Bitcoin Mining: Converting Computing Power Into Cash Flow

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Abstract

Bitcoin is the world's leading cryptocurrency, with a market capitalization briefly exceeding $300 billion. This hints at Bitcoin's amorphous nature: is this a monetary or a corporate measure? Hard values become explicit in the processing of transactions and the digital mining of Bitcoins. Electricity is a primary input cost. Bitcoins earned are often used to circumvent local currency controls and acquire US dollars. For the period August 2010 to February 2018, we examine the components of Bitcoin mining revenues, their statistical contribution to daily changes, and to its variance. We provide evidence that Bitcoin transaction processing is capacity constrained.

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Highlights

- Bitcoin mining rewards transaction processing tasks with new Bitcoins.
- Changes in Bitcoin USD price is primary factor in changes in Bitcoin mining revenues.
- Changes in Transactions (volumes) are also statistically significant.
- Peak in transactions, spike in mining revenues and fees indicate capacity constraints.

1. Introduction

The Bitcoin mining industry processes 300,000 transactions, and generates $15 million dollars worth of Bitcoins and $500k of fees daily (Figure 1). Historically, Bitcoin scaled efficiently with transactions. It offset transaction growth with higher transactions per block. Blocks processed per day - and consequently Bitcoin mining prize games - have been stable since 2011 (Table 1). More recently divergences occurred as Bitcoin reached its block size limit, which specifies how much data may be contained in each block.

These divergences include a peak in transactions, higher transaction fees and a rise in mining revenues. The latter two are a user cost and a system cost respectively. Mining revenues reached $50 million per day during December 2017. These divergences are now moderating with the adoption of SegWit, which reorganises data on and off blocks.

Bitcoin utilizes cryptographic digital signatures and proof of work computing tasks (Nakamoto, 2009). These form a pseudo public database, that transfers value without relying on a trusted central party. Iansiti and Lakhani (2017) describes Bitcoin as a narrow use case of blockchain, or distributed ledger technology, in an area with low coordination requirements.

Parties move Bitcoins, a unique digital asset, between elec-

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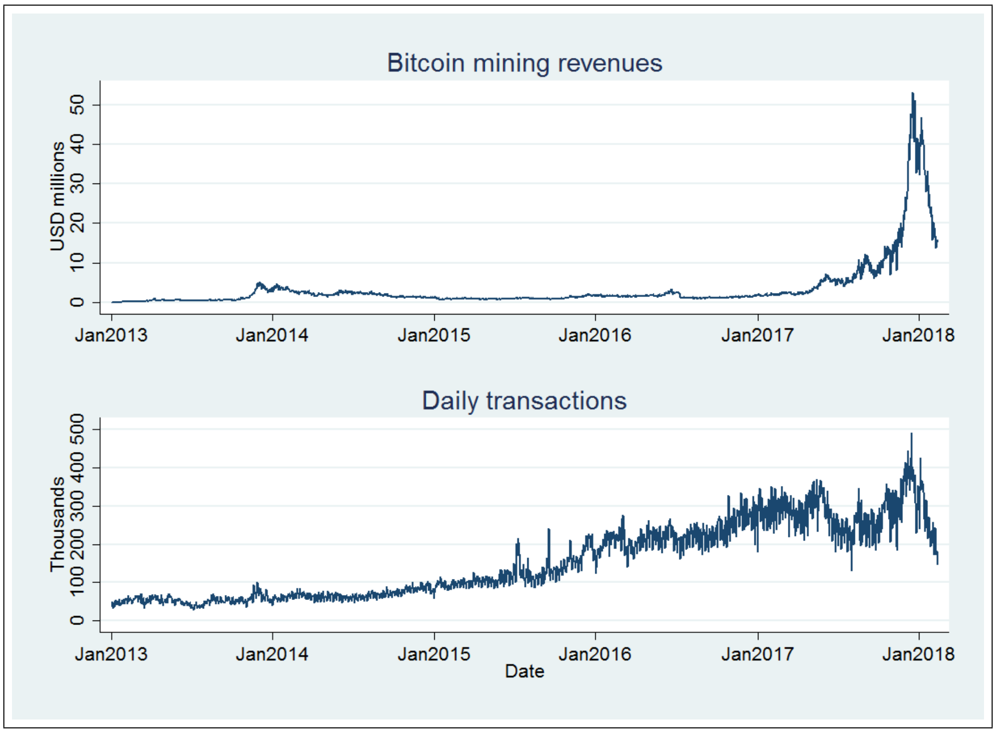

Figure 1: Daily Bitcoin mining revenues \$m, and transactions '000s

tronic addresses via transactions. Transactions are submitted to the mempool (temporary storage). Most processing is carried out by collective mining pools, that reduce individual reward variance, and divides in two the task of transferring transactions from the mempool to the blockchain (Gervais et al., 2014). The pool administrator checks, selects and orders transactions. Pool participants contribute computing to the resource intensive proof of work required to validate blocks. Blocks must contain a solution to a cryptographic puzzle related to its transactions and its place in the chain (Nakamoto, 2009). Block processing earns miners Bitcoin rewards and fees. Buterin (2013) describes this as a first-to-file system: transactions are ordered by when they are processed.

Although Vukolić (2016) suggests directions for addressing blockchain's limitations, most Bitcoin mining literature focuses on game theory and incentives. Eyal and Sirer (2014) outlines Bitcoin's vulnerability to selfish mining strategies. Schrijvers et al. (2017) models mining pool reward functions. Kroll et al. (2013) suggests the optimal mining rewards level is equal to the value of Bitcoin's collapse to an attacker. Other literature focuses on Bitcoin prices (Cheah and Fry, 2015), which our work confirms is central to changes in Bitcoin mining revenues.

Bitcoin mining rewards convert computing power into cash flow. This incentivizes participation. Successful malicious actors must control a quarter of this compute (Eyal and Sirer, 2014). Nakamoto (2009) and Kroll et al. (2013) consider spending on Bitcoin mining as an attacker's cost function.

This paper adds to the literature an empirical analysis of the components of Bitcoin mining revenues, plus their contribution to log daily changes and variance. We find that the Bitcoin USD price, and transactions, are statistically significant drivers of revenues. Rolling regressions of the coefficient on changes in daily transactions suggests that despite SegWit scaling remains an issue. The results highlight the rising expense of censorship resistance within Bitcoin. Those who consider Bitcoin a low cost financial network ignore that it is costly by design. The results support research into longer term efforts to help Bitcoin scale. We do not suggest that costs are the only reason transactions are declining, hash rates and the difficulty in finding new blocks have also accelerated. However, network issues impacting supply may have contributed to the rise in the Bitcoin price. If holders cannot transact efficiently, this may amplify price corrections, and has relevance to economists and policy makers.

2. Data

We source our Bitcoin mining data from blockchain.info via the Quandl platform. Effectively this outsources the creation of a single Bitcoin price index to the former, and the selection of time of day to the latter, which eases any effort to replicate our results. As a check of robustness, we also utilize daily pricing data from the Bitstamp exchange. Bitstamp's Bitcoin index is indirectly regulated by the CFTC via being referenced by the CME Future. This check highlights data quality issues in the field: most exchanges have no defined regulator, the period available (beginning 28 November 2014) is significantly shorter than for the blockchain.info index, and the time of day when the data is acquired impacts the nature of the sample. We download our Bitstamp data at 9:50am EST on the 12 February 2018. These discrepancies can be particularly glaring when using live API data feeds. The high and low intraday prices are provided by Cryptocompare, a data aggregator. Blockchain.info calculates mining revenues by tracking the number of blocks processed and the daily transaction fees. Table 1 shows a variety of descriptive statistics. The time period under analysis covers 17 August 2010 to 12 February 2018.

3. Empirical Model & Methodology

The blockchain algorithm ensures that less than 21 million Bitcoins (BTC) are issued. As part of this, mining rewards halved to 25 BTC per block on 28 November 2012 and to 12.5 BTC on 9 July 2016. Total daily compensation, or Bitcoin mining revenues, follow an identity.

$$E(RI_t) = \frac{T_t}{B_t} \times C_t \times U_t + F_t \quad (1)$$

Under this notation, RI_t is the Bitcoin mining revenue for a given day, including fees. T_t is the number of the transactions. B_t is the average number of transactions per block. C_t is the block reward rate, which does not have to be collected by the miner. U_t is blockchain.info's benchmark exchange rate of US dollars per Bitcoin. F_t is the daily total of an optional transaction fee.

Our analysis is focused on Bitcoin mining revenue RX_t excluding transaction fees, because fees and blocks are statistically collinear with the other variables, particularly on a daily basis. We exclude C_t as effectively discrete. We assume that miners behave optimally and collect coin rewards. We assume that miners convert the Bitcoins they mine into USD the same day.

We take first differences, which reject the null of non-stationarity at the 99% significance level. We transform our ex fees nonlinear identity into a linear equation by taking logarithms. We define a spread variable of the intraday $High/Low = S_t$. Baek and Elbeck (2015) found a monthly spread variable to be a statistically significant factor in monthly price changes. We follow the literature and incorporate S_t.

$$\Delta(lnRX_t) = \alpha + \beta_1\Delta(lnT_t) + \beta_2\Delta(lnU_t) + \beta_3\Delta(lnS_t) + \epsilon (2)$$

In addition to an analysis for the complete period, we calculate 365 day rolling regressions, with overlapping time periods, to chart the coefficients on log daily difference in BTCUSD, and log daily difference in Transactions, over time.

We carry out two separate checks of our analysis, with results presented in (Appendix A). We perform a winsorization of the variables of the empirical model (Dixon, 1960), and compare the full and modified dataset results. Our winsorization compacts the top and bottom 5% of each series, replacing them with the 95th and 5th percentile value respectively, to examine the impact of tail values. We also carry out the analysis with an alternate data source for the Bitcoin price - notably from the Bitstamp exchange.

4. Results & Analysis

As we have taken logs of both sides, based on the empirical model the coefficients β_n are elasticities. Consequently a

	N	Mean	Standard Deviation	Min	Max
Bitcoin mining rev inc fees, USD '000s	2,737	2,387.23	(5,886.94)	0.34	53,191.59
Bitcoin mining rev exc fees, USD '000s	2,737	2,096.62	(4,626.25)	0.34	42,863.09
Transactions, '000s	2,737	109.23	(103.81)	0.27	490.64
Bitcoin US Dollar (BTCUSD) price	2,737	924.48	(2,411.20)	0.06	19,498.68
Transaction fees, USD '000s	2737	290.62	(1,418.29)	0.00	22,724.84
Blocks processed	2737	166.14	(82.54)	6.5	2,941.5
Log difference in mining rev ex fees USD	2,736	0.0038	(.14391)	-1.03	.967785
Log difference in Transactions	2,736	0.0022	(.196634)	-3.27	2.879949
Log difference in BTCUSD	2,736	0.0042	(.064605)	-1.04	1.004342

Table 1: Descriptive statistics for Bitcoin Mining industry and log daily differences, 17 August 2010 to 12 February 2018

100% change in Transactions implies an 9% change in mining revenues. In comparison, our regression implies a one for one elasticity (almost 100%) between changes in the BTCUSD exchange rate and Bitcoin mining revenues. We did not find significance for the other variables from the expected Bitcoin mining revenue identity.

The VIFs in Table 2 indicate that the independent variables are unlikely to be collinear. At the 95% significance level, the Breusch-Pagan test result does not reject the null hypothesis of constant variance; and the Ramsay RESET test result does not reject the null hypothesis of no omitted variables but does reject at the 90% significance level.

When we regress the residuals of the model against lagged residuals, at the 99% significance level the F-test and t-test results reject the null of zero on the lagged residual coefficient. We find negative serial correlation (-0.389) is present even after log first differencing. Standard errors are overstated.

We present an analysis of model variance in Table 3. The R^2 for the empirical model is 22%, which is primarily explained by the Bitcoin USD price (20%). For comparison, the R^2 of the regression in levels exceeds 97% but may be subject to spurious consistencies between stochastic time series.

Moving to the rolling regressions, we find that the coefficient on the Bitcoin USD price reached a high of 1.15 in the 365 days to October 2011 and declined to a low of 0.47 in January 2016 (Appendix B). The rolling coefficient on the log daily change in Transactions varies from -0.01 to 0.58.

In the most recent 365 day period, a 100% change in BTCUSD or Transactions, implies a closer to 90% and 57% change in Bitcoin mining revenues respectively. This compares to 100% and 9% for the 2,560 day period encapsulated in our empirical model. The increasing coefficient on Transactions is coincident with the earlier peak in daily transactions in Spring 2017 (Figure 1). At that point it appears that mining revenues per transaction rose as transactions per block declined. Note that although the throughput capacity of Bitcoin is often given as 7 transactions per second, implying 600k transactions a day, this is with very small transaction sizes. Half this level is considered more plausible Croman et al. (2017).

Following the last cut in the block reward rate, Transaction fees rose to an average $48k per day between 9 July 2016 and 15 December 2016. This was a promising sign that Bitcoin mining could absorb block reward reductions. However, spikes in transaction fees during summer 2017, in parallel with the peak in transactions are concerning. They hint at the transaction capacity limit of the existing system.

5. Conclusion

A major beneficiary of Bitcoin's volatile appreciation in price is the Bitcoin mining industry. Average revenues over

Log first differences	Partial sum of squares	DF	Mean sum of squares	*Prob > F*
Empirical model	12.510	3	4.170	0.0000
Transactions	0.863	1	0.863	0.0000
BTCUSD	11.256	1	11.256	0.0000
Spread	0.000014	1	0.000014	0.9761
Residual	44.129	2,731	0.0162	
Total	56.639	2,734	0.0207	

Independent variables are specified as continuous

Table 3: Bitcoin mining: variance decomposition

	N	Mean	Standard Deviation	Min	Max
Coefficient on log daily change in BTCUSD	2,373	0.8537	(.12223)	0.47	1.149641
Coefficient on log daily change in Transactions	2,373	0.1732	(.119209)	-0.01	.578560

Table 4: Summary statistics of rolling 365 day coefficients

the last 7 years exceed \$1.2m US Dollars per day. Our analysis confirms that the dominant driver of daily differences in Bitcoin mining revenues is the Bitcoin USD price.

The importance of transactions appears to be changing. Unfortunately for proponents of Bitcoin, there are clear signs of growing pains, with a peak in transactions, higher fees being offered to gain processing priority, and higher Bitcoin mining cost per transaction. This supports the hard fork of Bitcoin Cash, with its higher capacity, and may be addressed within Bitcoin by the SegWit update.

The impact that these scaling issues are having on the Bitcoin price, and any subsequent correction, should be borne in mind by economists and policy makers. Future vectors for this research include a decomposition of the causes of the recent decline in transactions.

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Table 2: Empirical model

Log first difference	Mining revenues	
	β_i	VIF_i
Transactions	0.0905***	1.00
	(7.31)	
Bitcoin USD index	0.996***	1.01
	(26.39)	
Spread	0.000717	1.00
	(0.03)	
Constant	-0.000675	
	(-0.28)	
N	2735	
Adjusted R^2	0.220	
Breusch-Pagan test statistic	0.569	
BP(p)	0.451	
Ramsay RESET test statistic	2.569	
RR(p)	0.0527	

The variance inflation factor is calculated as $VIF_i = \frac{1}{1-R_i^2}$ where the independent variable i is regressed against the other independent variables

*** indicates statistical significance at the 0.001 level

Appendix A. Comparison with Winsorized dataset and Bitstamp pricing data

Log first differences	Complete period	Winsorized dataset	Bitstamp Bitcoin USD price
Transactions	0.0905***		0.348***
	(7.31)		(12.47)
Bitcoin USD index	0.996***		
	(26.39)		
Spread	0.000717		-0.0621
	(0.03)		(-0.76)
Winsorized Transactions		0.217***	
		(12.64)	
Winsorized Bitcoin USD index		1.071***	
		(18.44)	
Winsorized Spread		-0.0102	
		(-0.22)	
Bitstamp Bitcoin USD price			0.226*
			(2.49)
Constant	-0.000675	-0.000610	0.00114
	(-0.28)	(-0.29)	(0.31)
N	2735	2735	1171
r2_a	0.220	0.166	0.121

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.5: Comparison of empirical model dataset against winsorised dataset and Bitstamp Bitcoin USD price

Appendix B. Appendix B. Rolling coefficients

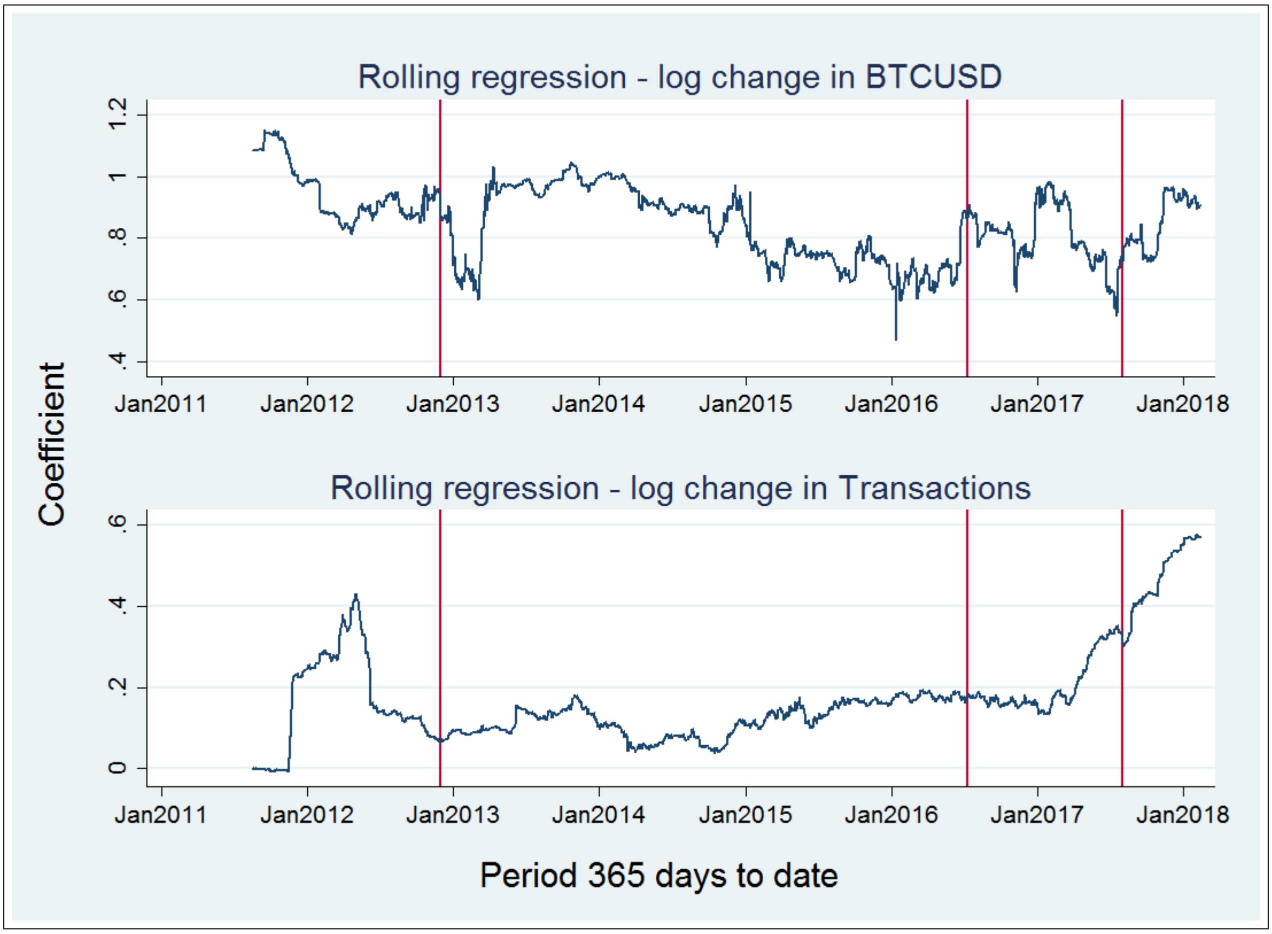

Figure B.2: Rolling 365 day coefficient on log daily change in BTCUSD and Transactions. First and second vertical lines from the left are reductions to coinbase reward rate. Third vertical line is Bitcoin Cash hard fork