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Bitcoin dilemma: Is popularity destroying value?

S. Thomas Kim

Collins College of Business, University of Tulsa, Oklahoma

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ABSTRACT

I measure the amount of congestion in the Bitcoin network by the time to execute a trade and find that congestion is harming Bitcoin's ability to function as a method of trade. The average time to execute a Bitcoin transaction increased from 30 min in 2016 to 413 min in 2018. I find that the congestion is associated with higher transaction fees and reduced volume. The congestion is also creating a distortion in Bitcoin price. The relationship between congestion and price is strongest during the business hours of East Asia.

1. Introduction

One of the central debates regarding Bitcoin is whether it can be a popular method of trade. The supporters of Bitcoin focus on the potential to execute transactions at a lower cost (Bernanke 2013; Harvey 2016; Kim 2017). Pessimists usually point to the large price volatility of Bitcoin, arguing that the price movement seems too risky (Krugman, 2013; Yermack, 2015; Glaser et al., 2014; Brandvold et al., 2015; Cheah and Fry, 2015; Dyhrberg, 2016; Gandal et al., 2018). Despite warnings from numerous economists, Bitcoin has gained popularity recently, and now there are two major exchanges (Chicago Mercantile Exchange and Chicago Board of Options Exchange) that trade derivatives on Bitcoin prices.

This paper studies a different aspect of Bitcoin and adds an opinion to the central debate. Instead of studying the price volatility, I determine that the current Bitcoin network is severely congested as it gains in popularity. I measure the degree of congestion by the time to execute a Bitcoin transaction and find that the time increased from around 30 min in 2016 to more than 413 min in 2018. Moreover, I show that this congestion is affecting Bitcoin's ability to function as a method of trade. The congestion increases transaction fees, reduces executed volume, and generates inefficient prices. The distortion in price is most severe during the business hours of East Asian countries, where the majority of Bitcoin trading occurs.

2. Congestion in the Bitcoin network

A well-functioning market needs some type of guarantee to prevent fraud. Examples of such guarantees include escrow, brokerage, the reputation of traders, or law. Alternatively, the Bitcoin network is a peer-to-peer market without a central authority, and has a different type of guarantee mechanism. When two traders make a Bitcoin transaction, the transaction is verified by other users in the network. A certain number of users, usually more than half of the participants in the network, must verify the transaction by keeping a record of the transaction in their computers. The transaction record kept by other users functions as a guarantee.

E-mail address: sthomas.kim@utulsa.edu.

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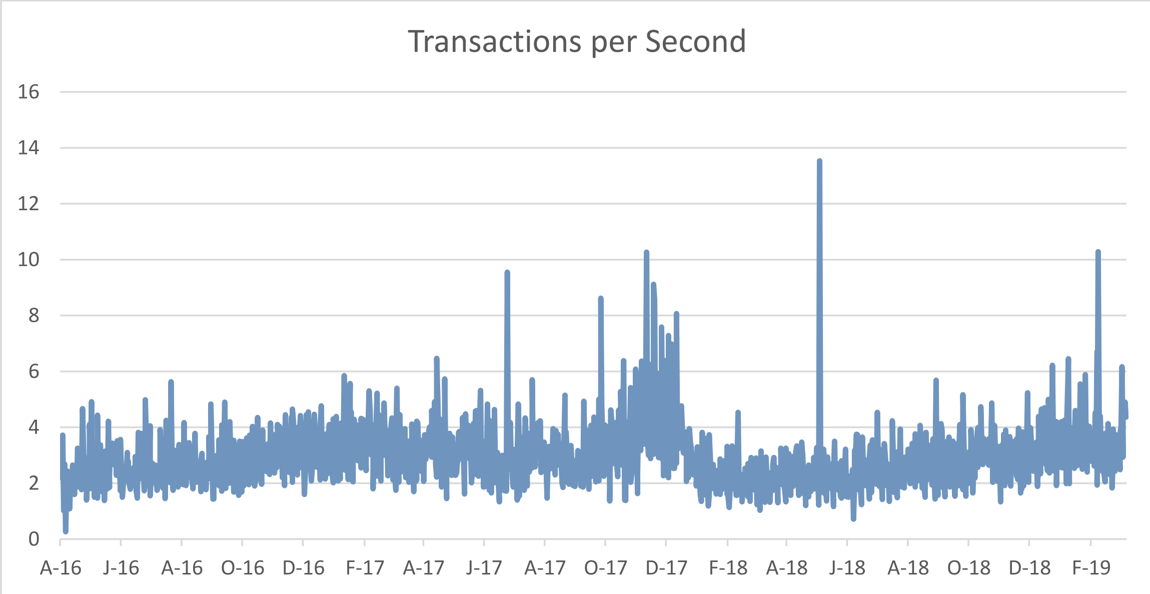

Fig. 1. Number of Bitcoin transactions per second.

The issue here is who would voluntarily keep records of others' trades as the book-keeping activity consumes computing resources and time. Bitcoin solves this issue by combining Bitcoin mining with record keeping. Bitcoin mining is done by converting recent transaction records into crypto data, and the miner who is able to complete the process the fastest receives a new Bitcoin as a reward.

This peer verification mechanism can be worse than other exchanges in terms of speed. For verification of a Bitcoin transaction, data must be sent to multiple miners in the network and responses from the miners must be received to verify that the transaction has been recorded. In addition, miners not only keep records of transactions, but also convert the record into crypto data to acquire new Bitcoin.

The Bitcoin network gathers several transactions to be recorded and processes the bunch (called blocks) at a time. Currently, the size of the block is limited to be 1 megabyte. This block size limit has been the bottleneck of the transaction recording process, and there is still an ongoing debate on how to increase the processing speed. This issue is called as “Bitcoin Scalability Problem”.

Croman et al. (2016) estimate that under these conditions, the maximum processing capacity of the Bitcoin network is between 3.3 and 7 transactions per second. In comparison, a centrally managed payment system, such as Visa credit card, processes 2000 transactions per second. In Fig. 1, I show number of Bitcoin transactions processed per second from April 2016 to March 2019. The data is from the Blockchain.info website. The number did not exceed 15 transactions per second, even in the early 2018 when the Bitcoin network was severely congested.

While the processing capacity of the Bitcoin network has limitations, Bitcoin has gained popularity in recent days and this popularity has led to greater demand for Bitcoin transactions. Dastgir et al. (2019) and Philippas et al. (2019) show that Bitcoin became a popular subject in internet search engines and the popularity is positively associated with Bitcoin prices. If the demand is more than the network can process, the Bitcoin network becomes congested and Bitcoin traders must wait until their transactions are recorded by miners. Thus, unlike most financial markets, the popularity of Bitcoin may lead to longer wait times resulting in overall higher costs of a transaction.

When the network gets congested, Bitcoin transaction fees will increase. Although Bitcoin transactions can be done without fees, traders who pay fees to miners will get the trades processed faster. As waiting time gets longer, more Bitcoin traders will increase the fees to get expedited processing. These frictions in trading may also affect Bitcoin prices, as indicated in the finance literature (e.g. Stoll, 2000).

3. Congestion and transaction costs

3.1. Data and summary statistics

I collect the confirmation time data from Blockchain.info, one of the largest websites regarding Bitcoin transactions. The website posts average confirmation times for a Bitcoin transaction until March 2018. Confirmation time is reported as the average of every six hours, which is divided as UTC (Universal Standard Time) 00:00 –06:00, 06:00–12:00, 12:00–18:00, and 18:00–24:00. First, I examine the development of congestion by plotting the trends of confirmation times from May 1, 2016-March 31, 2018. Bitcoin price and dollar volume is also included in the chart (Fig. 2).

Confirmation times stayed around 30 min until late 2017. However, once Bitcoin became popular and two major exchanges (Chicago Mercantile Exchange and Chicago Board of Options Exchange) began trading Bitcoin derivatives, confirmation times are

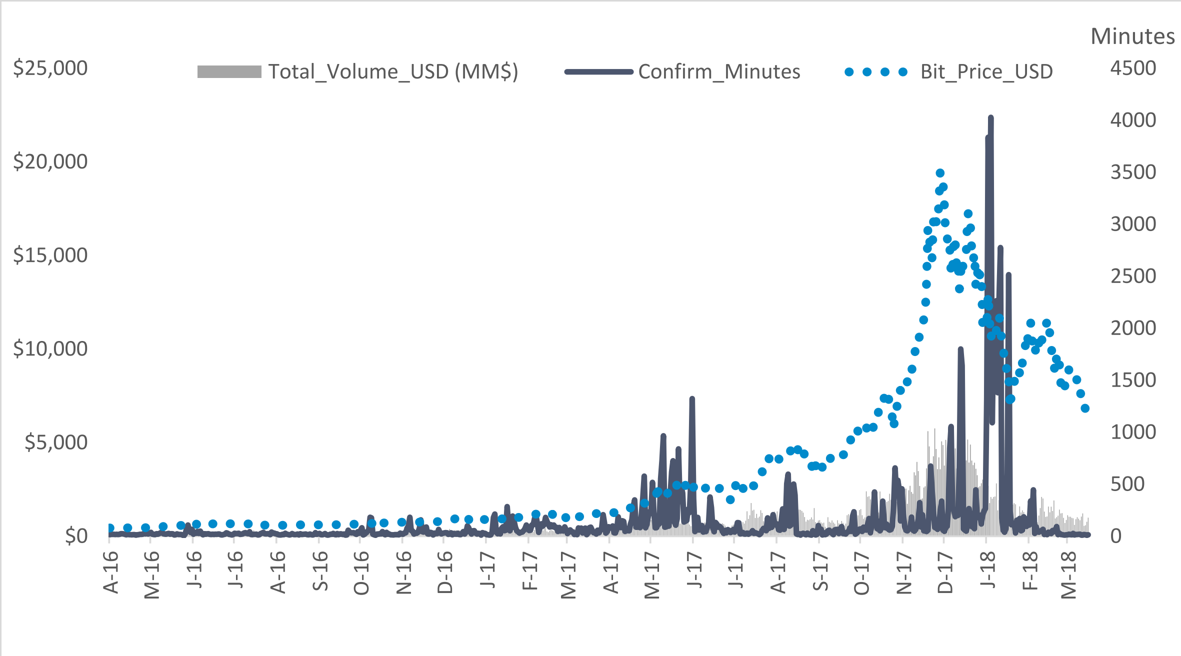

Fig. 2. Average time to confirm a Bitcoin transaction (minutes), Bitcoin price ($), and dollar volume (MM$).

often over 1000 min. The long confirmation time shows that demand for Bitcoin transactions has surpassed the processing capacity. The length of confirmation time itself casts doubt on the ability of Bitcoin to be used as a method of trade.

To further analyze the issues related to the long confirmation times, I collect other data on Bitcoin trading. Bitcoin prices in USD, transaction fees per trade in USD, Bitcoin trading volume in USD, and median confirmation times per day are acquired from the Blockchain.info website. These variables are in daily frequencies.

Table 1

Summary Statistics

This table presents the summary statistics of Bitcoin trading. All variables are in daily frequencies. Panel A is for the full sample from May 1, 2016 to March 31, 2018, Panel B is for the sample from May 1, 2016 to March 31, 2017, and Panel C is for the sample from April 1, 2017 to March 31, 2018.

Panel A: Full Sample (May 1, 2016–March 31, 2018)	Mean	Standard Deviation	P1	P25	P50 (Median)	P75	P99
Bitcoin Price in USD	3665	4309	446	695	1258	4763	17,225
Daily average confirmation time in minutes	133.48	352.20	10.28	20.97	44.09	98.55	2105.87
Daily median confirmation time in minutes	11.50	3.64	6.38	8.71	10.81	13.39	23.56
Transaction fee per transaction in USD	31.86	37.83	4.37	6.44	11.18	40.20	142.95
Daily transaction volume in USD	837 million	1011 million	96 million	194 million	389 million	1024 million	4836 million

Panel B: May 1, 2016 – March 31, 2017	Mean	Standard Deviation	P1	P25	P50 (Median)	P75	P99
Bitcoin Price in USD	747	207	442	606	675	897	1267
Daily average confirmation time in minutes	39.16	38.76	9.99	17.35	24.27	42.73	193.30
Daily Median confirmation time in minutes	10.69	3.65	6.10	8.20	9.78	12.17	23.88
Transaction fee per transaction in USD	6.89	2.13	4.16	5.24	6.39	7.88	13.27
Daily transaction volume in USD	203 million	80 million	85 million	149 million	189 million	234 million	458 million

Panel C: April 1, 2017–March 31, 2018	Mean	Standard Deviation	P1	P25	P50 (Median)	P75	P99
Bitcoin Price in USD	6344	4537	1142	2562	4580	9183	17,772
Daily average confirmation time in minutes	220.04	470.24	11.05	43.42	82.49	180.92	2776.30
Daily median confirmation time in minutes	12.24	3.48	6.43	9.90	11.80	14.28	22.93
Transaction fee per transaction in USD	54.77	40.54	8.16	22.59	38.61	89.59	145.84
Daily transaction volume in USD	1419 million	1117 million	238 million	681 million	992 million	1790 million	5152 million

Table 1 presents the summary statistics of these variables. Here, I convert the confirmation time data into daily frequency data by taking the average of the confirmation times from the four time slots.

Panel A presents the full sample summary, while Panels B and C provide a summary of the earlier and the later periods. When comparing Panels B and C, I note that Bitcoin has gained popularity in recent years as is reflected by higher prices in the recent period ($747–$6344). Meanwhile, confirmation times increased significantly. In the earlier period (Panel B), the average confirmation time is 39 min, while in the later period (Panel C), average confirmation times are more than five-fold (i.e., 220 min).

Median confirmation times do not look much different (10.69 min vs. 12.24 min) indicating that there is a considerable skewness in the confirmation times. Thus, some trades are confirmed fairly quickly, while others are left unconfirmed for a long time. These differences within transactions can be explained by fees per transaction. Bitcoin traders are hiking up the "voluntary" fees recently to expedite their transactions. In the earlier period (Panel B), fees per transaction are $6.89, while in the later period (Panel C), it is almost ten-fold at $54.77.

3.2. Congestion and efficiency of Bitcoin transactions

In this section, I analyze how the congestion, measured by the average confirmation time, affects the cost of Bitcoin transactions. The main explanatory variable of this paper's regression analyses will be the average confirmation time. Since the summary statistics indicate that most of variables, such as confirmation times, volume, or fees increase over time, running a time series regression without adjusting for this trend could generate misleading results. Thus, I de-trend the variables by using the daily differences in the regressions. For Bitcoin price, I calculate returns, which is the difference in price divided by the previous price. In Table 2, I report the summary statistics and correlation table of the change variables.

In Fig. 3, I show scatterplots of the change variables. The Figures indicate that taking daily difference successfully de-trends the variables.

First, I examine whether the congestion is forcing Bitcoin traders to pay higher fees per transaction. The model is:

$$\Delta\,\text{Fee per Transaction}_t = a + b_m \cdot \sum\nolimits_m^n \Delta \mathit{Average\ Confirmation\ Time}_{t-m} + \varepsilon_t \tag{1}$$

where Δ represents daily differences in a variable, t is the day, and n and m are number of lags for the average confirmation time variable.

In Table 3, I report that the change in average confirmation time is significantly and positively associated with the change in fees. This result confirms that traders are reacting to congestion by increasing transaction fees.

Next, I examine the relation between volume and congestion. Volume is a measure of realized trade as opposed to attempts to trade. If some of the trade attempts are not confirmed due to congestion, the attempts would not be recorded as volume. Thus, if congestion is dragging down Bitcoin trading activity, there will be more trade attempts (higher congestion), but less volume. The model is:

$$\Delta\ \text{Dollar Volume}_t = a + b_m \cdot \sum\nolimits_m^n \Delta\ \mathit{Average\ Confirmation\ Time}_{t-m} + \varepsilon_t \tag{2}$$

where Δ represents the daily difference in a variable, t is the day, and n and m are the number of lags for the average confirmation time variable.

In Table 4, I confirm that Bitcoin volume is negatively and significantly correlated with congestion. The results confirm the hypothesis that many of the Bitcoin trade attempts are not executed due to the congestion.

3.3. Congestion and price

Perhaps one of the reasons for Bitcoin's popularity is Bitcoin's price. Many speculators are trading Bitcoin just because Bitcoin prices have increased phenomenally. However, if the Bitcoin network is affected by congestion, the friction may affect the price.

Since it is often better to use higher frequency data to identify certain patterns in prices (Stoll, 2000), I acquire higher frequency price data from coindesk.com, a Bitcoin trading website. The coindesk.com data reports Bitcoin prices every hour or two. I take the price at the end of UTC 06:00, 12:00, 18:00, and 24:00 and match it with the confirmation time data. I calculate six-hour returns from the prices as:

$$\mathit{Return}_q = \frac{\mathit{Bitcoin\ Price}_q - \mathit{Bitcoin\ Price}_{q-1}}{\mathit{Bitcoin\ Price}_{q-1}} \tag{3}$$

where q is a quarter of a day (six hours).

I report the summary statistics of Bitcoin returns and confirmation times in Table 5. There is a considerable amount of difference in confirmation times by the time slot, indicating that higher frequency data contains additional information. The congestion in a specific time slot may represent the trading demand from a region that has business hours during that time.

Now, I examine whether Bitcoin prices are associated with the congestion. I use the Bitcoin returns as the dependent variable and the difference in the average confirmation time as the explanatory variable. The variables are within the six-hour frequency. The model is:

$$\mathit{Return}_q = a + b_m \cdot \sum\nolimits_m^n \Delta\ \mathit{Average\ Confirmation\ Time}_{q-m} + \varepsilon_t \tag{4}$$

Table 2
Summary statistics of change variables

This table presents the summary statistics and correlation table of change variables. All variables are in daily frequencies (daily differences of original variables). Panel A shows the summary statistics. Panel B reports correlation coefficients, and the *p*-values of the correlation coefficients are in the parentheses. A statistically significant correlation at the 1%, 5%, and 10% level are marked with a, b, and c, respectively.

Panel A: Summary Statistics	Mean	Standard Deviation	P1	P25	P50 (Median)	P75	P99
Bitcoin Return	0.50%	4.44%	−11.79%	−0.82%	0.45%	2.40%	12.99%
Δ Daily Average Confirmation Time in Minutes	−0.0009	267.20	−878.76	−11.89	0.78	17.96	793.64
Δ Transaction Fee per Transaction in USD	0.10	6.74	−24.58	−1.05	0.08	1.06	24.51
Δ Daily Transaction Volume in USD	1.2 million	327 million	−1076 million	−64 million	0.8 million	63 million	1148 million

Panel B: Correlation Table	Bitcoin Return	Δ Daily Average Confirmation Time in Minutes	Δ Transaction Fee per Transaction in USD	Δ Daily Transaction Volume in USD
Bitcoin Return		4.6% (0.22)	**25.8%^{a} (0.00)**	**14.1%^{a} (0.00)**
Δ Daily average confirmation time in minutes			**11.0%^{a} (0.00)**	−1.38% (0.71)
Δ Transaction fee per transaction in USD				**−17.5%^{a} (0.00)**
Δ Daily transaction volume in USD				

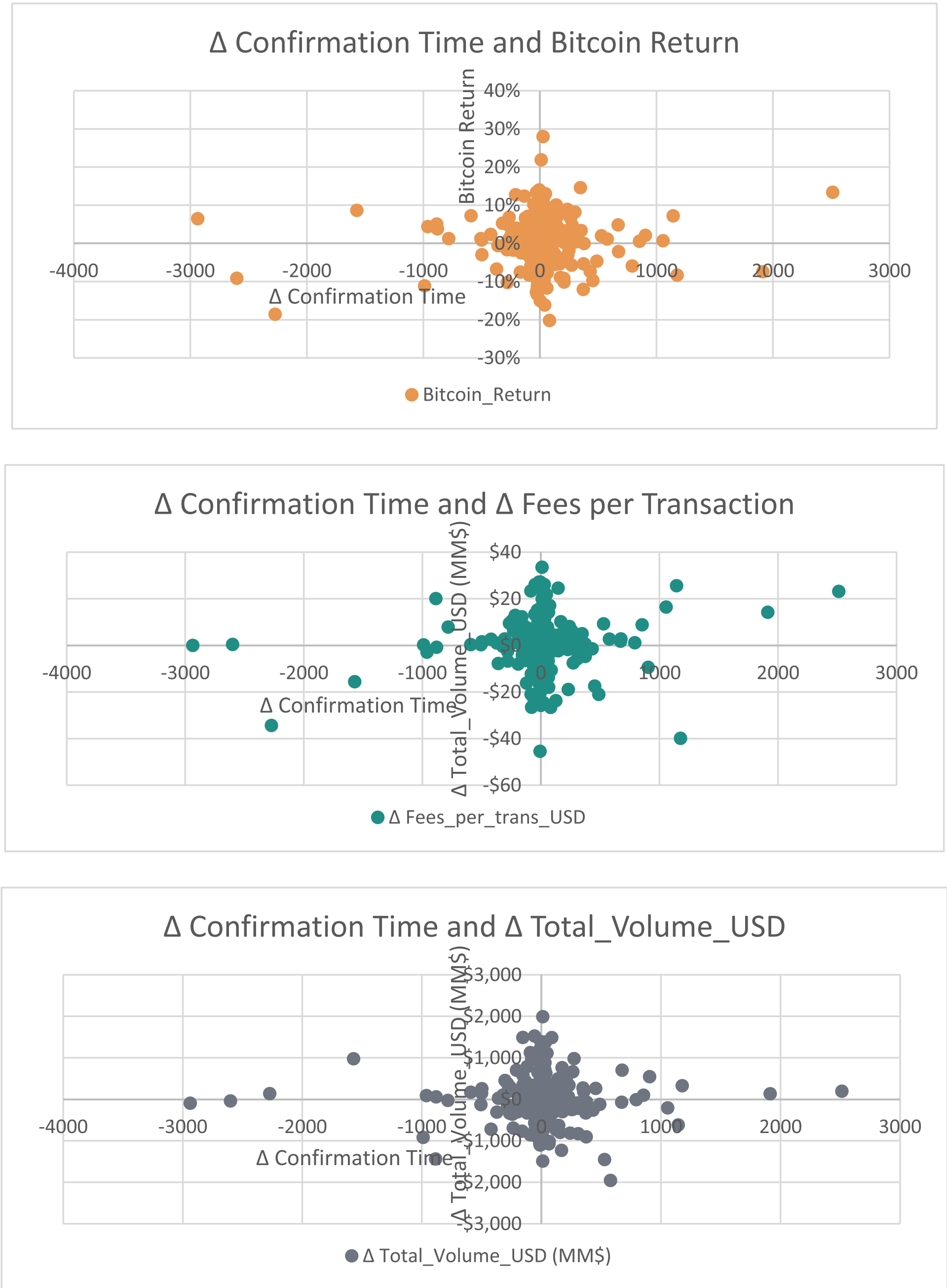

Fig. 3. Scatterplots of change variables.

where Δ represents the difference in a variable, q is the six-hour time slot, and n and m are the number of lags for the average confirmation time variable.

Table 6, Panel A reports that congestion is indeed significantly associated with prices. This result suggests that higher Bitcoin prices may not indicate that traders can trade at that price; unless the traders are willing to wait a long time or pay hefty transaction fees.

I estimate the regression by the six-hour time slot in Panel B. I find that the relationship between the congestion and the returns is strongest in the UTC 00:00–06:00 time slot. As demonstrated in Table 5, this time corresponds to the business hours of East Asia. Combined with the findings of Russo et al. (2018) that the majority of Bitcoin transactions are from East Asia, this result indicates that the distortion in price is most severe when the demand for the trading is the highest.

Table 3

Confirmation time and transaction fee per transaction this table presents the result of regressing transaction fee per transaction by confirmation time. I use the daily difference of the variables in the regression. The model is: $\Delta\,\text{Fee per Transaction}_t = a + b_m \cdot \sum_m^n \Delta \textit{Average Confirmation Time}_{t-m} + \varepsilon_t$ (1) where Δ represents daily differences in a variable, t is the day, and n and m are number of lags for the average confirmation time variable.

P-values are in the parentheses. Coefficients significant at the 1%, 5%, and 10% level are marked with a, b, and c, respectively.

Dependent Variable: Δ Fee per Transaction (in hundred USD)	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Δ Average Confirmation Time $_t$ (in minutes)	**0.28[a] (0.00)**		**0.37[a] (0.00)**	
Δ Average Confirmation Time $_{t-1}$		**0.25[a] (0.01)**	**0.34[a] (0.00)**	**0.22[b] (0.03)**
Δ Average Confirmation Time $_{t-2}$				−0.11 (0.24)
Adjusted-R^2	1.2%	1.0%	2.9%	1.1%
Observations	713	713	713	712
Durbin-Watson Statistic	2.2	2.1	2.2	2.1

Table 4

Confirmation time and trading activity

This table shows the result of regressing the average confirmation time by volume. I use the daily difference of the variables in the regression. The model is:

$\Delta\,\text{Dollar Volume}_t = a + b_m \cdot \sum_m^n \Delta\, \textit{Average Confirmation Time}_{t-m} + \varepsilon_t$ (2)

where Δ represents the daily difference in a variable, t is the day, and n and m are the number of lags for the average confirmation time variable. *P*-values are in the parentheses. Coefficients significant at the 1%, 5%, and 10% level are marked with a, b, and c, respectively.

Dependent Variable: Δ Daily Transaction Volume in USD (thousand dollars)	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Δ Daily Confirmation Time $_t$ (in minutes)	−16.87 (0.71)		−5.96 (0.21)	
Δ Daily Confirmation Time $_{t-1}$		**−148.22[a] (0.00)**	**−163.78[a] (0.00)**	**−161.14[a] (0.00)**
Δ Daily Confirmation Time $_{t-2}$				−49.51 (0.29)
Adjusted-R^2	0.0%	1.5%	1.7%	1.6%
Observations	713	713	713	712
Durbin-Watson Statistic	2.5	2.5	2.5	2.5

3.4. Congestion and Bitcoin trading characteristics

I combine the previous results in a multi-variate regression model to further examine the relationship among the variables. The previous results indicate that congestion should be treated as an endogenous variable that affects fees, volume, and return simultaneously. Thus, I construct a staged least squares regression model as follows:

$$\begin{aligned} Return_q &= a_1 + b_1 \cdot \Delta\ Conf\ \ Time_t + b_2 \cdot \Delta\ Conf\ \ Time_{t-1} + b_3 \cdot \Delta\ Conf\ \ Time_{t-2} \\ &\quad + c_1 \cdot \Delta Fee\ per\ \widehat{Transaction}_t + \ d_1 \cdot \Delta\ Dollar\widehat{\ }Volume_t + \varepsilon_t \\ \Delta Fee_t &= a_2 + f_1 \cdot \Delta\ Conf\ \ Time_t + f_2 \cdot \Delta\ Conf\ \ Time_{t-1} + f_3 \cdot \Delta\ Conf\ \ Time_{t-2}\ + \varepsilon_t \\ \Delta\ Volume_t &= a_3 + g_1 \cdot \Delta\ Conf\ \ Time_t + g_2 \cdot \Delta\ Conf\ \ Time_{t-1} + g_3 \cdot \Delta\ Conf\ \ Time_{t-2}\ + \varepsilon_t \end{aligned} \tag{5}$$

where Δ represents the difference in a variable, *Conf Time* is average time to confirm a Bitcoin transaction, *Fee* is Bitcoin transaction fee in dollars, and Volume is the natural log of dollar volume, and a hat sign indicates that a variable is estimated from a previous stage regression.[1]

In Table 7, after controlling for endogeneity, fees and dollar volume are positively and significantly correlated with Bitcoin return, while congestion lag 1 is negatively and significantly correlated with return. The negative relationship between congestion and return indicates that higher transaction costs make Bitcoin a less attractive method of trade. Dastgir et al. (2019) and Philippas et al. (2019) show that Bitcoin price increases by popularity. On the other hand, this paper demonstrates that popularity may actually harm Bitcoin value by slowing down the processing speed of the Bitcoin network. Furthermore, traders may not be able to trade at the observed prices unless they pay high transaction costs.

4. Conclusion

I explain why Bitcoin's popularity may lead to longer times to execute a trade, and I measure the degree of congestion in the Bitcoin network by the time required to confirm a trade. The confirmation time increased significantly after Bitcoin became popular from 30 min in 2016 to over 413 min in 2018. This long confirmation time is hampering Bitcoin's ability to function as a method of trade.

As a result of the congestion, Bitcoin traders must pay higher transaction fees to expedite their trade. The fee per Bitcoin

[1] Volume is rescaled by taking the natural log of volume first and then taking the difference of the log values.

Table 5
Confirmation time, prices, and returns by business hours

This table reports the summary statistics of the daily average confirmation time, prices, and returns by time slot. Each time slot is six hours, and the time slots are defined as UTC (Universal Standard Time) 00:00–06:00, 06:00–12:00, 12:00–18:00, and 18:00–24:00. If a time slot overlaps with the normal business hours (9am–5pm) of a city with a major financial market, I mark the city name in bold letters.

	Confirmation Time		Price		Return	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
UTC 00:00–06:00 (Chicago 19:00–01:00 London 01:00–07:00 **Tokyo 09:00–15:00**)	153 min	466 min	\$3639	\$4258	0.06%	2.09%
UTC 06:00–12:00 (Chicago 01:00–07:00 **London 07:00–13:00 Tokyo 15:00–21:00**)	70 min	184 min	\$3639	\$4249	0.17%	2.42%
UTC 12:00–18:00 (**Chicago 07:00–13:00 London 13:00–19:00** Tokyo 21:00–03:00)	104 min	302 min	\$3636	\$4242	0.02%	2.45%
UTC 18:00–24:00 (**Chicago 13:00–21:00** London 19:00–01:00 Tokyo 03:00–09:00)	206 min	809 min	\$3650	\$4264	0.25%	2.03%

Table 6

Confirmation time and Bitcoin returns

This table presents the time series regressions between confirmation time and Bitcoin returns. The model is:

$Return_q = a + b_m \cdot \sum_m^n \Delta\ Average\ Confirmation\ Time_{q-m} + \varepsilon_t$ (4)

where Δ represents the difference in a variable, q is the six-hour time slot, and n and m are the number of lags for the average confirmation time variable.

Panel A shows the result for the entire sample, and Panel B presents the results by each time slot. The coefficients are multiplied by 10^6 for visual convenience. P-values are in the parentheses. Coefficients significant at the 1%, 5%, and 10% level are marked with a, b, and c, respectively.

Panel A: Full Sample *Dependent Variable: Bitcoin Return*	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Δ Confirmation time $_q$ (in minutes)	**1.79[b] (0.03)**		**1.99[b] (0.02)**	
Δ Confirmation time $_{q-1}$		0.29 (0.72)	0.80 (0.35)	0.04 (0.96)
Δ Confirmation time $_{q-2}$				1.00 (0.24)
Adjusted-R^2	0.2%	0.0%	0.2%	0.1%
Observations	2799	2799	2798	2797
Durbin-Watson Statistic	2.1	2.1	2.1	2.1

Panel B: Results by Time Slot Dependent Variable: Bitcoin Return	UTC 00:00–06:00 (Chicago 19:00–01:00 London 01:00–07:00 **Tokyo 09:00–15:00**)	UTC 06:00–12:00 (Chicago 01:00–07:00 **London 07:00–13:00 Tokyo 15:00 –21:00**)	UTC 12:00–18:00 (**Chicago 07:00–13:00 London 13:00–19:00** Tokyo 21:00–03:00)	UTC 18:00–24:00 **(Chicago 13:00–21:00** London 19:00–01:00 Tokyo 03:00–09:00)
Δ Confirmation Time $_q$	**4.16[a] (0.00)**	**3.83[c] (0.09)**	1.93 (0.50)	−0.27 (0.82)
Adjusted-R^2	1.4%	0.4%	0.1%	0.0%
Observations	699	699	699	699
Durbin-Watson Statistic	2.2	2.1	2.0	2.2

Table 7

Confirmation time and Bitcoin trading characteristics This table presents the staged least squares model of Bitcoin trading characteristics. The model is:

$$Return_q = a_1 + b_1 \cdot \Delta\ Conf\ \ Time_t + b_2 \cdot \Delta\ Conf\ \ Time_{t-1} + b_3 \cdot \Delta\ Conf\ \ Time_{t-2}$$

$$+ c_1 \cdot \Delta Fee\ per\ \hat{T}ransaction_t + \ d_1 \cdot \Delta\ Dollar\hat{\ }Volume_t + \varepsilon_t$$

$$\Delta Fee_t = a_2 + f_1 \cdot \Delta\ Conf\ \ Time_t + f_2 \cdot \Delta\ Conf\ \ Time_{t-1} + f_3 \cdot \Delta\ Conf\ \ Time_{t-2}\ + \varepsilon_t$$

$$\Delta\ Volume_t = a_3 + g_1 \cdot \Delta\ Conf\ \ Time_t + g_2 \cdot \Delta\ Conf\ \ Time_{t-1} + g_3 \cdot \Delta\ Conf\ \ Time_{t-2}\ + \varepsilon_t$$

5 where Δ represents the difference in a variable. *Conf Time* is average time to confirm a Bitcoin transaction, *Fee* is Bitcoin transaction fee in dollars, and Volume is the natural log of dollar volume, and a hat sign above a variable indicates the variables estimated from the previous stage regression. Volume is rescaled by taking the natural log first and then taking the difference of the log-volumes. Contemporaneous and Lagged changes in *Conf Time* are endogenous variables that explain Return, Fee, and Volume. The results of the final stage regression, which is the regression equation with return as the dependent variable, are reported. The coefficients on change in confirmation time are multiplied by 10^6 and the coefficients on fee and volume are multiplied by 10^3 for visual convenience. P-values are in the parentheses. Coefficients significant at the 1%, 5%, and 10% level are marked with a, b, and c, respectively.

Dependent Variable: Bitcoin Return	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Δ Confirmation time$_t$	−3.98 (−0.64)		−4.04 (−0.66)	
Δ Confirmation time$_{t-1}$	**−22.03^a (−3.44)**	**−21.20^a (−3.58)**	**−23.30^a (−3.62)**	**−20.88^a (−3.40)**
Δ Confirmation time$_{t-2}$	1.01 (0.87)			1.24 (0.20)
Δ Fee per transaction$_t$	**2.04^a (8.38)**	**2.01^a (8.39)**	**2.03^a (8.39)**	**2.02^a (8.37)**
Δ Dollar volume$_t$	**27.21^a (4.43)**	**27.15^a (4.43)**	**27.22^a (4.44)**	**27.15^a(4.42)**
Adjusted-R^2	10.4%	10.6%	10.5%	10.5%
Observations	711	712	712	711

transaction increased from \$6.89–\$54.77 and may increase further given the significant correlation between congestion and transaction fees. I also show that congestion is significantly and negatively correlated with Bitcoin volume.

This congestion is also affecting Bitcoin prices. I find that Bitcoin returns are significantly associated with the degree of congestion. This result indicates that transaction costs distorts price. The relationship between congestion and the price is the strongest during the business hours of East Asia, where the majority of Bitcoin trading occurs. Overall, the results suggest that the current Bitcoin network is severely congested and lost its ability to function as a method of trade.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.frl.2019.07.001.

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