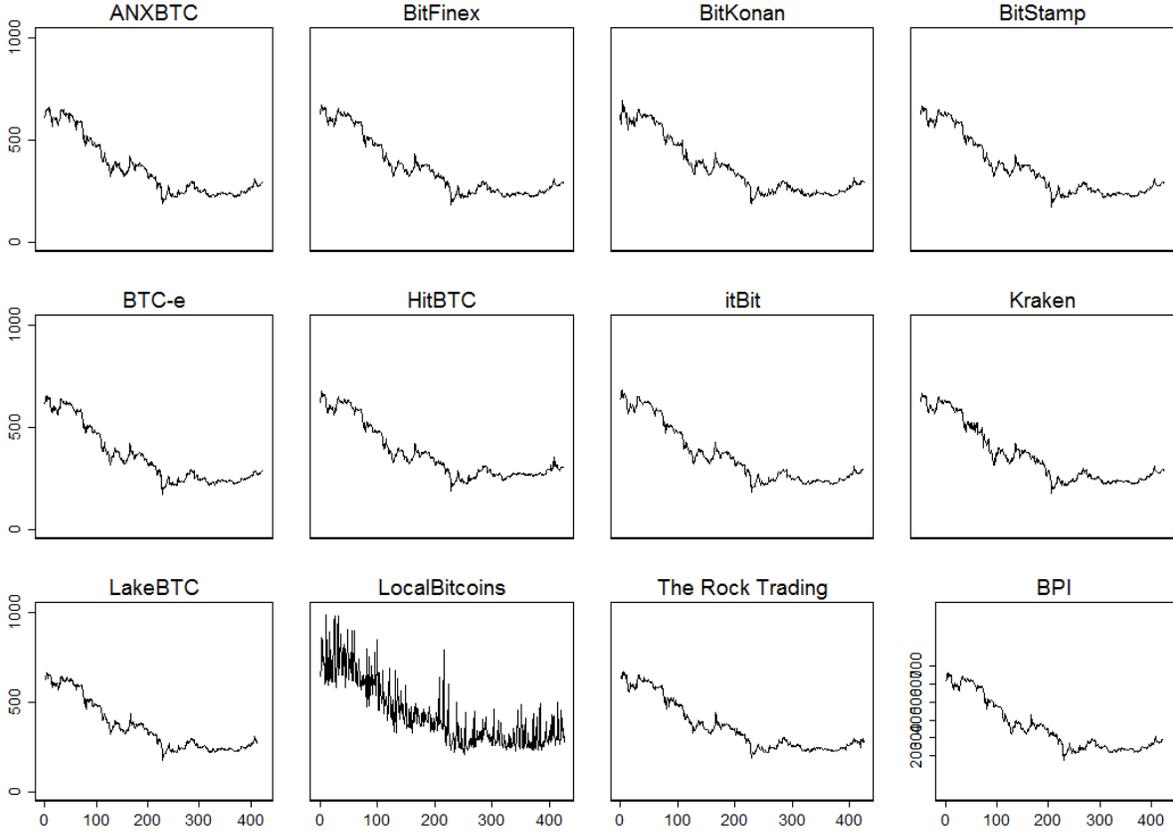
The data contain several clear outliers. For example, on 3 November 2014 the exchange LakeBTC reports a High price of \$1000 for one bitcoin. The highest LakeBTC price on the day preceding this transaction was \$330.52 and the highest price on August 2nd, the day following, was \$329.67. The average High price across all the other exchanges on November 3rd was \$392.88. Outliers could contribute towards a finding of LOOP failure if kept, and— given that determining whether outliers are bad data or an actual transaction price is beyond the scope of this paper—we remove them to minimize potential false identification. Outliers are replaced by the average of the adjacent prices on the exchange (in the example above, \$1000 is replaced by \$330.10).⁹ Removing outliers with this method reduces the number of price deviations, and therefore biases the data against our main finding of non-LOOP behavior.

3.2 Summary of Bitcoin Prices

The Open price-series for each exchange is shown in Figure 1. Visually, the prices for all exchanges are similar, decreasing from a high of \$600, at the beginning of the sample, to a mid-sample low of approximately \$200, followed by a slow increase. The turning point does not correspond to a known event in bitcoin history, and the exact timing varies across exchanges. The LocalBitcoins price-series are clearly more volatile than other exchanges, but despite this follow the same trend as other exchanges. LocalBitcoins Transaction-weighted

⁹Significant outliers are defined as a price satisfying at least one of the following criteria: A price less than \$1 or greater than \$3,000; a percent change in daily price further than 10 standard deviations away from the mean of the changes for the series; or a price that doubles (or halves) then approximately returns to its original value the following day.

Figure 1: Open USD Bitcoin Price



price displays a volatility comparable to other exchanges.¹⁰

The median daily Open, Close, High, Low, and Transaction-weighted price behavior across exchanges is summarized in Table 2. LocalBitcoins posts a median Open, Close, Weighted, and High price well above the other exchanges, while Low prices are below those of other exchanges. LocalBitcoins' median daily High/Low Price Premium (the difference between the High and Low price, relative to the Low price) is 136.75%, easily the highest of all the exchanges (the second-highest is BitKonan, where the median daily High price is 6.12% above the Low price).¹¹ It should come as no surprise that LocalBitcoins data will be found to be unrepresentative of bitcoin prices. It is less obvious from Table 2 that this distinction is shared by HitBTC as well. A comparison of bitcoin price levels is therefore not sufficient to identify exchanges that are not representative of the bitcoin market.

The remaining four columns of Table 2 compare the transaction volumes on each exchange relative to the estimated transaction volume across the entire bitcoin market, provided by Blockchain (www.blockchain.info,

¹⁰Series volatility is examined in Section A.1.

¹¹Recall that outliers within each series were removed. Despite this, LocalBitcoins High prices are persistently higher, and its low prices persistently lower than other exchanges.

Table 2: Median Price and Volume Characteristics Across Exchanges

	Price (USD)					High/Low Premium (%)	Transaction Volume			
	Open	Close	High	Low	Wei		BTC	%	USD	%
ANXBTC	315	314	321	296	314	4.84	856	0.53	255,944	0.52
BitFinex	315	314	320	304	312	4.26	17,511	11.25	5,580,123	11.25
BitKonan	315	320	328	301	310	6.12	3	0.00	899	0.00
BitStamp	315	313	320	306	314	4.33	8,803	5.87	2,887,517	5.87
BTC-e	312	311	315	304	311	3.79	5,990	4.09	1,883,258	4.05
HitBTC	320	321	331	311	320	4.29	370	0.25	123,580	0.25
itBit	315	313	317	305	313	2.94	1,485	1.11	528,609	1.11
Kraken	315	314	320	305	316	3.75	10	0.00	3,457	0.00
Lake	322	321	330	315	319	3.21	3,865	2.69	1,309,233	2.69
LocalBitcoins	386	381	1001	249	345	136.75	1,458	0.91	567,164	1.00
TheRock	317	313	335	312	316	2.05	10	0.00	3,051	0.00
BPI	315	314	319	308	—	3.55	—	—	—	—
BkCn	—	—	—	—	—	—	160,353	100.00	48,689,795	100.00

Abbreviations: BkCn, Blockchain; BPI, Bitcoin Price Index; H/L, high/low ratio; Wei, transaction-weighted price.

BkCn). The share of global bitcoin trades and the share of USD trades in global bitcoin markets are similar, indicating that these exchanges all primarily trade in USD-BTC. The selected exchanges account for 26% of the USD-BTC trade volume during this time period. According to Bitcoincharts¹², there are 72 active exchanges globally—though many do not trade in USD—thus, these eleven exchanges represent 15% of all exchanges. BitFinex is the largest exchange, representing a daily median of 11.25% of global bitcoin transactions, whereas the transaction volume of the smallest exchanges (BitKonan, Kraken, and The Rock Trading) are negligible on the scale of the global bitcoin market.¹³

4 Investigating Law of One Price Between Exchanges

Each bitcoin price-series contains a time trend, so we use a cointegration test to verify whether LOOP is satisfied. Given the price of bitcoin in two different markets, $m1$ and $m2$, a cointegration test determines if any linear combination of the price-series results in a stationary residual, ϵ_t .¹⁴

$$p_t^{m1} - \beta p_t^{m2} = \epsilon_t \tag{1}$$

The cointegration test establishes whether a β exists. If the two series do not cointegrate, then no linear combination can be found that results in a stationary residual and therefore the two series cannot obey the LOOP. If the two series cointegrate, LOOP requires that the long run linear cointegrating parameter, β ,

¹²bitcoincharts.com/markets/list

¹³Like any currency, a bitcoin is divisible — A trade volume of 3 bitcoin does not correspond to a maximum of three trades of 1 bitcoin each. Currently, the smallest unit is called 1 bitcoin satoshi, a hundred-millionth of a bitcoin (10^{-9}). Each exchange can determine the smallest trade it will accept.

¹⁴This definition is adopted from the purchasing power parity example in Greene (2007), Chapter 20.

equals one: the two prices should be the same up to a constant.¹⁵ If it does not equal one, the two price-series display a statistically significant drift over the sample period.

4.1 Method

We first verify that both price-series are unit root, employing two tests with opposing null hypotheses for increased robustness. Our test with a null of the unit root is the Elliot et al. (1996) method of evaluating the Dickey-Fuller test (Dickey and Fuller, 1979) using generalized least squares (DFGLS). The test with a null of level stationarity is the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test (Kwiatkowski et al., 1992).

If both series are unit root, we apply the Johansen (1995) trace test to each at lag ℓ . The Johansen trace test iteratively examines the hypothesis that r or fewer cointegrating equations exist, with $r = 0$ representing no cointegration. With two series, a cointegrating relationship is the simultaneous result that $r \leq 1$ is significant and $r = 0$ is not. If the Johansen trace test finds cointegration, the cointegrating parameter can be estimated using a vector error correction model (VECM) with the vector of the bitcoin price $p_{m,t}$ for a given exchange m and the reference series r_t , $\mathbf{P}_{m,t} = [p_{m,t}, r_t]$:

$$\Delta \mathbf{P}_t = \alpha \Pi' \mathbf{P}_{t-1} + \sum_{i=1}^{\ell-1} \Gamma_i \Delta \mathbf{P}_{t-i} + \gamma + \epsilon_t \quad (2)$$

where $\Delta \mathbf{P}_t = \mathbf{P}_t - \mathbf{P}_{t-1}$, and the market specific subscript on each term is omitted. The lag is first selected according to the Schwarz Bayesian information criterion (SBIC). The residual of the VECM model is evaluated for autocorrelation using a Lagrange Multiplier (LM) test as described in Johansen (1995). If autocorrelation is found, the lag is increased by one and the tests are repeated.

If at least one series is not unit root at the selected lag, the Johansen trace test cannot be applied. Instead, we apply the Pesaran et al. (2001) test (PSS). The PSS test allows for one series to be non-unit root, but requires a single direction of granger-causality between the series. Formally, the PSS bounds test is based on the unrestricted conditional error-correction model (CECM), expressed in notation of equation 2 as:

$$\Delta p_t^y = \alpha + \sum_{i=1}^{\ell} \Gamma_i \Delta \mathbf{P}_{t-i} + \gamma \Pi' \log \mathbf{P}_{t-1} + \omega' \Delta p_t^x + \epsilon_t \quad (3)$$

where p_t^x refers to the exchange that granger-causes the prices on exchange y , p_t^y .¹⁶ In cases where granger-causality is confirmed, BitFinex is usually identified as the granger-causing series. Given the presence of series that are not stationary, we use the methodology of Toda and Yamamoto (1995) (TY) to determine

¹⁵It is expected that $\epsilon \neq 0$ as each exchange has various fees, which should introduce an arbitrage band.

¹⁶Or, in the words of Pesaran et al. (2001), p_t^x is the forcing function for p_t^y .

Granger causality, first estimating a vector autoregression model (VAR) on the data with lags $\ell + 1$:

$$\mathbf{P}_t = c + \sum_{i=1}^{\ell+1} \Psi_i \mathbf{P}_{t-i} + \epsilon_t \quad (4)$$

where $\mathbf{P}_{t-(\ell+1)}$ is an exogenous variable. If we find residual autocorrelation at either ℓ , the lag is incremented and the procedure repeated.

The long-run price-series relationship is captured in the coefficient $\Pi = [1, -\beta]$. If $\beta = 1$, the market and the reference series perfectly share the same long-run trend. The typical size of the 99% confidence interval around β is 0.03, therefore $\beta \in [0.97, 1.03]$ will be interpreted as showing LOOP.

4.2 Long-Run Relationships

The results from the unit root test, cointegration test, and long run cointegrating relationship for each price-series are displayed in Table 3 and 4.¹⁷ The rows labeled “Unit Root?”, “Cointegrated?”, and “Law of One Price?” report whether the tests in the preceding rows confirm series unit root, series cointegration with BitFinex, and Law of One Price with BitFinex respectively. We use BitFinex, the largest bitcoin exchange, as the reference series. This does not imply that other exchanges are less valid or less important: BitStamp, the second-largest exchange, has a longer time series than BitFinex; BTC-e, the third largest exchange, was found to be a price leader by Brandvold et al. (2015). The CoinDesk Bitcoin Price Index (BPI), created by Quandl, reports bitcoin prices averaged across selected exchanges and may therefore be more robust to exchange-specific effects.¹⁸ We verify robustness using other series in section 4.3.1. The BitKonan Open, LocalBitcoins Weighted, and The Rock Trading Low price suffer from residual autocorrelation for all lags up to 15, indicated by $\ell > 15$, and are therefore not tested. The BPI does not have a Transaction-weighted price-series.

For any given exchange, LOOP findings in Tables 3 and 4 are the same for all tested price-series. The cause of LOOP failure is therefore not a characteristic that can be isolated to a single price-series, but is a general feature of an exchange. The price-series from HitBTC and LocalBitcoins consistently fail to attain LOOP with BitFinex. HitBTC fails as it does not have a cointegrating relationship with BitFinex while LocalBitcoins does cointegrate but does not obey LOOP.

Figure 2 is the difference between BitFinex and the series prices for LocalBitcoin and HitBTC—the two

¹⁷VECM postestimation test results for eigenvalue stability are not included, but are consistent with well behaved series: There is one unit modulus, with all others strictly less than one.

¹⁸There are several shortcomings of the BPI, variants of which are shared by most bitcoin price indexes: it only posts bitcoin prices in US dollars, Euros, and Chinese yuan even though bitcoin is purchased using many currencies; the criteria for an exchange’s initial selection is unknown, as are the details of the price averaging procedure; the BPI only posts open, close, high, and low prices, not a transaction-weighted price; and it does not provide trade volumes tailored to the price index it reports. Once selected, an exchange in the BPI must satisfy criteria described at CoinDesk (www.coindesk.com/bitcoin-price-index/).

Table 3: Price Cointegration with BitFinex: Open and Close Prices

	ANX	BitK	BitS	BTC-e	HitBTC	itBit	Kraken	Lake	Local	Rock	BPI
OPEN											
Lag ℓ	4	> 15	2	1	3	1	1	1	1	6	1
<i>Unit Root Test</i>											
DFGLS	0.30	–	0.34	0.31	0.18	0.29	0.27	0.29	-2.61***	0.33	0.21
KPSS	7.17***	–	11.9***	17.7***	8.51***	17.8***	17.9***	17.7***	16.2***	5.2***	17.8***
Unit root?	Yes	–	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
<i>Cointegration Test</i>											
$r = 0$	89	–	81	110	14***	136	202	111	–	35	110
$r \leq 1$	5.21***	–	3.64***	3.28***	5.14	3.77***	3.45***	3.22***	–	5.37***	3.44***
PSS	–	–	–	–	–	–	–	–	180***	–	–
Cointegrated?	Yes	–	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
<i>Long-Run Cointegrating Trend</i>											
β	1.00***	–	1.00***	0.99***	–	1.00***	1.01***	1.00***	1.14***	0.98***	1.00***
LOOP?	Yes	–	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes
CLOSE											
Lag ℓ	1	3	7	5	3	2	4	5	4	1	5
<i>Unit Root Test</i>											
DFGLS	0.35	-0.04	0.41	0.43	0.21	0.41	0.32	0.57	-0.49	0.29	0.41
KPSS	17.7***	8.93***	4.52***	5.96***	8.46***	11.8***	7.19***	5.96***	7.11***	17.9***	5.97***
Unit root?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Cointegration Test</i>											
$r = 0$	263	83	30	30	15***	84	53	32	90.37	208	29
$r \leq 1$	3.47***	5.62***	5.45***	4.56***	5.54	5.05***	4.27***	4.90***	4.71***	3.45***	5.45***
Cointegrated?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
<i>Long-Run Cointegrating Trend</i>											
β	1.01***	0.98***	1.00***	0.99***	–	1.00***	1.00***	1.00***	1.13***	0.99***	1.00***
LOOP?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes

Abbreviations: ANX, ANXBTC; BitK, BitKonan; BitS, BitStamp; DFGLS, Dickey-Fuller with Generalized Least Squares; KPSS, Kwiatkowski-Phillips-Schmidt-Shin; Lake, LakeBTC; Local, LocalBitcoin; LOOP, law of one price; Rock, The Rock Trading. Significance: ***1%, **5%, *10%.

series that failed to yield LOOP.¹⁹ The HitBTC differences are not stationary, visually confirming the lack of cointegration reported in Tables 3 and 4. Recall that LocalBitcoins cointegrates with BitFinex, but does not have LOOP, consistent with the observable trends in Figures 2b, 2d, 2f, and 2g.²⁰ The high volatility of LocalBitcoins—detected in price summaries presented Table 2—is clearly visible.

4.3 Robustness

4.3.1 Other Exchanges As The Reference Series

We re-examine LocalBitcoins and HitBTC using the other exchanges as reference series, to evaluate whether the failure of LOOP could result from the decision to use BitFinex as a reference series. We apply all the methods of section 4.1, but unlike the detailed results in Tables 3 and 4, we report only the cointegrating parameter β in Table 5. An *NC* value indicates the Johansen test found no cointegration between the two series, *NGC* indicates that a single direction of granger-causality could not be established when a series failed the unit root test. Results in Table 5 confirm that failure to find LOOP does not stem from using Bitfinex

¹⁹A trend line constructed using a Lowess smoother with a bandwidth of 40% is included to facilitate analysis of long run trends.

²⁰For example, according the results in Table 4, the LocalBitcoins Low price difference, $p_t^{Local,Low} - p_t^{BitFinex,Low}$ graphed in Figure 2g is not stationary (as required by LOOP), but $p_t^{Local,Low} - 0.89p_t^{BitFinex,Low}$ would be.

Table 4: Price Cointegration with BitFinex: Weighted, High, and Low Prices

	ANX	BitK	BitS	BTC-e	HitBTC	itBit	Kraken	Lake	Local	Rock	BPI
WEIGHTED											
Lag ℓ	5	2	5	6	6	5	5	5	> 15	6	–
<i>Unit Root Test</i>											
DFGLS	0.46	0.41	0.47	0.45	0.43	0.54	0.39	0.58	–	0.42	–
KPSS	5.96***	11.9***	5.99***	6.13***	4.91***	6***	6.02***	5.97***	–	5.21***	–
Unit root?	Yes	–	Yes	–							
<i>Cointegration Test</i>											
$r = 0$	53.12	119.11	48.27	23.79	11.54***	72.48	57.62	40.53	–	38.20	–
$r \leq 1$	4.62***	3.95***	5.34***	4.08***	4.82	5.57***	5.60***	4.91***	–	4.27***	–
Cointegrated?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	–	Yes	–
<i>Long-Run Cointegrating Trend</i>											
β	1.00***	0.99***	1.01***	0.99***	–	1.00***	1.00***	1.00***	–	0.98***	–
LOOP?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	–	Yes	–
LOW											
Lag ℓ	5	1	1	5	5	4	5	2	1	> 15	1
<i>Unit Root Test</i>											
DFGLS	0.33	-0.22	0.10	0.27	0.21	0.29	0.25	0.29	-0.58	–	-1.23
KPSS	5.83 [†]	17.4 [†]	17.4 [†]	5.88 [†]	5.65 [†]	7.08 [†]	5.92 [†]	11.7 [†]	3.97 [†]	–	4.04 [†]
Unit root?	Yes	–	Yes								
<i>Cointegration Test</i>											
$r = 0$	44	150	185	39	16***	66	53	103	229	–	251
$r \leq 1$	4.78 [†]	3.49***	3.67***	4.53***	4.56	4.28***	5.27***	3.49***	3.54***	–	3.64***
Cointegrated?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	–	Yes
<i>Long-Run Cointegrating Trend</i>											
β	0.98 [†]	0.98 [†]	1.00 [†]	0.99***	–	1.00***	1.00***	1.00***	0.89***	–	1.00***
LOOP?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	–	Yes
HIGH											
Lag ℓ	5	1	4	1	3	1	2	1	1	3	5
<i>Unit Root Test</i>											
DFGLS	0.55	0.36	0.60	0.53	0.38	0.48	0.48	0.51	-8.19***	0.34	0.58
KPSS	6.06***	18***	7.28***	18***	8.53***	17.9***	12.1***	17.9***	2.08***	9.3***	6.06***
Unit root?	Yes	No	Yes	Yes							
<i>Cointegration Test</i>											
$r = 0$	76	248	48	129	14.01***	133.45	115.57	107.99	–	60.69	36.84
$r \leq 1$	4.73***	4.97***	5.02***	4.98 [†]	5.67	5.53***	4.88***	4.74***	–	5.53***	5.21***
PSS	–	–	–	–	–	–	–	–	60.78***	–	–
Cointegrated?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
<i>Long-Run Cointegrating Trend</i>											
β	1.02***	0.99***	1.00***	0.98***	–	0.99***	1.00***	1.00***	1.06***	0.97***	0.99***
LOOP?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes

Abbreviations: ANX, ANXBTC; BitK, BitKonan; BitS, BitStamp; DFGLS, Dickey-Fuller with Generalized Least Squares; KPSS, Kwiatkowski-Phillips-Schmidt-Shin; Lake, LakeBTC; Local, LocalBitcoin; LOOP, law of one price; Rock, The Rock Trading. Significance: ***1%, **5%, *10%.

as the reference series. In all 90 cases where the reference series had LOOP with BitFinex, LocalBitcoins and HitBTC do not yield LOOP.²¹

We can establish market segmentation if the markets that do not satisfy LOOP with the reference series obey LOOP with each other. The relationship between LocalBitcoins and HitBTC exchanges is subtle: They are always cointegrated with each other, though they never obey LOOP with each other. Therefore, even though their price trends have more in common with each other than with BitFinex, they do not represent their own segmented market.

²¹LOOP results are transitive: all exchanges that adhere to LOOP with BitFinex also enjoy LOOP with each other.

Figure 2: Price difference for series that failed LOOP

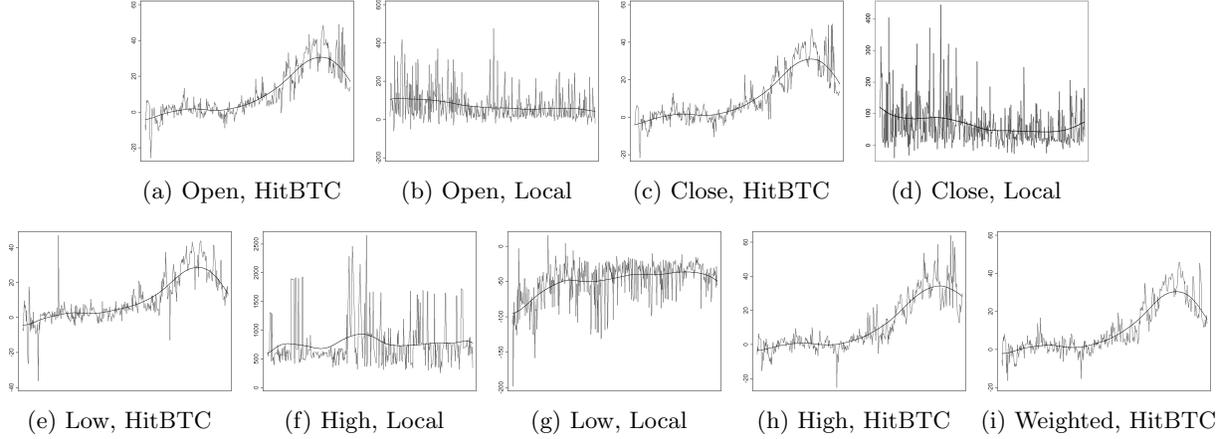


Table 5: Consistency of LOOP failure using other reference series

	BitFinex	Series with BitFinex LOOP									Series w/o BitFinex LOOP	
		ANX	BitK	BitS	BTC-e	itBit	Kraken	Lake	Rock	BPI	HitBTC	Local
<i>LocalBitcoin</i>												
Open	1.14	1.14	NGC	1.14	1.16	1.14	1.13	1.14	1.15	1.15	1.21	—
Close	1.13	1.13	1.13	1.13	1.14	1.13	1.14	1.13	1.15	1.14	1.20	—
Low	0.89	0.91	0.91	0.90	0.91	0.90	0.89	0.89	0.90	0.90	0.95	—
High	1.06	NGC	1.03	1.07	NGC	NGC	NGC	NGC	NGC	NGC	NGC	—
<i>HitBTC</i>												
Open	NC	NC	$\ell > 15$	NC	NC	NC	NC	NC	NC	NC	—	1.21
Close	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	—	0.84
Weighted	NC	NC	NC	NC	NC	NC	NC	NC	NC	—	—	$\ell > 15$
Low	NC	0.95	NC	NC	0.94	NC	0.92	NC	$\ell > 15$	NC	—	1.06
High	NC	NC	0.94	NC	NC	0.94	NC	NC	NC	NC	—	NGC

All observations are significant at 1%

Abbreviations: $\ell > 15$, Lag to avoid residual autocorrelation greater than 15 days; NC, Not Cointegrated; NGC, Could not establish single direction granger-causality.

4.3.2 Structural Breaks

Visual examination of the series presented in Figures 1 and 2 reveals potential structural breaks occurring between mid-December, 2014 and mid-January, 2015. There is no known major event occurring within this time-period in bitcoin history. To verify that cointegration failure is not a result of a structural break, the sample is split into two sub-periods—the first 200 observations preceding 17 December 2014 (the “first segment”), and the final 176 observations after 5 February 2015 (the “second segment”). We again apply the methods from section 4.1 to each sub-segment. This division separates the decreasing and increasing sections of the price-series for all exchanges, as well as the observed “hump” for HitBTC in Figure 2, while retaining same-size sample within each segment across all exchanges. Results for all series are presented in Table 6, using BitFinex as the reference series and the same notation as Table 5.

The results for HitBTC show that failure of LOOP in the full sample is caused by the behavior of the

Table 6: Structural Break Cointegration with BitFinex

	ANX	BitK	BitS	BTC-e	HitBTC	itBit	Kraken	Lake	Local	Rock	BPI
<i>Open</i>											
Full Sample	1.00	$\ell > 15$	1.00	0.99	NC	1.00	1.01	1.00	1.14	0.98	1.00
First Segment	1.00	0.96	0.99	0.99	0.99	1.00	0.98	1.00	1.15	0.98	0.99
Second Segment	1.01	1.01	0.99	0.91	0.84	0.99	1.01	0.97	0.88	0.93	0.98
<i>Close</i>											
Full Sample	1.01	0.98	1.00	0.99	NC	1.00	1.00	1.00	1.12	0.99	1.00
First Segment	1.00	0.95	0.99	0.99	0.99	1.00	0.98	0.99	NGC	0.99	0.99
Second Segment	1.01	1.04	0.99	0.91	NC	1.00	0.99	0.97	1.35	0.92	0.98
<i>Weighted</i>											
Full Sample	1.00	0.99	1.00	0.99	NC	1.00	1.00	1.00	$\ell > 15$	0.98	–
First Segment	1.01	0.97	1.00	0.99	1.00	1.00	0.99	1.00	1.05	0.98	–
Second Segment	NC	1.04	1.00	0.91	NC	0.99	1.01	0.97	1.04	0.93	–
<i>Low</i>											
Full Sample	0.98	0.98	1.00	0.99	NC	1.00	1.00	1.00	0.89	$\ell > 15$	1.00
First Segment	0.99	0.96	0.99	0.99	0.99	1.01	0.98	1.00	0.88	1.00	0.99
Second Segment	1.02	1.01	1.01	0.92	NC	0.98	0.98	0.96	0.80	0.86	NC
<i>High</i>											
Full Sample	1.02	0.99	1.00	0.98	NC	0.99	1.00	1.00	NGC	0.97	0.99
First Segment	1.03	0.97	0.99	0.99	1.00	1.00	0.98	0.99	NGC	0.95	0.99
Second Segment	1.02	1.02	0.99	0.89	NC	1.00	1.00	0.97	NC	0.97	0.97

All observations are significant at 1%

Abbreviations: $\ell > 15$, Lag to avoid residual autocorrelation greater than 15 days; NC, Not Cointegrated; NGC, Could not establish single direction granger-causality.

second segment; the first segment does satisfy LOOP. There are no publicly stated reasons that could explain this turning point for HitBTC. This is additional evidence that failure of LOOP is not caused by market segmentation between exchanges: LocalBitcoins fails LOOP in both segments.²²

BitKonan and Rock Trading illustrate that structural issues such as autocorrelation (indicated by $\ell > 15$ in the full sample) may point to trend changes within the sample (the Low price result for Rock Trading shows a clear change in the cointegration parameter for the two periods), but not necessarily so (the β parameter for the LocalBitcoin Transaction-weighted price is relatively stable). This could reflect limitations inherent in the significantly reduced sample size, diminishing our ability to establish additional conclusions.

The differences in the β parameter for the shorter sample is greater than the full series, making verification of LOOP harder. The second segment of BitKonan Low prices clearly fails LOOP with a β of 0.85, but how should we regard LakeBTC’s Low β of 0.96? Given that the 99% confidence interval around LakeBTC is [0.93,0.99], a $\beta = 1$ is statistically unlikely. We shall classify an exchange containing at least one segment with $\beta \notin [0.90, 1.10]$ as displaying “Strong LOOP Failure”, while an exchange containing $\beta \in [0.90, 1.10]$ but $\beta \notin [0.97, 1.03]$ displays “Weak LOOP Failure”. There are therefore four exchanges that have no LOOP failure: ANXBTC, BitStamp, itBit, and Kraken, as well as the BPI. Two exchanges (LakeBTC and

²²We emphasize that data from LocalBitcoins and HitBTC should not be avoided *per se*, rather that the nature of bitcoin exchanges requires initial testing to verify that a price-series is representative.

BitKonan) have “Weak LOOP Failure”, while two more (The Rock Trading and BTC-e) have “Strong LOOP Failure”. LocalBitcoins and HitBTC display “Consistent LOOP Failure” as they do not achieve LOOP over the full sample.

5 Exchange Characteristics and Bitcoin Pricing Behavior

The preceding section identifies the extent to which bitcoin exchanges may — or may not — be representative of bitcoin price trends. In this section, we examine the extent to which differences in prices may be explained by characteristics of the exchanges.

5.1 Exchange Characteristics

Table 7 summarizes select characteristics of the 11 exchanges across three categories: fees, exchange transparency, and regulations. Additional notes are in italics. BPI is not an exchange and is not included.

Table 7: Characteristics of Bitcoin Exchanges

Name	Fees			Exchange Transparency			Regulations	
	Trading	Deposit [†]	Withdrawal [†]	Incorp.	Physical	Server	AML/KYC	ID required at
ANXBTC	Free	Free	\$30	Hong Kong	Hong Kong	Hong Kong	Yes	Funding
	<i>Offers a debit card. A fully centralized service: upon indicating a quantity to buy/sell, users receive a 30-second “take-it-or-leave-it” price offer. Also accepts EUR, GBP, CHF, CAD, AUD, YEN, HKD, NZD, and SGD.</i>							
BitFinex	0.00%-0.20%	\$20	\$20	British Virgin Islands	UK	Italy	Yes	W-USD
	<i>Advertising a job opening at London office. Claims offices in New York, Hong Kong and Taiwan. Included in BPI. Free Bitcoin deposit</i>							
BitKonan	0.29%	\$15	\$15	Croatia	Croatia	Netherlands	Yes	None
	<i>Accepts deposits in multiple currencies, but automatically converts into USD.</i>							
BitStamp	0.10%-0.25%	\$7.50	\$15	UK	UK, USA, Luxembourg	(?)	Yes	Funding
	<i>Offers a debit card. Included in the CoinDesk BPI. Hacked during sample period. Also accepts EUR, GBP.</i>							
BTC-e	0.20%	\$0-\$60	\$0-\$60	Cyprus	(?)	(?)	Yes	None
	<i>Included in the CoinDesk BPI. Known for an active message board displayed alongside the buy/sell window. Fees may vary by user. Also accepts EUR, RUR.</i>							
HitBTC	0.10%	\$9	\$9	(?)	(?)	(?)	Yes (Tiered)	W-USD
	<i>No countries are referenced in the Terms of Service Agreement. Also accepts EUR.</i>							
itBit	0.10%-0.50%	\$10	\$20	USA	USA	USA	Yes	Funding
	<i>Board of directors includes former FDIC chairman, Sheila Bair. Also accepts EUR, SGD.</i>							
Kraken	0.10%-0.35%	\$20	\$20	USA	USA	(?)	Yes	Funding
	<i>Also accepts EUR, GBP, JPY. Does not allow off-chain transactions.</i>							
LakeBTC	0.00%-0.20%	Free	\$6-\$8	(?)	China	(?)	Yes	None
	<i>Terms of Service Agreement refers to USA, Sweden and the UK. Also accepts CNY, SEK.</i>							
LocalBitcoins	0.00%-1.00%	N/A	N/A	Finland	Finland	(?)	No	None
	<i>Acts as a message board and bitcoin wallet to facilitate peer-to-peer trades. Allows prices to be posted in any currency or commodity (gold, etc.), but only accepts bitcoin deposits into wallets. Has a fee to deposit bitcoin. Database hacked during sample period.</i>							
The Rock Trading	0.075%-0.50%	Free	€11	Malta	Malta	(?)	Yes (Tiered)	W-USD
	<i>Also accepts EUR, GBP</i>							

Abbreviations: AML, anti-money laundering; Incorp., country of incorporation; KYC, know-your-client/customer; Tiered: Has tiered KYC compliance

[†]: The fee for a transfer of US\$1,000 via bank wire either into (deposit) or out of (withdrawal) the exchange.

The “Fees” columns summarize various fees across the exchanges. Fees typically depend on trade volume, with most trading fees between 0% to 0.50%. LocalBitcoins is unusual in that it charges no fee for buying,

and a 1% fee for selling bitcoin, regardless of volume. Deposit and withdrawal fees are calculated for a transfer of US\$1,000 via bank wire.²³ LocalBitcoins—which does not accept currency deposits—has no currency transfer fees. Most exchanges charge a higher fee for withdrawals than deposits.

The next section in Table 7 represent measures of an exchange’s transparency: is it even possible to determine which country’s laws the exchange should follow? The country of incorporation (“Incorp.”) is determined by the laws referenced in the exchange’s Terms of Service. The physical location (“Physical”) reflects either a mailing address or the location of an advertised job opening. Job location may be misleading as employees may telecommute, while the mailing address may be for a holding company. Finally, we also report server location (“Server”) as this may be a better indicator of the physical location of the exchange’s headquarters. It is rare that a country of incorporation cannot be determined. The physical address usually reflects the country of incorporation, although it may be different (BitFinex). Most exchanges refuse to reveal their server locations. The available data reveals the global diversity of bitcoin exchanges, with 11 exchanges revealing known connections to 12 countries.

The final pair of columns (“Regulations”) are measures of an exchange’s adherence to AML/KYC. The functional details required to adhere to AML/KYC may vary, but broadly speaking KYC adherence involves collecting data to verify the identity of an account holder (drivers license, passport, etc.), while AML requires that an exchange monitor transaction data to identify suspicious behavior. “AML/KYC” indicates whether an exchange has a statement that implies that it adheres to AML/KYC. Some exchanges will state compliance to only AML policies, but their description of enforcement includes collecting passport or ID photos, which we interpret as evidence of a KYC policy, even if it not stated as such.

It is possible that an exchange claims it adheres to an AML/KYC policy, without effectively implementing one. While we cannot verify AML compliance, we can test an exchange’s KYC adherence. We open accounts at each exchange in the sample to identify when (and if) an exchange attempts to gather KYC information. We make no attempt to hide the geographic location of the computer (USA) and indicate USA residency if prompted. Beyond the email address used to establish the account, we provide no additional information to the exchange. We attempt to fund each account with 0.01 bitcoin (approximately USD \$6), sell the bitcoin for USD, buy a replacement bitcoin on the exchange, and withdraw both USD and bitcoin.²⁴

Four exchanges—ANXBTC, BitStamp, itBit, and Kraken— do not allow any transfers or transactions without identity verification, indicated by “Funding” in the final column in Table 7. The remaining ex-

²³Alternatives to bank wires that are accepted at some—but not all—exchanges are virtual payments (i.e., PayPal) or credit card funding (VISA, MasterCard). The bank wire fee may change based upon the value transferred.

²⁴All bitcoin are sent from the same wallet at the exchange Coinbase, which is not an exchange in the study. We initiate (but do not complete) the procedure to withdraw the USD generated by the bitcoin sale due to legal and security concerns. USD withdrawals cannot occur on LocalBitcoins as it does not provide a platform for the transfer of currency. We do not sell the transferred bitcoin on LocalBitcoin due to legal and security concerns.

changes allow the account to be funded with the bitcoin, sold for USD, and a replacement bitcoin to be purchased and withdrawn from the exchange. These exchanges differ, however, in regards to withdrawing USD. Three exchanges—BitKonan, BTC-e, and LakeBTC— would allow us to withdraw USD without providing additional information. It is possible that these three exchanges have a limit below which they do not require ID, and that the amount of USD we were attempting to withdraw was below this limit.

Exchanges differ in other, less quantifiable ways, noted in Table 7. The currencies accepted for bitcoin purchases vary across exchanges. ANXBTC and BitStamp offer a debit card. In addition to AML and KYC compliance, itBit secured a charter from the New York State Department of Financial Services and have appointed former FDIC chair Sheila Bair to their board of directors. Only one exchange, Kraken, states that it does not allow off-chaining—allowing transactions to complete prior to their integration into the blockchain. The remaining exchanges do not address when or how they reconcile off-chain transactions to the blockchain.

Most exchanges do not hold their own inventory of either currency or bitcoin, instead they match user with a buy (sell) to a user with an offer (bid). ANXBTC users, on the other hand, submit the number of bitcoin they wish to trade, and then have 30 seconds to accept a price offered by the ANXBTC exchange. In contrast, LocalBitcoins allows users to transfer bitcoin to another user’s wallet, but does not provide a platform for the reciprocal transfer of currency.²⁵ Instead, a LocalBitcoins user posts an offer with price and payment specifications on a LocalBitcoins posting board, which aggregates and lists all individual offers by username, price, and zip code. Examples of payment specifications include making a cash deposit at a specific bank branch, PayPal transfer, or a face-to-face meeting for a commodity swap (such as gold). Stop and limit orders are available on all exchanges except LocalBitcoin. Because it uses a posting board system, LocalBitcoins is one of the few exchanges where one user can single out another user with whom to conduct their transaction.

5.2 Price trend and Exchange Characteristics

In Section 1 we argued that it is not unreasonable to expect bitcoin to adhere to LOOP, and that LOOP failure of an exchange must result from a characteristic of that exchange rather than an inherent property of bitcoin. To evaluate which characteristics may contribute to our finding of non-LOOP exchanges, Table 8 groups exchanges by LOOP results, and summarize as indicator variables the exchange characteristics contained in Table 7 and trade volumes from Table 2. For example, if the exchange posts an AML/KYC statement “Stated AML/KYC” takes a value of 1. If an exchange requires additional information for a user to withdraw currency (whether that in the funding stage or the withdrawal stage), the “ID for W-Currency”

²⁵As the LocalBitcoin platform does not transfer fiat currency, it maintains that it does not need to comply with AML/KYC.

takes a value of 1.

Free Fiat Deposits an indicator variable for fees, as it is uniform across all depositors regardless of currency, account size, transaction size, or transaction frequency. LocalBitcoins is the only exchange that does not have free bitcoin deposits. We also indicate whether exchanges have fixed trading fees (“Fixed Trading Fee”): A sliding trading fee typically rewards larger trades which may distort the market, especially if large trades allows users to avoid paying a trade fee altogether (“Free Trades Feasible”). Inclusion in the BPI is a proxy for an exchange’s reputation in the bitcoin community. Several exchanges allow trades in currencies other than USD. Only Kraken states that it does not allow off-chain transactions, and only LocalBitcoins allows users to select who they wish to trade with (“Targeted Trading”). If any of the three locations associated with the exchange is located within the USA (“USA location?”), the exchange is legally required to comply with AML/KYC.

Table 8: Cointegration and Exchange Properties

	Exchanges with LOOP				Weak LOOP Fail		Strong LOOP Fail		Consistent LOOP Fail	
	ANX	BitS	itBit	Kraken	BitK	Lake	BTC-e	Rock	HitBTC	Local
<i>Exchange Transparency (Table 7)</i>										
Known incorporation?	1	1	1	1	1	0	1	1	0	1
Known physical address?	1	1	1	1	1	1	0	1	0	1
Known server location?	1	1	1	0	1	0	0	0	0	0
USA location?	0	1	1	1	0	0	0	0	0	0
<i>Regulation Compliance (Table 7)</i>										
Stated AML/KYC?	1	1	1	1	1	1	1	1	1	0
ID for Funding	1	1	1	1	0	0	0	0	0	0
ID for W-BTC	1	1	1	1	0	0	0	0	0	0
ID for W-Currency	1	1	1	1	0	0	0	1	1	–
<i>Fees (Table 7)</i>										
Free Fiat Deposit	1	0	0	0	0	1	0	1	0	–
Free Bitcoin Deposit	1	1	1	1	1	1	1	1	1	0
Fixed Trading Fee	1	0	0	0	1	0	1	0	1	0
Free Trades Feasible	1	0	0	0	0	1	0	0	0	1
<i>Share of Global Transactions (Table 2)</i>										
High (> 4%)	0	1	0	0	0	0	1	0	0	0
Low (\approx 0%)	0	0	0	1	1	0	0	1	0	0
<i>Other Characteristics (Table 2)</i>										
Included in BPI	0	1	0	0	0	0	1	0	0	0
EUR trade	1	1	1	1	0	0	1	1	1	1
GBP trade	1	1	0	1	0	0	0	1	0	1
Non EUR/GBP fiat	1	0	1	1	0	1	1	0	0	1
Hacked	0	1	0	0	0	0	0	0	0	1
Debit Card Available	1	1	0	0	0	0	0	0	0	0
Does not allow off-chaining	0	0	0	1	0	0	0	0	0	0
Targeted Trading	0	0	0	0	0	0	0	0	0	1

Abbreviations: AML, anti-money laundering; ANX, ANXBTC; BitK, BitKonan; BitS, BitStamp; KYC, know-your-customer; Local, LocalBitcoin; LOOP, relative law of one price; Rock, The Rock Trading.

The two exchanges that Consistently Fail LOOP share seven characteristics: neither disclose their server location; they are not located in the USA; they allow funding of accounts and withdrawal of BTC without

ID; neither have an extreme trade share (either high or approximately zero share of global transactions); neither have a statement banning off-chain transactions; and neither have a debit card available. Of these seven characteristics, six are found in at least one of the LOOP exchanges — server location (Kraken), USA location (ANXBTC), no extreme high/low volume (ANXBTC, Kraken), off-chaining (all), and debit card (itBit, Kraken) — so it seems unlikely that these characteristics can explain why LOOP fails.²⁶ This leaves only the KYC implementation variables: all exchanges with LOOP require ID’s to Fund the account, a requirement that neither HitBTC nor LocalBitcoin enforce.

The exchanges that exhibit Inconsistent LOOP Failure (Weak or Strong) also do not require identification information to fund the account, so we interpret a failure to require an ID to fund as predictive of LOOP failure. There is no characteristic that distinguishes exchanges with Consistent LOOP Failure from those that have Inconsistent LOOP Failure. Inconsistent LOOP exchanges differ from each other on acceptance of Euro trades, yet it seems unlikely that these are a distinguishing feature as both LOOP and Failed LOOP exchanges allow Euro trades. This implies that there are additional, potentially hidden, exchange characteristics not captured on Table 8 that explain the degree of LOOP failure.

5.3 Price Deviation and Exchange Characteristics

We define the price deviation of an exchange as the difference between a given price-series and the corresponding price-series for the reference exchange (BitFinex):

$$Deviation_t^i = \log \left(\left| \frac{p_t^i}{p_t^{BitFinex}} - 1 \right| \right) \quad (5)$$

For some series, like the High price-series, a deviating price is typically greater than the reference series ($\frac{p_t^i}{p_t^{BitFinex}} > 1$) so a positive coefficient would indicate more deviation, while for others, like the Low price series, deviating prices are typically less than the reference series ($\frac{p_t^i}{p_t^{BitFinex}} < 1$) and a negative coefficient indicates more deviation. By using the absolute value of the deviation from parity in equation 5, a positive coefficient can consistently be interpreted as greater price deviation from the reference series.²⁷ We also calculate the daily Trade Volume (TVR_t^i) for each exchange, normalized by the daily BitFinex volume to account for a growth in bitcoin trading over the sample

$$TVR_t^i = \frac{Vol_t^i}{Vol_t^{BitFinex}}$$

²⁶It is important to recall that we only selected exchanges reporting 410 days or more with transactions; the finding regarding trade volume can therefore more accurately be considered as suggesting that active exchanges follow long-run price trends regardless of size.

²⁷The log is applied to normalize the distribution.

Table 9: Mean and Standard Deviation of Price Deviation and Normalized Trade Volume

	No LOOP Failure				Weak LOOP Failure		Strong LOOP Failure		LOOP Failure		Aggregate
	ANX	BitS	itBit	Kraken	Lake	BitK	BTC-e	Rock	Local	HitBTC	
Open	-5.47 (1.38)	-6.08 (1.26)	-5.70 (1.18)	-4.85 (1.36)	-5.41 (1.05)	-4.35 (1.06)	-4.59 (0.93)	-4.51 (1.12)	-2.02 (1.17)	-4.05 (1.64)	-4.70 (1.64)
Close	-5.32 (1.31)	-6.07 (1.27)	-5.72 (1.20)	-4.77 (1.25)	-5.39 (1.00)	-4.09 (1.11)	-4.64 (1.00)	-4.61 (1.17)	-2.09 (1.14)	-3.99 (1.59)	-4.67 (1.62)
Weighted	-5.08 (1.22)	-6.00 (1.20)	-5.44 (1.20)	-5.02 (1.36)	-5.39 (1.07)	-4.23 (1.17)	-4.60 (0.93)	-4.56 (1.07)	-2.24 (0.28)	-4.01 (1.59)	-4.65 (1.52)
High	-4.99 (1.31)	-5.77 (1.24)	-5.23 (1.04)	-4.79 (1.24)	-5.32 (1.08)	-4.09 (1.31)	-4.50 (0.87)	-4.14 (1.28)	0.78 (0.65)	-4.10 (1.77)	-4.21 (2.13)
Low	-4.88 (1.44)	-5.75 (1.27)	-5.52 (1.36)	-4.92 (1.26)	-5.17 (1.05)	-4.16 (1.19)	-4.64 (1.06)	-4.71 (1.34)	-2.06 (0.50)	-3.93 (1.52)	-4.57 (1.58)
TVR	0.08 (0.10)	0.63 (0.38)	0.16 (0.17)	0.00 (0.00)	0.30 (0.27)	0.00 (0.00)	0.41 (0.24)	0.00 (0.00)	0.10 (0.09)	0.04 (0.06)	0.17 (0.27)

The mean and standard deviation for each price-series and exchange are summarized in Table 9. Price deviations for exchanges that achieve LOOP are below average, while exchanges with Consistent LOOP Failure have more deviations than the average. Daily trade volume varies over the four categories, with the exchanges that have a negligible share of global bitcoin trade (Kraken, BitKonan, and Rock) also have a negligible share of trade relative to BitFinex.

The relationship between LOOP failure and the magnitude of price deviations is evaluated using an OLS regression with robust standard error. Table 10 reports the coefficients.²⁸ Prices from the BPI are removed as it is an index constructed using prices from exchanges in this sample, not an exchange. BitFinex is removed as it is the reference series. Date fixed effects are included.

Table 10: Price Deviation and LOOP Results

	LocalBitcoins Included					LocalBitcoins Removed				
	Open	Close	Weighted	High	Low	Open	Close	Weighted	High	Low
Weak LOOP Failure	0.65***	0.74***	0.58***	0.49***	0.61***	0.65***	0.74***	0.58***	0.49***	0.61***
Strong LOOP failure	0.98***	0.84***	0.80***	0.87***	0.59***	0.98***	0.84***	0.80***	0.87***	0.59***
Consistent LOOP Failure	2.49***	2.43***	2.26***	3.53***	2.27***	1.48***	1.48***	1.37***	1.09***	1.33***
Constant	-5.53***	-5.47***	-5.38***	-5.19***	-5.27***	-5.53***	-5.47***	-5.38***	-5.19***	-5.27***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	0.30	0.30	0.31	0.36	0.30	0.14	0.14	0.14	0.10	0.14
N	4243	4243	4238	4241	4233	3817	3818	3812	3815	3807

Significance: ***1%, **5%, *10%. [95% confidence interval].

Two observations can be made from Table 10: The positive coefficients on all three dummy variables show that LOOP failure is associated with larger price deviations. Secondly, the magnitude of price deviations and the severity of LOOP failure are positively associated for all price-series except the Low prices. For the Low price-series the magnitude of deviations associated with Weak LOOP Failure is slightly larger than Strong LOOP Failure. Table 2 showed that LocalBitcoins prices are more volatile than other exchanges; excluding

²⁸The regression is $Deviation_i = \beta^1 \text{Weak LOOP Failure} + \beta^2 \text{Stong LOOP failure} + \beta^3 \text{Consistent LOOP failure} + \text{constant}$

it from the regression does not change the findings, though it does reduce the magnitude of deviations associated with Consistent LOOP failure. Even with this reduction, the magnitude of price deviations on exchanges that Consistently Fail LOOP are twice as large as the magnitude of deviations for exchanges that have Weak LOOP Failure. Understanding which of the 22 exchange characteristics (summarized in Table 8) contribute toward price deviations can therefore help us identify characteristics associated with LOOP failure.

Table 11 reports the results from an OLS regression of price deviation and exchange characteristics with robust standard errors,²⁹

$$Deviation_t = \alpha + \sum_k \beta^k I^k + \beta^V TVR_t^i + \sum_t \beta_t FE_t + \epsilon \quad (6)$$

where I^k are the exchange characteristics indicated in Table 8, as well as their interactions, and FE_t is a date fixed effect.

Four of the 22 potential characteristics act as fixed effects for specific exchanges and are not considered: A Stated AML/KYC policy, Free Bitcoin Deposit, and Targeted Trading all act as fixed effects for LocalBitcoin, while Not Allowing Off-chaining is a fixed effect for Kraken. An additional six — Known Incorporation, Known Physical Address, High Volume Trade, Inclusion in the BPI, Hacked, and Debt Card Available — differ for only two exchanges, and frequently cause multicollinearity issues if included. Two more, Free Fiat Deposits and ID For Currency Withdrawals, are problematic as they cannot be evaluated for LocalBitcoins which does not allow fiat currency deposits. Finally, the values for “ID for BTC withdrawals” duplicates the values of “ID for Funding”. This leaves nine of the original 22 characteristics for consideration.

Results in section 5.2 showed that requiring an ID to fund an account is an important characteristic in explaining LOOP failure, and therefore “ID to Fund” must be included. Indicator variables for Knowledge of Server Location, USA Location, Trades in Euros, GBP, and Trades in Other Currencies all result in a variance-inflation factor above 3, indicating multicollinearity when included with ID to Fund, so they are removed. This leaves 4 characteristics for consideration with price deviation: ID for Funding, Fixed Trading Fee, Free Trades Feasible, and Low Global Share of bitcoin trade volume.

The basic regression, (i), for each price-series considers only the impact that requiring an ID to Fund has on price deviations. Regression (ii) uses the remaining characteristics, trade volume, and their interactions if they do not result in multicollinearity. All statistically significant variables have consistent signs across all price-series, confirming results from Section 4.2 that the effects documented in this paper are not isolated to a single price series.

²⁹Allowing for lags with Newey West Errors does not change results.

Table 11: Price Deviation and Exchange Characteristics

	Open		Close		Weighted		High		Low	
	(i)	(ii)								
ID to Fund	-1.38***	-1.92***	-1.34***	-1.79***	-1.22***	-1.53***	-1.64***	-2.27***	-1.16***	-1.53***
ID to Fund x Low Share		1.50***		1.50***		0.98***		1.25***		1.18***
Low Global Share		-0.40***		-0.23**		-0.32***		-0.57***		-0.32***
Fixed Cost to Trade		-0.12*		0.05		0.01		-0.83***		0.09
Free Trade Feasible		0.83***		0.82***		0.78***		1.86***		0.99***
Trade Volume		-0.33***		-0.39***		-0.58***		-0.74***		-0.33**
Volume x Low Share		-167.55***		-248.08***		-159.61***		-160.24***		-227.45***
Volume x Fixed Cost		-1.02***		-1.07***		-0.73***		-0.74***		-1.07***
Volume x Free Trade		-3.06***		-2.56***		-2.47***		-5.07***		-2.72***
Constant	-4.15***	-3.87***	-4.13***	-3.99***	-4.17***	-3.99***	-3.55***	-3.03***	-4.10***	-4.01***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	0.15	0.25	0.15	0.25	0.15	0.24	0.09	0.30	0.13	0.24
N	4243	4243	4243	4243	4238	4238	4241	4241	4233	4233

Significance: ***1%, **5%, *10% .

Exchanges that require ID to Fund have smaller price deviations those than those that do not, though the effect is diminished for exchanges with a low global share of bitcoin trades. Having a larger trade volume is also associated with smaller deviations, an effect that is especially potent for the small exchanges.³⁰ Exchanges where free trade is feasible — usually as a result of trading large volumes — see larger price deviations, although this is mitigated in exchanges with larger trade volumes. It is worth noting this suggests that fees on bitcoin exchanges are substantial enough to impact prices.

Of the characteristics considered above, requiring an ID to Fund an account have largest impact on decreasing price deviations. This is consistent with findings that showed ID to be a good indicator of LOOP.

6 Conclusions

Crypto-currencies like Bitcoin are a comparatively new financial mechanism, and are not yet assimilated into a consistent global regulatory framework. Of the 11 bitcoin exchanges we evaluate, we find that exchanges which do not fully implement AML and/or KYC—two regulatory policies already in broad use across the global financial system—exhibit statistically different price patterns from exchanges that do. This suggests two things. First, standard financial regulations can affect bitcoin markets, even across a group of different global exchanges. Second, bitcoin-pricing data can differ across exchanges, not obeying the Law of One Price, in ways that are not always obvious, demanding a deliberate approach to data sourcing.

It may seem strange that requiring an ID to fund an account should matter to bitcoin users. Although bitcoin transactions are more private than cash transactions they are actually less anonymous. Every bitcoin wallet is identified by a unique “private key”. The private keys of both wallets in a bitcoin transaction are

³⁰Recall that “Low Global Share” was defined as an exchange that traded approximately 0% of global bitcoin trades, so a coefficient of -167.55 has a substantially smaller impact than it appears.

recorded on the “blockchain”. The blockchain can be thought of as a digital ledger, maintaining a history of bitcoin transactions. Anonymity results only if it is impossible to prove a connection between the private key and an individual.³¹ There is some evidence that users with criminal intentions use bitcoin: using Google search data, [Wilson and Yelowitz \(2015\)](#) find evidence of significant criminal interest in bitcoin. For these users, the anonymity promised by using bitcoin is its primary benefit, a benefit which is eliminated (or substantially undermined) by exchanges which require ID.

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³¹For a discussion of the technology involved, refer to [Badev and Chen \(2014\)](#) or [Böhme et al. \(2015\)](#).

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Appendices

A Implications for bitcoin research

A.1 Are differences in bitcoin exchange prices sufficient to impact research?

The failure of some exchanges to achieve LOOP has important ramifications for those studying bitcoin. By design, there is no central “official” source for bitcoin prices. Studies prior to February 2014 used the bitcoin marketplace “Mt. Gox” for price information, as it handled approximately 70% of the global bitcoin trade. Mt. Gox, however, declared bankruptcy in February 2014, and the largest exchange during the period we study (BitFinex) handles only 11% of bitcoin transactions. As the sample of published bitcoin papers in Table 12 illustrates, researchers currently use prices from any source that suits the purpose of their study—or use prices from a bitcoin index—under the assumption that their results generalize across all bitcoin markets.

Table 12: Sources of Bitcoin Price Information for papers after the collapse of Mt. Gox

Author	Bitstamp	BTC-e	BitFinex	BTC China	Quandl/BPI/Index	OKCoin
Badev and Chen (2014)	X	X	X	X		X
Ciaian, Rajcaniova, and dArtis Kancs (2016)					X	
Chu, Nadarajah, and Chan (2015)	X					
Lo and Wang (2014)	X					
Urquhart (2016)					X	

Might different research results be achieved by using a price-series from a different exchange? To investigate the extent of possible distortions we examine bitcoin volatility, a transparent statistic, to see if there are substantial differences across exchanges and price-series. Table 13 lists the median volatility of a 30-day rolling window of bitcoin prices, with exchanges grouped by adherence to LOOP. There are three different measures of volatility employed for each market: the standard-deviation-based volatility based on a single price-series, $\sigma^{SD,x}$; the Parkinson (1980) volatility, σ^{HL} , based on High and Low prices; and the Rogers and Satchell (1991) volatility, σ^{OHLC} which uses Open, High, Low, and Close prices.

$$\sigma^{SD,x} = \frac{\sqrt{\frac{1}{T} \sqrt{\sum_{t=1}^T (p_t^x - \bar{p}^x)^2}}}{\bar{p}^x} \quad (7)$$

$$\sigma^{HL} = \frac{\sqrt{\frac{1}{T} \sqrt{\frac{1}{4 \ln 2} \sum_{t=1}^T (p_t^H - p_t^L)^2}}}{\frac{1}{2} (\bar{p}^H + \bar{p}^L)} \quad (8)$$

$$\sigma^{OHLC} = \frac{\sqrt{\frac{1}{T} \sqrt{\sum_{t=1}^N (p_t^H - p_t^C) (p_t^H - p_t^O) + (p_t^L - p_t^C) (p_t^L - p_t^O)}}}{\frac{1}{4} (\bar{p}^O + \bar{p}^H + \bar{p}^L + \bar{p}^C)} \quad (9)$$

Table 13: Median 30-Day Price Volatility (%)

	$\sigma^{SD,x}$					σ^{HL}	σ^{OHLC}
	Open	Close	Weighted	Low	High		
<i>LOOP Exchanges</i>							
ANXBTC	6.32	6.39	6.28	6.83	6.38	4.76	5.60
BitFinex	6.37	6.37	6.32	6.60	6.29	3.49	3.64
BitStamp	6.33	6.34	6.27	6.61	6.18	3.43	3.52
BPI	6.40	6.40	—	6.60	6.27	3.11	3.07
itBit	6.27	6.29	6.24	6.45	6.16	3.00	3.85
Kraken	6.40	6.45	6.32	6.61	6.27	3.79	4.09
<i>LOOP Average</i>	6.35	6.37	6.29	6.62	6.26	3.60	3.96
<i>Weakly LOOP Failure Exchanges</i>							
LakeBTC	6.27	6.28	6.17	6.42	6.18	3.25	3.27
BitKonan	6.32*	6.93	6.49	7.08	6.98	5.30	6.37*
<i>Strong LOOP Failure Exchanges</i>							
BTC-e	6.22	6.28	6.13	6.38	6.14	3.42	3.57
The Rock Trading	6.22	6.38	5.99	6.27*	6.51	4.78*	5.84*
<i>Consistent LOOP Failure Exchanges</i>							
HitBTC	6.08	6.09	5.87	6.20	6.09	3.56	3.85
LocalBitcoins	20.37	19.08	5.97*	10.32	39.32	86.34	173.77

*:Obtained using the price series that cannot be tested for LOOP

Where x indicates the Open (O), High (H), Low (L), or Close (C) price respectively, \bar{p}^x indicates the average price, and exchange specific indexes are suppressed. To make the measures comparable across each exchange and price series, each σ is normalized using the mean of the daily price for the period (or averaged price if multiple price series are used). Over the same time period, the equivalent standard deviation-based volatility of the price of gold is 1.8%, the USD-EUR exchange rate is 1.4%, and the S&P 500 is 1.3%.³²

The data in Table 13 confirm that bitcoin is more volatile than gold, exchange rate, and stock market prices, regardless of the exchange or price-series—how much more volatile bitcoin is depends on the data used. The volatility on LocalBitcoins is magnitudes larger than other exchanges for all price-series except transaction-weighted prices. HitBTC yields the opposite: it usually has the lowest volatility. These results show that using data from an exchange that fails to yield LOOP can impact empirical conclusions, but that it is difficult to precisely predict the effect: The volatility of LocalBitcoin is consistently greater than that of LOOP series, while the volatility of HitBTC is almost always below average. The exchanges that failed to yield LOOP in the robustness checks are less consistent in their deviations from LOOP average than HitBTC and LocalBitcoins.

Volatility varies even among LOOP exchanges. Volatility estimates using standard deviations vary from

³²We obtain the daily 10 a.m. Gold Fixing Price in London Bullion Market in USD, the USD-EUR exchange rate, and the S&P 500 Index from the Federal Reserve Economic Database (FRED) of the St. Louis Federal Reserve Bank for the time period of the bitcoin sample.

6.16% to 6.83% (a range of 0.67 percentage points). Estimates that combine different price-series, σ^{HL} and σ^{OHLCL} , vary even more. Parkinson volatility ranges from 3.00% to 4.76% (a 1.76 percentage point spread) while the Rogers-Satchell volatility ranges from 3.07% to 5.60% (a 2.53 percentage point spread). Volatility across bitcoin markets are highly dependent upon which exchange, price-series, and measure is used.

A.2 Correlations

Bitcoin prices are non-stationary, which biases correlation results. Despite this, some studies have drawn their conclusions from only correlations. We repeat our analysis from section 4 but examine only the *correlations* of the twelve exchanges to BitFinex (the largest exchange), with results presented in Table 14.

Table 14: Correlation Characteristics Across Exchanges

	ANX	BitK	BitS	BTC-e	HitB	itBi	Krak	Lake	Local	Rock
Open	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.87	1.00
Close	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.89	1.00
Weighted	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Low	1.00	0.99	1.00	1.00	1.00	0.98	1.00	1.00	0.97	1.00
High	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.14	0.99

The correlation results are similar regardless of which reference series is used and are typically close to one, implying (incorrectly) that all series are interchangeable. Possible exceptions exist only for some LocalBitcoins price-series. This contradiction of the cointegration results in section 4.2 should give pause when basing interpretations on correlation results alone.

B Online Appendix: Additional Figures and Robustness Checks

B.1 Prices Levels

Figures (3) - (7) plot all price series for all exchanges. The two vertical lines denote the end of the first segment and beginning of the second segment used for the structural break test in section 4.3.2. All price series for all exchanges are still descending at the end of the first segment; all have plateaued by the beginning of the second segment. The volatility of the Transaction Weighted price series for LocalBitcoins in Figure 5 is noticeably lower than it is for the other four price series.

Figure 3: Open Prices

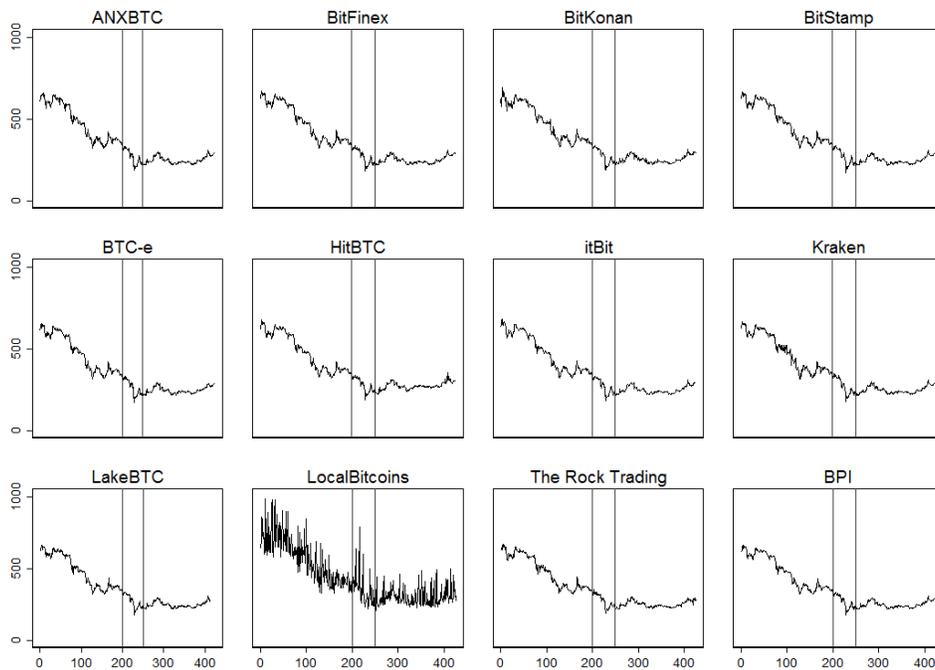


Figure 4: Close Prices

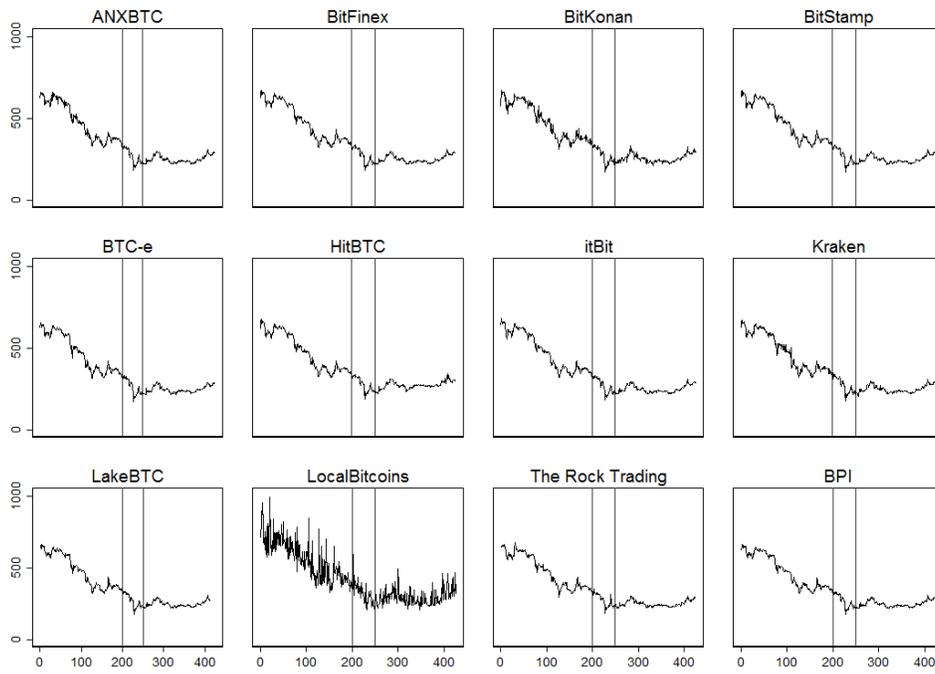


Figure 5: Weighted Prices

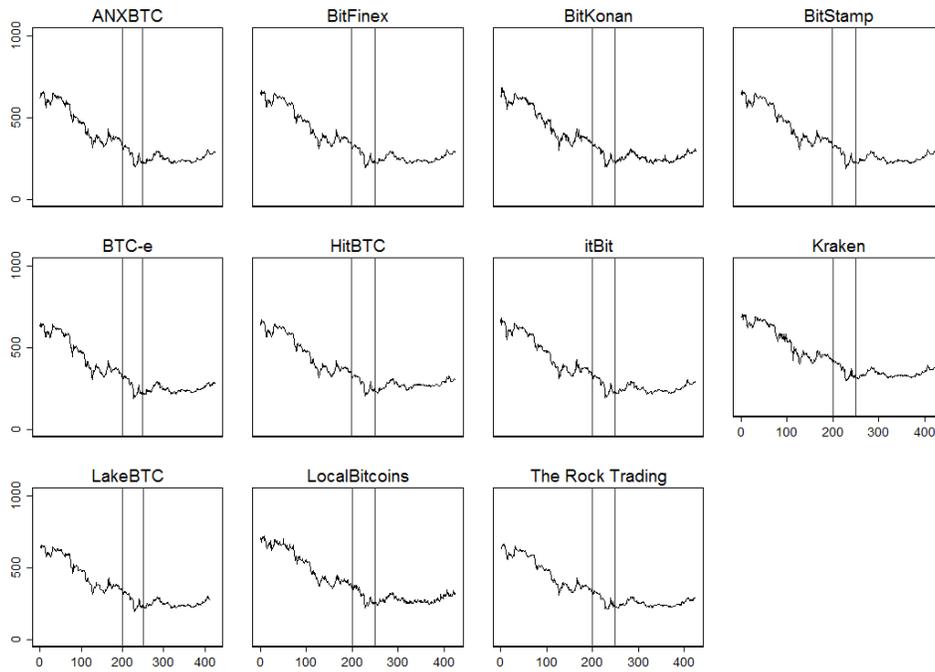


Figure 6: Low Prices

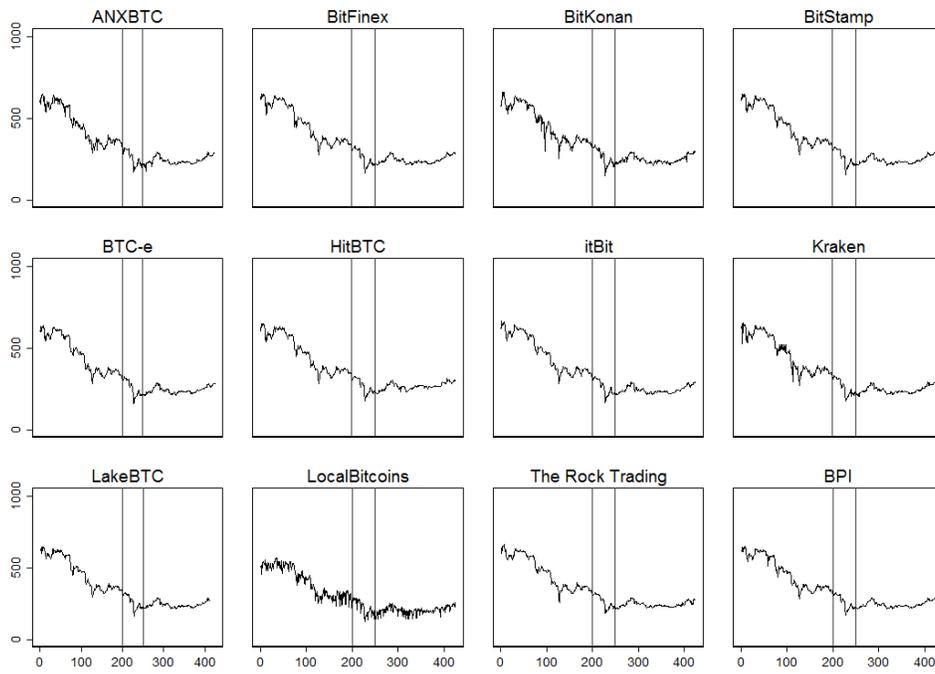
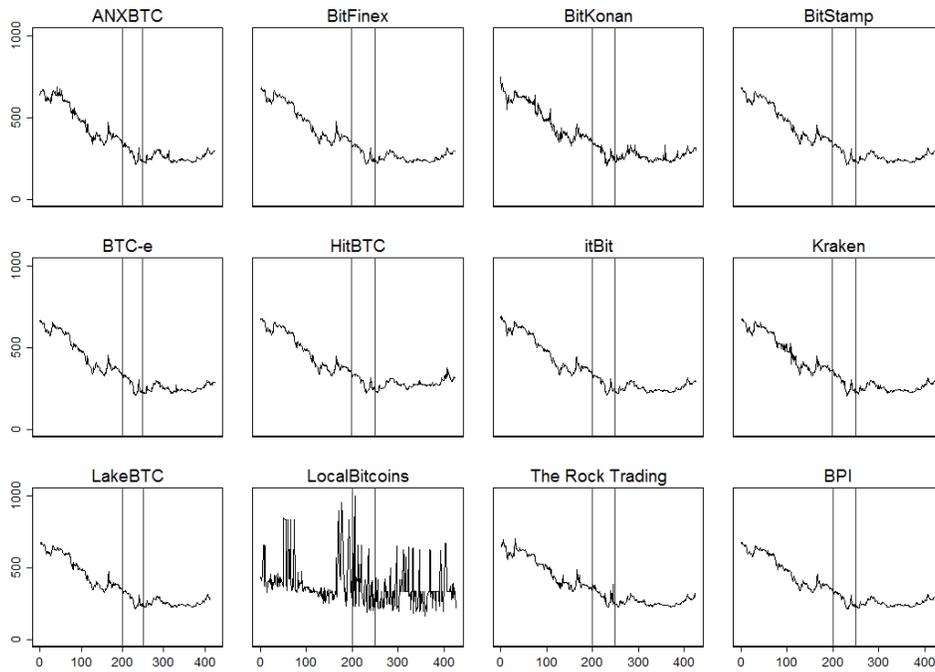


Figure 7: High Prices



B.2 Differences between exchange prices and BitFinex

Figures (8)-(12) plot the difference between the price-series of the indicated exchange and BitFinex, $p_t^i - p_t^{BitFinex}$. A trend line constructed with a Lowess smoother is included. The two vertical lines denote the end of the first segment and beginning of the second segment for the structural break exercise in section 4.3.2.

Figure 8: Difference in Open Prices

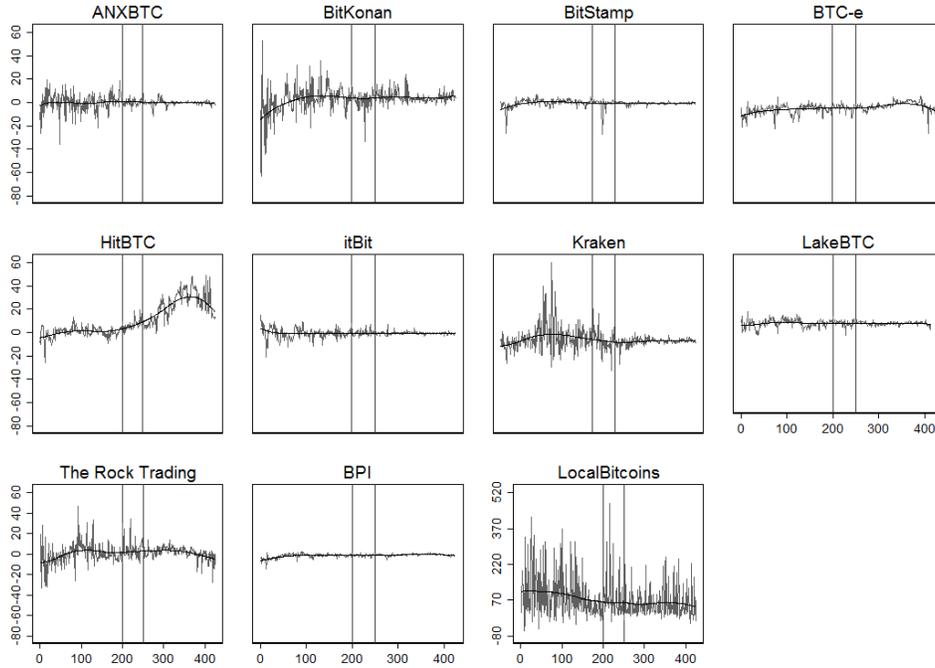


Figure 9: Difference in Close Prices

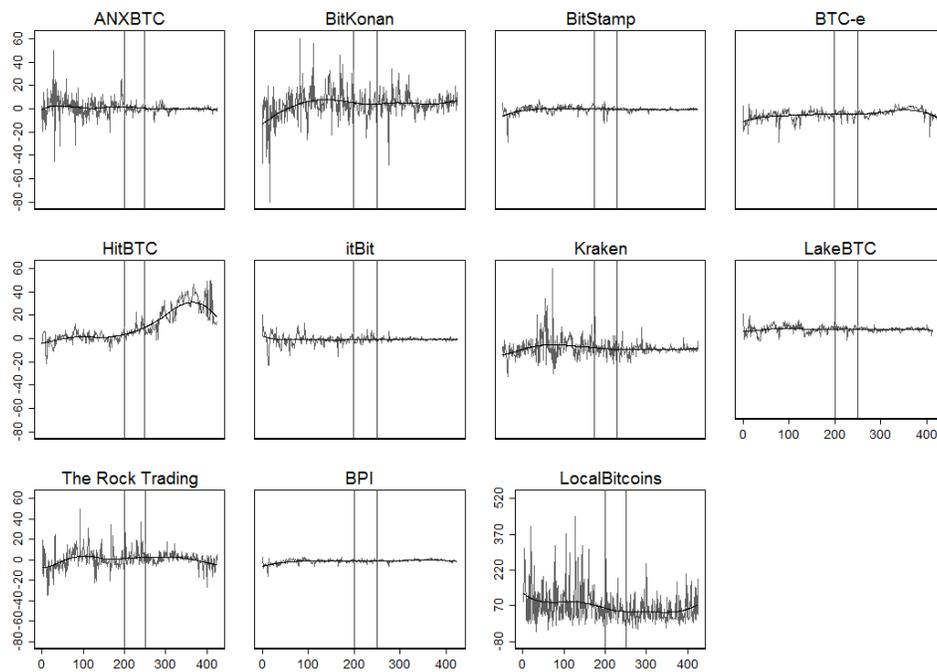


Figure 10: Difference in Weighted Prices

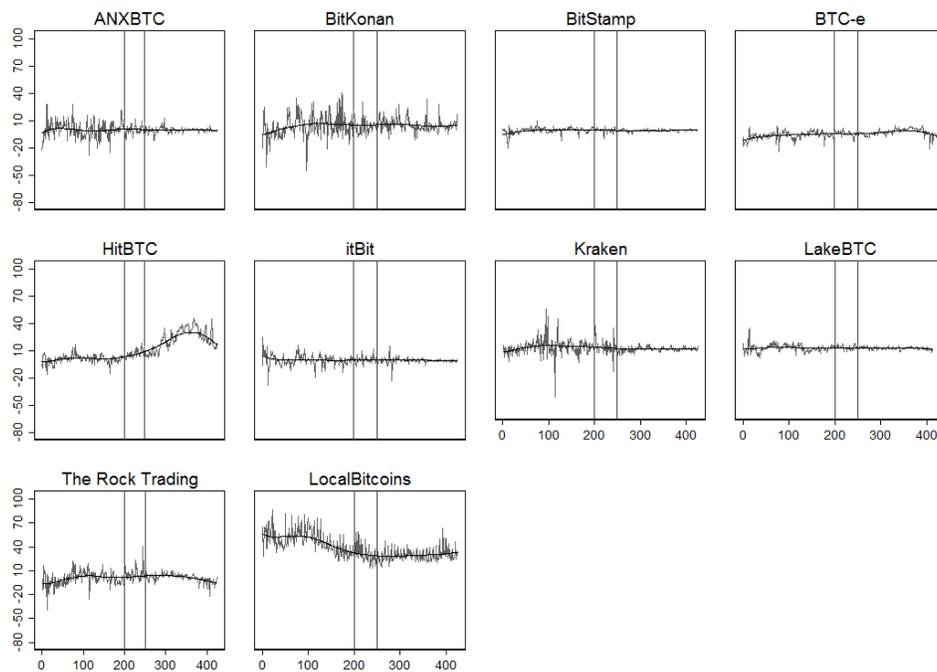


Figure 11: Difference in Low Prices

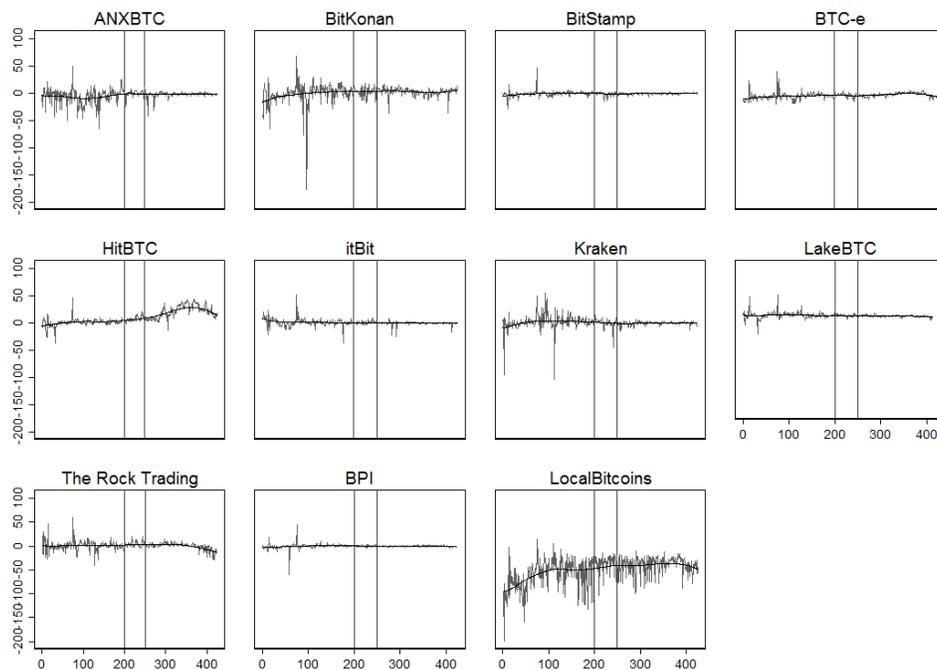
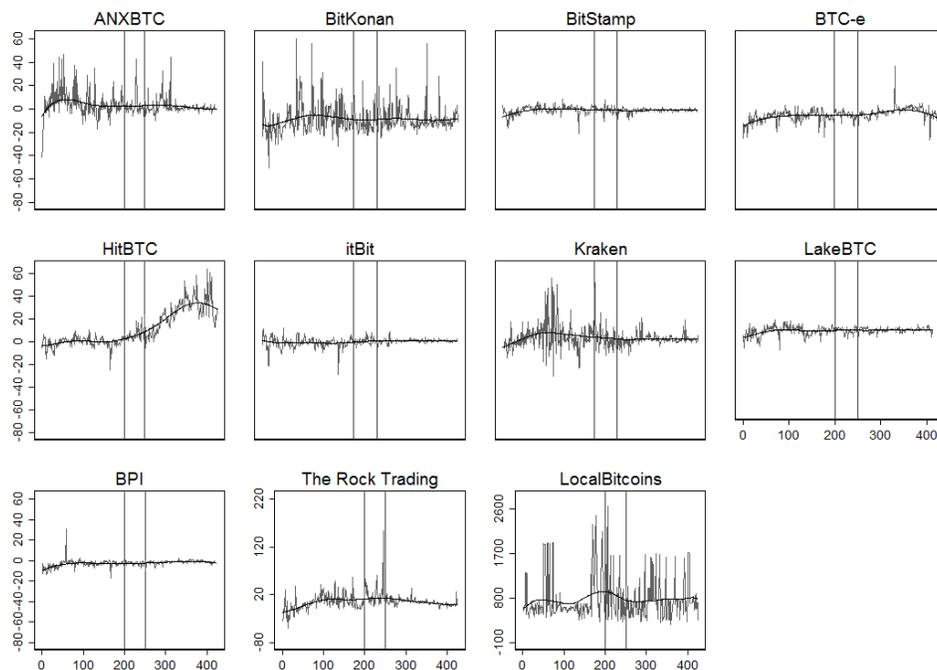


Figure 12: Difference in High Prices



B.3 Cointegration results, all series

For completeness, tables (15) - (17) contain the results of cointegration tests for all exchanges relative to all other exchanges, using the methods of section 4.1. If a series does not affirm unit root, a result of *NGC* indicates a single direction of granger-causality could not be established. An *NC* indicates that cointegration was not found, while $\ell > 15$ indicates that the series residual displayed auto-correlation up to lag 15. If none of these issues were found, the cointegration parameter, β is reported. All β results are significant at 1%. The results relative to BitFinex (the first column) are the results reported in section 4.2. LOOP status is transitive: any series that consistently achieves LOOP with BitFinex has LOOP with any other series that does the same. As documented in section 4.3.1, if a series does not achieve LOOP with BitFinex it does not achieve LOOP with any other series.

Table 15: Cointegration with All Series, Open Prices

	BitF	ANX	BitK	BitS	BTC-e	HitBTC	itBit	Kraken	Lake	Local	Rock
ANXBTC	1.00	—	—	—	—	—	—	—	—	—	—
BitKonan	$\ell > 15$	0.98	—	—	—	—	—	—	—	—	—
BitStamp	1.00	1.00	$\ell > 15$	—	—	—	—	—	—	—	—
BTC-e	0.99	0.99	$\ell > 15$	0.99	—	—	—	—	—	—	—
HitBTC	<i>NC</i>	<i>NC</i>	$\ell > 15$	<i>NC</i>	<i>NC</i>	—	—	—	—	—	—
itBit	1.00	1.00	$\ell > 15$	1.00	1.01	<i>NC</i>	—	—	—	—	—
Kraken	1.01	1.00	1.02	1.00	1.02	<i>NC</i>	1.01	—	—	—	—
Lake	1.00	1.00	$\ell > 15$	1.00	1.01	<i>NC</i>	1.00	0.99	—	—	—
Local	1.14	1.14	<i>NGC</i>	1.14	1.16	1.21	1.14	1.13	1.14	—	—
Rock	0.98	0.98	1.00	0.98	0.99	<i>NC</i>	0.99	0.98	0.99	1.15	—
BPI	1.00	0.99	$\ell > 15$	1.00	1.01	<i>NC</i>	1.00	0.99	1.00	1.15	$\ell > 15$

Abbreviations: $\ell > 15$, Lag to avoid residual autocorrelation greater than 15 days; *NC*, Not Cointegrated. *NGC*, Could not establish single direction granger-causality.

Table 16: Cointegration with All Series, Close Prices

	BitF	ANX	BitK	BitS	BTC-e	HitBTC	itBit	Kraken	Lake	Local	Rock
ANXBTC	1.01	—	—	—	—	—	—	—	—	—	—
BitKonan	0.98	0.98	—	—	—	—	—	—	—	—	—
BitStamp	1.00	0.99	1.01	—	—	—	—	—	—	—	—
BTC-e	0.99	0.98	1.01	0.99	—	—	—	—	—	—	—
HitBTC	<i>NC</i>	<i>NC</i>	<i>NC</i>	<i>NC</i>	<i>NC</i>	—	—	—	—	—	—
itBit	1.00	0.99	1.01	1.00	1.01	<i>NC</i>	—	—	—	—	—
Kraken	1.00	1.00	1.02	1.00	1.01	<i>NC</i>	1.00	—	—	—	—
Lake	1.00	0.99	1.02	1.00	1.01	<i>NC</i>	1.01	1.00	—	—	—
Local	1.13	1.13	1.13	1.13	1.14	1.20	1.13	1.14	1.13	—	—
Rock	0.99	0.98	1.00	0.99	1.00	<i>NC</i>	0.99	0.98	0.99	1.15	—
BPI	1.00	0.99	1.01	1.00	1.01	<i>NC</i>	1.00	0.99	1.00	1.14	1.00

Abbreviations: *NC*, Not Cointegrated.

Table 17: Cointegration with All Series, Weighted Prices

	BitF	ANX	BitK	BitS	BTC-e	HitBTC	itBit	Kraken	Lake	Local
ANXBTC	1.00	–	–	–	–	–	–	–	–	–
BitKonan	0.99	0.99	–	–	–	–	–	–	–	–
BitStamp	1.00	0.99	1.01	–	–	–	–	–	–	–
BTC-e	0.99	0.98	1.00	0.99	–	–	–	–	–	–
HitBTC	<i>NC</i>	<i>NC</i>	<i>NC</i>	<i>NC</i>	<i>NC</i>	–	–	–	–	–
itBit	1.00	0.99	1.01	1.00	1.01	<i>NC</i>	–	–	–	–
Kraken	1.00	1.00	1.01	1.01	1.02	<i>NC</i>	1.01	–	–	–
Lake	1.00	0.99	1.01	1.00	1.01	<i>NC</i>	1.00	1.00	–	–
Local	$\ell > 15$	$\ell > 15$	1.08	$\ell > 15$	$\ell > 15$	$\ell > 15$	$\ell > 15$	1.07	$\ell > 15$	–
Rock	0.98	0.98	1.00	0.99	0.99	<i>NC</i>	0.98	0.98	0.98	0.92

Abbreviations: $\ell > 15$, Lag to avoid residual autocorrelation greater than 15 days; NC, Not Cointegrated.

Table 18: Cointegration with All Series, Low Prices

	BitF	ANX	BitK	BitS	BTC-e	HitBTC	itBit	Kraken	Lake	Local	Rock
ANXBTC	0.98	–	–	–	–	–	–	–	–	–	–
BitKonan	0.98	0.99	–	–	–	–	–	–	–	–	–
BitStamp	1.00	1.01	1.02	–	–	–	–	–	–	–	–
BTC-e	0.99	1.00	1.02	0.99	–	–	–	–	–	–	–
HitBTC	<i>NC</i>	0.95	<i>NC</i>	<i>NC</i>	<i>NC</i>	–	–	–	–	–	–
itBit	1.00	1.02	1.03	1.01	1.01	<i>NC</i>	–	–	–	–	–
Kraken	1.00	1.03	1.03	1.01	1.02	1.09	1.01	–	–	–	–
Lake	1.00	1.02	1.02	1.01	1.01	<i>NC</i>	1.00	1.00	–	–	–
Local	0.89	0.91	0.91	0.90	0.91	0.95	0.90	0.89	0.89	–	–
Rock	$\ell > 15$	1.01	1.02	$\ell > 15$	$\ell > 15$	$\ell > 15$	0.99	0.98	0.99	0.90	–
BPI	1.00	1.01	1.02	1.00	1.01	<i>NC</i>	0.99	0.99	0.99	0.90	$\ell > 15$

Abbreviations: $\ell > 15$, Lag to avoid residual autocorrelation greater than 15 days; NC, Not Cointegrated.

Table 19: Cointegration with All Series, High Prices

	BitF	ANX	BitK	BitS	BTC-e	HitBTC	itBit	Kraken	Lake	Local	Rock
ANXBTC	1.02	–	–	–	–	–	–	–	–	–	–
BitKonan	0.99	0.98	–	–	–	–	–	–	–	–	–
BitStamp	1.00	0.98	1.01	–	–	–	–	–	–	–	–
BTC-e	0.98	0.97	0.99	0.99	–	–	–	–	–	–	–
HitBTC	<i>NC</i>	<i>NC</i>	0.95	<i>NC</i>	<i>NC</i>	–	–	–	–	–	–
itBit	0.99	0.97	1.01	1.00	1.01	1.07	–	–	–	–	–
Kraken	1.00	0.99	1.01	1.00	1.02	<i>NC</i>	1.01	–	–	–	–
Lake	1.00	0.98	1.00	1.00	1.01	<i>NC</i>	1.00	0.99	–	–	–
Local	1.06	NGC	1.03	1.07	NGC	NGC	NGC	NGC	NGC	–	–
Rock	0.97	0.95	0.98	0.97	0.98	<i>NC</i>	0.97	0.96	0.97	NGC	–
BPI	0.99	0.98	1.00	0.99	1.01	<i>NC</i>	1.00	0.99	1.00	NGC	1.03

Abbreviations: NC, Not Cointegrated. NGC, Could not establish single direction granger-causality.

B.4 Price Deviation Results

Tables 20 - 37 represent variations of the data and regressions presented in section 5.3. Results show a decrease in price deviations associated with a requirement of ID for funding.

B.4.1 Summary Statistics

Table 20 is an expansion of Table 9, including the Min and Max values for each exchange.

Table 20: Detailed Summary Statistics, Price Deviation and Trade Volume

market		Open	Close	Weighted	High	Low	TVR
ANXBTC	Mean	-5.47	-5.32	-5.08	-4.99	-4.88	0.08
	Std. Dev	1.38	1.31	1.22	1.31	1.44	0.10
	Min	-9.88	-10.14	-10.45	-9.53	-9.83	0.00
	Max	-2.86	-2.47	-2.72	-1.65	-1.64	0.80
BitKonan	Mean	-4.35	-4.09	-4.23	-4.09	-4.16	0.00
	Std. Dev	1.06	1.11	1.17	1.31	1.19	0.00
	Min	-10.22	-8.15	-9.46	-8.85	-10.13	0.00
	Max	-1.92	-1.68	-1.94	-1.00	-0.99	0.01
BitStamp	Mean	-6.08	-6.07	-6.00	-5.77	-5.75	0.63
	Std. Dev	1.26	1.27	1.20	1.24	1.27	0.38
	Min	-10.52	-10.66	-10.50	-10.09	-10.55	0.17
	Max	-2.39	-2.84	-3.33	-3.11	-2.28	3.31
BTC-e	Mean	-4.59	-4.64	-4.60	-4.50	-4.64	0.41
	Std. Dev	0.93	1.00	0.93	0.87	1.06	0.24
	Min	-10.07	-9.38	-9.78	-9.39	-10.47	0.02
	Max	-2.46	-2.56	-2.65	-1.84	-2.42	2.88
HitBTC	Mean	-4.05	-3.99	-4.01	-4.10	-3.93	0.04
	Std. Dev	1.64	1.59	1.59	1.77	1.52	0.06
	Min	-9.39	-9.15	-8.97	-10.98	-9.49	0.00
	Max	-1.52	-1.56	-1.59	-1.36	-1.63	0.44
itBit	Mean	-5.70	-5.72	-5.44	-5.23	-5.52	0.16
	Std. Dev.	1.18	1.20	1.20	1.04	1.36	0.17
	Min	-11.10	-10.95	-10.10	-10.98	-10.52	0.00
	Max	-3.35	-3.26	-2.55	-2.76	-2.16	1.43
Kraken	Mean	-4.85	-4.77	-5.02	-4.79	-4.92	0.00
	Std. Dev.	1.36	1.25	1.36	1.24	1.26	0.00
	Min	-11.05	-10.29	-10.39	-9.08	-9.03	0.00
	Max	-1.67	-1.69	-1.89	-1.89	-1.35	0.01
LakeBTC	Mean	-5.41	-5.39	-5.39	-5.32	-5.17	0.30
	Std. Dev	1.05	1.00	1.07	1.08	1.05	0.27
	Min	-10.16	-9.37	-10.14	-10.69	-9.27	0.02
	Max	-3.08	-3.15	-3.07	-3.29	-2.31	2.92
LocalBitcoins	Mean	-2.02	-2.09	-2.24	0.78	-2.06	0.10
	Std. Dev	1.17	1.14	0.28	0.65	0.50	0.09
	Min	-9.66	-6.92	-3.14	-0.41	-5.27	0.00
	Max	0.64	0.55	-1.37	3.15	-1.01	0.51
The Rock Trading	Mean	-4.51	-4.61	-4.56	-4.14	-4.71	0.00
	Std. Dev	1.12	1.17	1.07	1.28	1.34	0.00
	Min	-9.57	-10.20	-9.93	-9.89	-9.15	0.00
	Max	-2.04	-2.00	-1.71	-0.42	-2.01	0.01

B.4.2 Single Exchange Characteristic

Tables (21)-(25) report single effect results from the OLS regression on price deviation (regression (i) in Table 11). Results of statistically significant variables usually retain the same sign regardless of which price-series is used. There are only two exceptions, both of which occur for the High price: regression (viii) (Fixed Trading Fee) and regression (ix) (Indicator for Low Global Share), which increase deviations for all except

the High price-series.

Table 21: Price Deviation and Single Exchange Characteristics, OPEN price-series

	Exchange Transparency				Regulations		Fees			Exchange Size		Other Exchange Characteristics					
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)	(xiii)	(xiv)	(xv)	(xvi)	(xvii)
Know Incorporation	0.02																
Know Physical Location		-0.48***															
Know Server Location			-1.17***														
USA Location				-1.21***													
ID to Fund					-1.38***												
ID for Fiat Withdrawal						-1.02***											
Free Fiat Deposit							-0.61***										
Fixed Trading Fee								0.15**									
Free Trades Feasible									0.59***								
High Global Share										-0.79***							
Low Global Share											0.18***						
In BPI												-0.79***					
Trade EUR													0.22***				
Trade GBP														0.23***			
Trade non-EUR/GBP															0.08		
Hacked																0.81***	
Offers Debit Card																	-1.34***
Constant	-4.72***	-4.32***	-4.23***	-4.34***	-4.15***	-4.08***	-4.52***	-4.76***	-4.88***	-4.54***	-4.76***	-4.54***	-4.88***	-4.82***	-4.75***	-4.86***	-4.43***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	-0.04	-0.03	0.09	0.08	0.15	0.06	-0.01	-0.04	-0.01	-0.00	-0.04	-0.00	-0.04	-0.04	-0.04	0.00	0.08
N	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243

Significance: ***1%, **5%, *10% .

Table 22: Price Deviation and Single Exchange Characteristics, CLOSE price-series

	Exchange Transparency				Regulations		Fees			Exchange Size		Other Exchange Characteristics					
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)	(xiii)	(xiv)	(xv)	(xvi)	(xvii)
Know Incorporation	0.02																
Know Physical Location		-0.44***															
Know Server Location			-1.06***														
USA Location				-1.22***													
ID to Fund					-1.34***												
ID for Fiat Withdrawal						-1.03***											
Free Fiat Deposit							-0.62***										
Fixed Trading Fee								0.26* **									
Free Trades Feasible									0.58***								
High Global Share										-0.86***							
Low Global Share											0.25***						
In BPI												-0.86***					
Trade EUR													0.08				
Trade GBP														0.19***			
Trade non-EUR/GBP															0.04		
Hacked																0.73***	
Offers Debit Card																	-1.28***
Constant	-4.68***	-4.31***	-4.24***	-4.30***	-4.13***	-4.04***	-4.48***	-4.77* **	-4.84***	-4.49***	-4.74***	-4.49***	-4.73***	-4.76***	-4.69***	-4.81***	-4.41***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	-0.03	-0.02	0.08	0.10	0.15	0.08	0.00	-0.03	-0.00	0.02	-0.03	0.02	-0.03	-0.03	-0.03	0.00	0.08
N	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243	4243

Significance: ***1%, **5%, *10% .

Table 23: Price Deviation and Single Exchange Characteristics, WEIGHTED price-series

	Exchange Transparency				Regulations		Fees			Exchange Size		Other Exchange Characteristics					
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)	(xiii)	(xiv)	(xv)	(xvi)	(xvii)
Know Incorporation	0.04																
Know Physical Location		-0.43***															
Know Server Location			-0.89***														
USA Location				-1.19***													
ID to Fund					-1.22***												
ID for Fiat Withdrawal						-0.91***											
Free Fiat Deposit							-0.50***										
Fixed Trading Fee								0.29***									
Free Trades Feasible									0.61***								
High Global Share										-0.81***							
Low Global Share											0.07						
In BPI												-0.81***					
Trade EUR													0.18***				
Trade GBP														0.15**			
Trade Non-EUR/GBP															0.08		
Hacked																0.68***	
Offers Debit Card																	-1.10***
Constant	-4.69***	-4.31***	-4.30***	-4.30***	-4.17***	-4.11***	-4.50***	-4.77***	-4.84***	-4.49***	-4.67***	-4.49***	-4.80***	-4.73***	-4.70***	-4.79***	-4.43***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	-0.02	-0.01	0.07	0.12	0.15	0.07	0.00	-0.01	0.01	0.03	-0.02	0.03	-0.02	-0.02	-0.02	0.01	0.07
N	4238	4238	4238	4238	4238	4238	4238	4238	4238	4238	4238	4238	4238	4238	4238	4238	4238

Significance: ***1%, **5%, *10% .

Table 24: Price Deviation and Single Exchange Characteristics, HIGH price-series

	Exchange Transparency				Regulations		Fees			Exchange Size		Other Exchange Characteristics					
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)	(xiii)	(xiv)	(xv)	(xvi)	(xvii)
Know Incorporation	0.62***																
Know Physical Location		0.11															
Know Server Location			-1.34***														
USA Location				-1.50***													
ID to Fund					-1.64***												
ID for Fiat Withdrawal						-1.57***											
Free Fiat Deposit							-0.86***										
Fixed Trading Fee								-0.35***									
Free Trades Feasible									1.50***								
High Global Share										-1.15***							
Low Global Share											-0.18**						
In BPI												-1.15***					
Trade EUR													0.61***				
Trade GBP														0.86***			
Trade Non-EUR/GBP															0.52***		
Hacked																2.16***	
Offers Debit Card																	-1.46***
Constant	-4.71***	-4.30***	-3.67***	-3.76***	-3.55***	-3.27***	-3.95***	-4.07***	-4.66***	-3.98***	-4.15***	-3.98***	-4.70***	-4.64***	-4.52***	-4.64***	-3.92***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	-0.05	-0.07	0.04	0.05	0.09	0.08	-0.03	-0.06	0.05	-0.02	-0.07	-0.02	-0.05	-0.02	-0.05	0.12	0.02
N	4241	4241	4241	4241	4241	4241	4241	4241	4241	4241	4241	4241	4241	4241	4241	4241	4241

Significance: ***1%, **5%, *10% .

Table 25: Price Deviation and Single Exchange Characteristics, LOW price-series

	Exchange Transparency				Regulations		Fees			Exchange Size		Other Exchange Characteristics					
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)	(xiii)	(xiv)	(xv)	(xvi)	(xvii)
Know Incorporation	-0.03																
Know Physical Location		-0.35***															
Know Server Location			-0.84***														
USA Location				-1.18***													
ID to Fund					-1.16***												
ID for Fiat Withdrawal						-0.95***											
Free Fiat Deposit							-0.49***										
Fixed Trading Fee								0.28***									
Free Trading Fee									0.78***								
High Global Share										-0.78***							
Low Global Share											-0.04						
In BPI												-0.78***					
EUR Trade													0.11*				
GBP Trader														0.22***			
Trade Non-EUR/GBP															0.11*		
Hacked																0.85***	
Offers Debit Card																	-0.93***
Constant	-4.54***	-4.29***	-4.23***	-4.21***	-4.10***	-4.00***	-4.42***	-4.68***	-4.80***	-4.41***	-4.56***	-4.41***	-4.66***	-4.68***	-4.63***	-4.74***	-4.38***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	-0.01	-0.00	0.06	0.12	0.13	0.08	0.01	-0.01	0.04	0.03	-0.01	0.03	-0.01	-0.01	-0.01	0.04	0.05
N	4233	4233	4233	4233	4233	4233	4233	4233	4233	4233	4233	4233	4233	4233	4233	4233	4233

Significance: ***1%, **5%, *10% .

B.4.3 Combined Exchange Characteristics

Tables (26)-(30) examines grouped regressions of exchange characteristics for groupings that do not result in multicollinearity. The interaction of Fixed Cost to Trade and Free Trades Feasible is a fixed effect for ANXBTC, and is not used. Increases in transparency (Known Server Location) decrease deviations, as does requiring an ID to Fund or having a larger exchange. Fees increase deviations. Accepting trades in multiple foreign currencies has a mixed effect, though overall an exchange that allows for trade in Euros, GBP, and at least one other currency has larger deviations than an exchange that does not.

Table 26: Price Deviation and Grouped Exchange Characteristics, OPEN price-series

	Transparency		Regulations (iii)	Fees (iv)	Exchange Size		Other	
	(i)	(ii)			(v)	(vi)	(vii)	(viii)
Know Server Location	-0.88***	-0.80***						
USA Location	-0.87***	-0.75***						
Server x USA		-0.23*						
ID to Fund			-1.38***					
Fixed Trade Cost				0.19***				
Free Trade Feasible				0.60***				
Low Global Share					-0.21***	-0.08		
Trade Volume					-1.62***	-1.64***		
Low x Volume						-186.64***		
EUR Trade							0.09	
GBP Trade							0.19**	-1.10***
Non EUR/GBP Trade							0.07	-1.03***
GBPxNon EUR/GBP								2.22***
Constant	-4.09***	-4.11***	-4.15***	-4.96***	-4.36***	-4.35***	-4.91***	-4.20***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	0.15	0.15	0.15	-0.01	0.01	0.02	-0.04	0.08
N	4243	4243	4243	4243	4243	4243	4243	4243

Significance: ***1%, **5%, *10% .

Table 27: Price Deviation and Grouped Exchange Characteristics, CLOSE price-series

	Transparency		Regulations (iii)	Fees (iv)	Exchange Size		Other	
	(i)	(ii)			(v)	(vi)	(vii)	(viii)
Know Server Location	-0.74***	-0.56***						
USA Location	-0.94***	-0.63***						
Server x USA		-0.56***						
ID to Fund			-1.34***					
Fixed Trade Cost				0.31***				
Free Trades Feasible				0.61***				
Low Global Share					-0.15**	0.05		
Trade Volume					-1.66***	-1.70***		
Low Share x Volume						-284.83***		
Trade EUR							-0.06	
Trade GBP							0.21***	-1.30***
Trade Non-EUR/GBP							0.04	-1.21***
GBP x Non-EUR/GBP								2.49***
Constant	-4.09***	-4.14***	-4.13***	-4.97***	-4.33***	-4.32***	-4.75***	-4.04***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	0.15	0.15	0.15	0.01	0.03	0.04	-0.03	0.13
N	4243	4243	4243	4243	4243	4243	4243	4243

Significance: ***1%, **5%, *10% .

Table 28: Price Deviation and Grouped Exchange Characteristics, WEIGHTED price-series

	Transparency		Regulations (iii)	Fees (iv)	Exchange Size		Other	
	(i)	(ii)			(v)	(vi)	(vii)	(viii)
Know Server Location	-0.57***	-0.50***						
USA Location	-0.97***	-0.87***						
Server x USA		-0.20*						
ID to Fund			-1.22***					
Fixed Trade Costs				0.34***				
Free Trade Feasible				0.65***				
Low Global Share					-0.35***	-0.20***		
Trade Volume					-1.70***	-1.73***		
Low Share x Volume						-214.34***		
Trade EUR							0.11	
Trade GBP							0.11*	-1.16***
Trade Non-EUR/GBP							0.07	-1.02***
GBP x Non-EUR/GBP								2.18***
Constant	-4.13***	-4.15***	-4.17***	-4.98***	-4.26***	-4.25***	-4.83***	-4.12***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	0.15	0.15	0.15	0.03	0.04	0.05	-0.02	0.12
N	4238	4238	4238	4238	4238	4238	4238	4238

Significance: ***1%, **5%, *10% .

Table 29: Price Deviation and Grouped Exchange Characteristics, HIGH price-series

	Transparency		Regulations (iii)	Fees (iv)	Exchange Size		Other	
	(i)	(ii)			(v)	(vi)	(vii)	(viii)
Know Server Location	-0.97***	-1.09***						
USA Location	-1.13***	-1.34***						
Server x USA		0.39***						
ID to Fund			-1.64***					
Fixed Trade Costs				-0.23***				
Free Trade Feasible				1.47***				
Low Global Share					-0.79***	-0.70***		
Trade Volume					-2.47***	-2.49***		
Low Share x Volume						-130.52**		
Trade EUR							0.00	
GBP Trade							0.86***	-0.86***
Trade Non-EUR/GBP							0.52***	-0.92***
GBP x Non-EUR/GBP								2.87***
Constant	-3.48***	-3.45***	-3.55***	-4.56***	-3.55***	-3.54***	-4.95***	-4.09***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	0.10	0.10	0.09	0.05	0.01	0.01	-0.01	0.11
N	4241	4241	4241	4241	4241	4241	4241	4241

Significance: ***1%, **5%, *10% .

B.4.4 Grouped Exchange Characteristics

Tables (31)-(35) moves iteratively from regression (i) to regression (ii) in Table 11. The result that ID to Fund decreases deviations never changes, though the magnitude may vary.

Table 30: Price Deviation and Grouped Exchange Characteristics, LOW price-series

	Transparency		Regulations	Fees	Exchange Size		Other	
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
Know Server Location	-0.52***	-0.42***						
USA Location	-0.98***	-0.83***						
Know Server x USA		-0.29**						
ID to Fund			-1.16***					
Fixed Trade Cost				0.35***				
Free Trade Feasible				0.81***				
Low Global Share					-0.44***	-0.25***		
Trade Volume					-1.65***	-1.69***		
Low Share x Volume						-274.65***		
Trade EUR							-0.06	
Trade GBP							0.25***	-1.18***
Trade Non-EUR/GBP							0.11*	-1.06***
GBP x Non-EUR/GBP								2.34***
Constant	-4.07***	-4.09***	-4.10***	-4.95***	-4.15***	-4.14***	-4.71***	-4.05***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	0.14	0.14	0.13	0.06	0.04	0.05	-0.01	0.14
N	4233	4233	4233	4233	4233	4233	4233	4233

Significance: ***1%, **5%, *10% .

Table 31: Price Deviation and Exchange Characteristics, OPEN price-series

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
ID to Fund	-1.38***	-1.34***	-1.66***	-1.33***	-1.44***	-1.92***
ID to Fund x Low Share			1.22***			1.50***
Fixed Cost to Trade		-0.12*	-0.04	-0.24***	-0.32***	-0.12*
Free Trade Feasible		0.58***	0.54***	0.38***	0.78***	0.83***
Low Global Share		0.29***	-0.16**	-0.09	0.06	-0.40***
Trade Volume				-1.16***	-0.77***	-0.33***
Volume x Fixed Cost					-0.08	-1.02***
Volume x Free Trade					-2.42***	-3.06***
Volume x Low Share					-94.95**	-167.55***
Constant	-4.15***	-4.38***	-4.25***	-3.96***	-3.97***	-3.87***
Date fixed effect?	Y	Y	Y	Y	Y	Y
Adj. R^2	0.15	0.17	0.20	0.19	0.21	0.25
N	4243	4243	4243	4243	4243	4243

Significance: ***1%, **5%, *10% .

Table 32: Price Deviation and Exchange Characteristics, CLOSE price-series

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
ID to Fund	-1.34***	-1.24***	-1.56***	-1.23***	-1.32***	-1.79***
ID to Fund x Low Share			1.20***			1.50***
Fixed Cost to Trade		0.04	0.12*	-0.08	-0.15**	0.05
Free Trade Feasible		0.65***	0.61***	0.46***	0.78***	0.82***
Low Global Share		0.41***	-0.03	0.05	0.23***	-0.23**
Trade Volume				-1.11***	-0.82***	-0.39***
Volume x Fixed Cost					-0.13	-1.07***
Volume x Free Trade					-1.92***	-2.56***
Volume x Low Share					-175.80***	-248.08***
Constant	-4.13***	-4.50***	-4.38***	-4.10***	-4.10***	-3.99***
Date fixed effect?	Y	Y	Y	Y	Y	Y
Adj. R^2	0.15	0.18	0.21	0.20	0.22	0.25
N	4243	4243	4243	4243	4243	4243

Significance: ***1%, **5%, *10% .

Table 33: Price Deviation and Exchange Characteristics, WEIGHTED price-series

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
ID to Fund	-1.22***	-1.13***	-1.34***	-1.12***	-1.22***	-1.53***
ID to Fund x Low Share			0.78***			0.98***
Fixed Cost to Trade		0.07	0.13**	-0.05	-0.12*	0.01
Free Trade Feasible		0.62***	0.59***	0.42***	0.75***	0.78***
Low Global Share		0.23***	-0.06	-0.16**	-0.02	-0.32***
Trade Volume				-1.20***	-0.87***	-0.58***
Volume x Fixed Cost					-0.12	-0.73***
Volume x Free Trade					-2.05***	-2.47***
Volume x Low Share					-112.55**	-159.61***
Constant	-4.17***	-4.48***	-4.41***	-4.05***	-4.06***	-3.99***
Date fixed effect?	Y	Y	Y	Y	Y	Y
Adj. R^2	0.15	0.18	0.19	0.21	0.22	0.24
N	4238	4238	4238	4238	4238	4238

Significance: ***1%, **5%, *10% .

Table 34: Price Deviation and Exchange Characteristics, HIGH price-series

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
ID to Fund	-1.64***	-1.68***	-1.94***	-1.67***	-1.88***	-2.27***
ID to Fund x Low Share			0.97***			1.25***
Fixed Cost to Trade		-0.65***	-0.58***	-0.84***	-1.00***	-0.83***
Free Trade Feasible		1.36***	1.33***	1.05***	1.82***	1.86***
Low Global Share		0.17***	-0.18**	-0.42***	-0.19*	-0.57***
Trade Volume				-1.82***	-1.11***	-0.74***
Volume x Fixed Cost					0.05	-0.74***
Volume x Free Trade					-4.53***	-5.07***
Volume x Low Share					-99.56*	-160.24***
Constant	-3.55***	-3.73***	-3.64***	-3.08***	-3.12***	-3.03***
Date fixed effect?	Y	Y	Y	Y	Y	Y
Adj. R^2	0.09	0.21	0.22	0.24	0.28	0.30
N	4241	4241	4241	4241	4241	4241

Significance: ***1%, **5%, *10% .

Table 35: Price Deviation and Exchange Characteristics, LOW price-series

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
ID to Fund	-1.16***	-1.06***	-1.29***	-1.05***	-1.16***	-1.53***
ID to Fund x Low Share			0.88***			1.18***
Fixed Cost to Trade		0.09*	0.15**	-0.02	-0.07	0.09
Free Trade Feasible		0.78***	0.75***	0.60***	0.96***	0.99***
Low Global Share		0.20***	-0.12*	-0.14*	0.04	-0.32***
Trade Volume				-1.06***	-0.67***	-0.33**
Volume x Fixed Cost					-0.32*	-1.07***
Volume x Free Trade					-2.21***	-2.72***
Volume x Low Share					-169.98***	-227.45***
Constant	-4.10***	-4.48***	-4.39***	-4.10***	-4.10***	-4.01***
Date fixed effect?	Y	Y	Y	Y	Y	Y
Adj. R^2	0.13	0.18	0.19	0.20	0.22	0.24
N	4233	4233	4233	4233	4233	4233

Significance: ***1%, **5%, *10% .

B.4.5 Controlling for possible autocorrelation in the residual

Tables (36) and (37) reports the result from the OLS regression using Newey-West errors, allowing for autocorrelation in the residual up to lag length ℓ . A Newey West with lag 0 is the same as robust standard errors reported in Table 11 (ii). All results regarding the ID to Fund remain statistically significant.

Table 36: Price Deviation and Exchange Characteristics, Regression (i), Newey-West Regression

$\ell =$	Open			Close			Weighted			High			Low		
	0	2	15	0	2	15	0	2	15	0	2	15	0	2	15
ID to Fund	-1.38***	-1.38***	-1.38***	-1.34***	-1.34***	-1.34***	-1.22***	-1.22***	-1.22***	-1.64***	-1.64***	-1.64***	-1.16***	-1.16***	-1.16***
Constant	-4.59***	-4.59***	-4.59***	-3.63***	-3.63***	-3.63***	-4.38***	-4.38***	-4.38***	-2.98***	-2.98***	-2.98***	-3.80***	-3.80***	-3.80***
Date fixed effect?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	4243	4243	4243	4243	4243	4243	4238	4238	4238	4241	4241	4241	4233	4233	4233

Significance: ***1%, **5%, *10% .

Table 37: Price Deviation and Exchange Characteristics, Regression (ii), Newey-West Regression

$\ell =$	Open			Close			Weighted			High			Low		
	0	2	15	0	2	15	0	2	15	0	2	15	0	2	15
ID to Fund	-1.92***	-1.92***	-1.92***	-1.79***	-1.79***	-1.79***	-1.53***	-1.53***	-1.53***	-2.27***	-2.27***	-2.27***	-1.53***	-1.53***	-1.53***
Low Global Share	-0.40***	-0.40***	-0.40	-0.23**	-0.23*	-0.23	-0.32***	-0.32**	-0.32	-0.57***	-0.57***	-0.57*	-0.32***	-0.32**	-0.32
ID to Fund x Low Share	1.50***	1.50***	1.50***	1.50***	1.50***	1.50***	0.98***	0.98***	0.98***	1.25***	1.25***	1.25***	1.18***	1.18***	1.18***
Trade Volume	-0.33***	-0.33**	-0.33	-0.39***	-0.39**	-0.39*	-0.58***	-0.58***	-0.58**	-0.74***	-0.74***	-0.74**	-0.33***	-0.33**	-0.33
Fixed Trading Costs	-0.12*	-0.12	-0.12	0.05	0.05	0.05	0.01	0.01	0.01	-0.83***	-0.83***	-0.83***	0.09	0.09	0.09
Volume x Fixed Trading	-1.02***	-1.02***	-1.02*	-1.07***	-1.07***	-1.07*	-0.73***	-0.73**	-0.73	-0.74***	-0.74**	-0.74	-1.07***	-1.07***	-1.07**
Free Trade Feasible	0.83***	0.83***	0.83***	0.82***	0.82***	0.82***	0.78***	0.78***	0.78***	1.86***	1.86***	1.86***	0.99***	0.99***	0.99***
Volume x Free Trade	-3.06***	-3.06***	-3.06***	-2.56***	-2.56***	-2.56***	-2.47***	-2.47***	-2.47***	-5.07***	-5.07***	-5.07***	-2.72***	-2.72***	-2.72***
Volume x Low Share	-167.55***	-167.55***	-167.55***	-248.08***	-248.08***	-248.08***	-159.61***	-159.61***	-159.61***	-160.24***	-160.24**	-160.24*	-227.45***	-227.45***	-227.45***
Constant	-4.43***	-4.43***	-4.43***	-3.61***	-3.61***	-3.61***	-4.31***	-4.31***	-4.31***	-2.67***	-2.67***	-2.67***	-3.83***	-3.83***	-3.83***
N	4243	4243	4243	4243	4243	4243	4238	4238	4238	4241	4241	4241	4233	4233	4233

Significance: ***1%, **5%, *10% .