Why you should not invest in mining endeavour? The efficiency of BTC mining under current market conditions.

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Abstract: The main aim of this paper is to analyse the efficiency of BTC mining under current market conditions. After thorough analysis of initial assumptions concerning the (1) price of mining machine and its effective amortization period, (2) difficulty and hash rate of BTC network, (3) BTC transaction fees and (4) energy costs, we have found that currently BTC mining is not profitable, except for some rare cases. The main reason of this phenomenon is the fast and unpredictable increase of difficulty of BTC network over time which results in decreasing participation of our mining machines in BTC network hash rate. The research is augmented with detailed sensitivity analysis of mining efficiency to initial parameters assumptions, which allows to observe that the conditions for BTC mining to be efficient and profitable are very challenging to meet.

Keywords: cryptocurrencies, mining, bitcoin, blockchain, investment strategy, efficiency of financial markets, new asset class, VC and PE

JEL codes: C15, G11, F30, G12, G13, G14, G15

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[2]The views presented in this text are those of the authors and do not necessarily represent those of LHF project or Circus Consulting Group sp. z o.o.

1 Introduction

The main rationale for this paper is to address some kind of collective misunderstanding about the subject of cryptocurrency mining which nowadays is raised very often in many sources like websites analysis, new mining ICOs white papers, cryptocurrency blogs, etc. We want to provide a precise analysis of efficiency of BTC mining when the rapid growth of difficulty and hash rate of BTC network is responsible for ultra fast decrease of participation rate[3] of bought mining machines with the time passing by.

The main objective of this research is to focus on the efficiency of BTC mining. We want to refer to the following main research hypothesis:

- H1: Is BTC mining profitable under current mining conditions?

And answer the following research questions:

- Q1: What is the sensitivity of BTC mining profitability to initial assumptions and future trajectories of main parameters?
- Q2: Is there a strong positive relation between BTCUSD and difficulty/hash rate of BTC network?
- Q3: What are the breakeven levels of the main BTC mining parameters in order to make this activity profitable?
- Q4: What is the rational level of amortization period for our mining machines?
- Q5: What are the consequences of BTC mining efficiency for future ability of blocks to be mined further?
- Q6: Can we expect that blocks will not be confirmed if the efficiency of BTC mining is negative for an extended period of time?
- Q7: Should we invest in BTC mining if we expect very strong growth of BTC price?
- Q8: Is it possible that technological advancements in the ASICs performance would change BTC mining landscape and make mining profitable?
- Q9: What kind of new financial instruments may stimulate BTC mining industry?

All these hypotheses and research questions enabled us to plan our paper as follows. After Introduction, in the second section, we present literature review with description of highest capitalization ICOs focused on cryptocurrency mining and publicly listed companies which announced that they undertook mining activity as well. Crucial assumptions of our model and detailed description of our data will be presented in the third section. Methodology with model description and additional assumptions will be described in the forth section. The fifth section will contain main results. Then sensitivity analysis divided in separate parts for one-factor and two-factors is in the next section. The following section will describe breakeven conditions for BTC mining to be profitable and the last section concludes.

2 Literature review and business mining activities review

In this section, in order to shed some light on theoretical and practical world of BTC mining, we review recent scientific papers and practical mining activities financed in the form of ICO or undertaken by publicly listed companies.

2.1 Literature review

At the beginning of this part we have to notice that we did not find numerous papers describing the issue of BTC or other cryptocurrencies mining efficiency in details with rigorous scientific manner. This was one of the reason we decided to write this article and shed some light on this subject.

One of the most recent research about Bitcoin mining efficiency was presented by Bendiksen and Gibbons (2018). The authors came to the conclusions that mining activity is profitable (as of the publishing date) but only under certain assumptions. The authors also concluded that Bitcoin mining network is mainly powered by renewable energy, dominated by hydro sources.

[3]Participation rate of mining machines is defined here as hash rate of our mining machine divided by BTC network hash rate.

Chepurnoy, Kharin, and Meshkov (2018), proposed a modification of a transaction fee scheme. Recommended components of a fee should be associated with resources utilized: network, computation or storage. This is an interesting direction of consideration for blockchain developers, especially now, when the moment of block reward reduction is imminent and the importance of the level of future BTC transaction fees will naturally grow.

The recent research by Hayes (2018) presented convergence effect of BTC prices and its marginal cost of production. The conclusion has been confirmed using simple OLS regression as well as the VAR model. It should be underlined that no hardware costs, i.e. CAPEX, was taken into account in the analysis. Therefore, one can not properly conclude on actual profitability of mining based on the final results of this paper.

Hale et al. (2018) presented the thesis explaining BTC prices dynamics in the late 2017 and early 2018. The increase and following sharp decrease in prices was related to the speculative dynamics that were able to materialize after introduction of futures on the CME/CBOE.

Taylor (2017) presented evolution of mining hardware over time, which is one of the most important driver of mining profitability. He showed detailed historical daily revenue per GH/s with regards to single mining machines since 2011 until 2016.

Hayes (2015) presented detailed analysis of bitcoin mining profitability. The calculations were based on objective mathematical formulae. This was an objective attempt to measure mining efficiency, however there were no assumptions on the future evolution of main drivers of their formulae.

More realistic approach, in our opinion, was taken by Deutsch (2018). Mining difficulty change over time was explicitly assumed in a form of linear regression of logarithmic transformation of raw variable. Thus it presents the importance of dynamics of this part of the model, which as Deutsch underlines, is omitted by naive profitability calculators available on many websites. Such ignorance may lead to substantial bias of conclusions based on these mining calculators. Deutsch presented sensitivity analyses of mining profitability versus synthetic measure alpha. In our research, the attempt is made to analyze sensitivity versus most basic components of profitability. Worth mentioning is that Deutsch extended his work with block-reward halving-days effect.

2.2 Review of mining activities financed by ICO

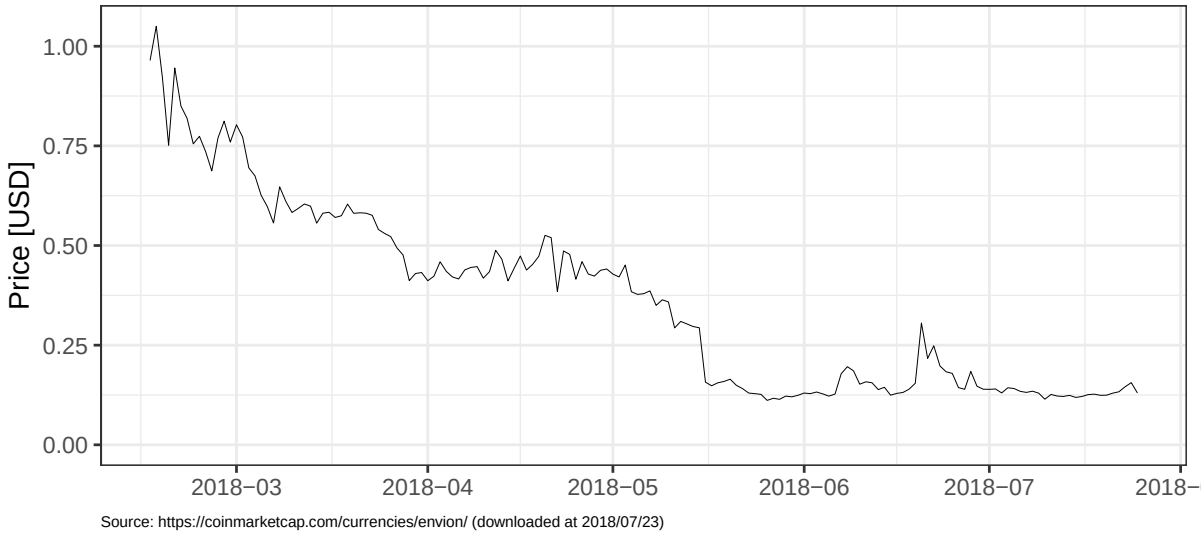
Direct information of the real business mining vehicles profitability is very limited. Companies related to the mining industry do not publish, for obvious reasons, any detailed information on efficiency nor any other aspects (e.g. detailed assumptions) of their businesses. It is virtually impossible to obtain any precise financial statements of such companies, and scraps of information tossed on their websites is very far from being regarded as reliable source of scientific data. In this part we analyse the business profitability and potential prospects of the ICO-financed mining companies. It was assumed that ICO exchange market is characterized by some level of informational efficiency. Even though the Efficient Market Hypothesis could be difficult to defend for the ICO market, we assume that general conclusions drawn from ICO prices evolution could be treated as justifiable.

i. Envion, 2018

One of the biggest and quite recent attempts to create a cryptocurrency mining enterprise is Swiss Envion. Their main advantages presented on the website (https://www.envion.org/en/) are: the mobility of the infrastructure, the cheap energy sources (mainly from solar sources and wind farm), remote management and patented cooling technology. The company was able to attract substantial investment capital. The ICO finished with 100m USD raised within short period of time i.e. from 2017/12/15 until 2018/01/15. Based on the White Paper one may conclude that primary activity was Etherum mining. The White Paper described it as so called smart mining operations approach. This means that the company was prepared to flexibly switch from mining one cryptocoin to another. The operation has been performing only for a few months up to date, nevertheless the most objective conclusions about its profitability can be drawn from Envion ICO quotes. Figure 1 presents quotation from HitBTC exchange.

Based on the real valuation of the ICO one may conclude that prospects of this mining activity may not match the initial ICO valuation. Since the first day of trading Envion has lost about 86% of the ICO nominal price of the token (as of 2018/07/25).

Figure 1: Envion token price in USD.



ii. Ambit, 2018

The other newly established mining company, financed via ICO in June 2018, is Ambit with headquarters in Georgia. No detailed public data is available for this company except for the fact that fundraising is closed. Price of the token was defined at 0.5 USD and 88m tokens were planned to be sold. Final fundraising has been closed with 4m USD (https://icobench.com/ico/ambit as of 2018/07/25). The company promised very high profits, exceeding 86% annually (https://ambitmining.io/ as of 2018/07/23) but unfortunately we do not have any detailed information about current ICO quotes nor revenues of the company from mining.

iii. Veritas and Xenium, 2018

The other ICO funded mining companies are Veritas Mining and Xenium, both related to each other, that issued respectively VRTM and XENM tokens (https://www.veritasmining.co/ as of 2018/07/21). We are not able to evaluate the evolution of tokens prices as one of them is not listed as of research date and the quotations of the second one have hardly any liquidity.

iv. Other ICO

There are other cases of mining ICO currently gathering funds but taking into account their initial fundraising stage we are not able to describe them.

2.3 Other mining activities, non ICO-financed

There are also several other companies, non ICO-financed, that are oriented on mining activities. They are financed in more traditional way and usually traded on stock exchanges. Five examples of such companies are presented below with the evolution of their shares' prices (Figures 2 - 6).

i. 360 Blockchain (CSE:CODE). The company is traded on Canadian Securities Exchange. Current share price is at the level of 0.065 CAD (data as of 2018/07/25).

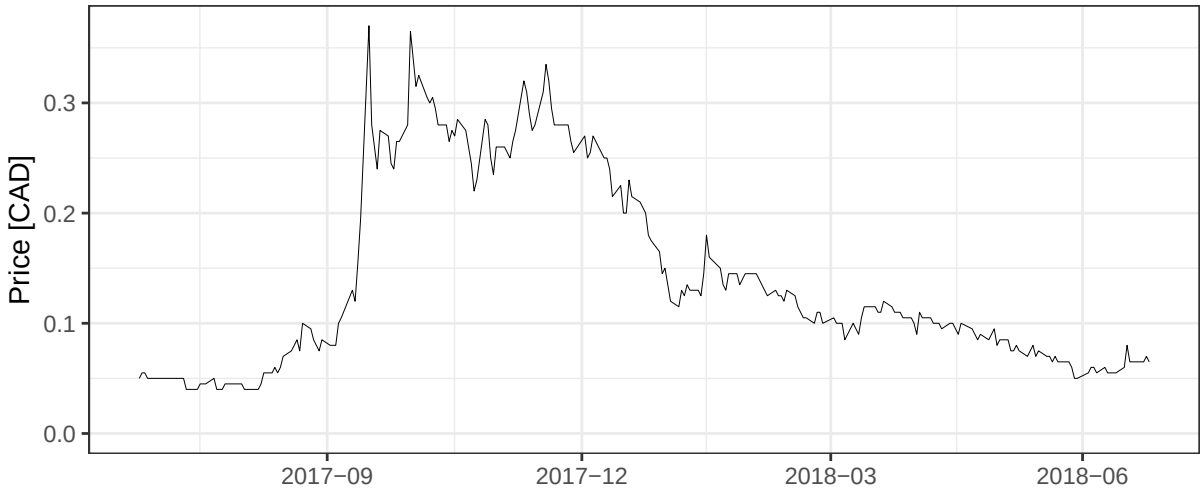
ii. DMG Blockchain (TSXV:DMGI). The company is traded on Toronto Stock Exchange. Current share price is at the level of 0.405 CAD (data as of 2018/07/25).

iii. HashChain Technology (TSXV:KASH). The company is traded on Toronto Stock Exchange. Current share price is at the level of 0.1247 USD (data as of 2018/07/25).

iv. HIVE Blockchain (TSXV:HIVE). The company is traded on Toronto Stock Exchange. Current share price is at the level of 0.73 USD (data as of 2018/07/25).

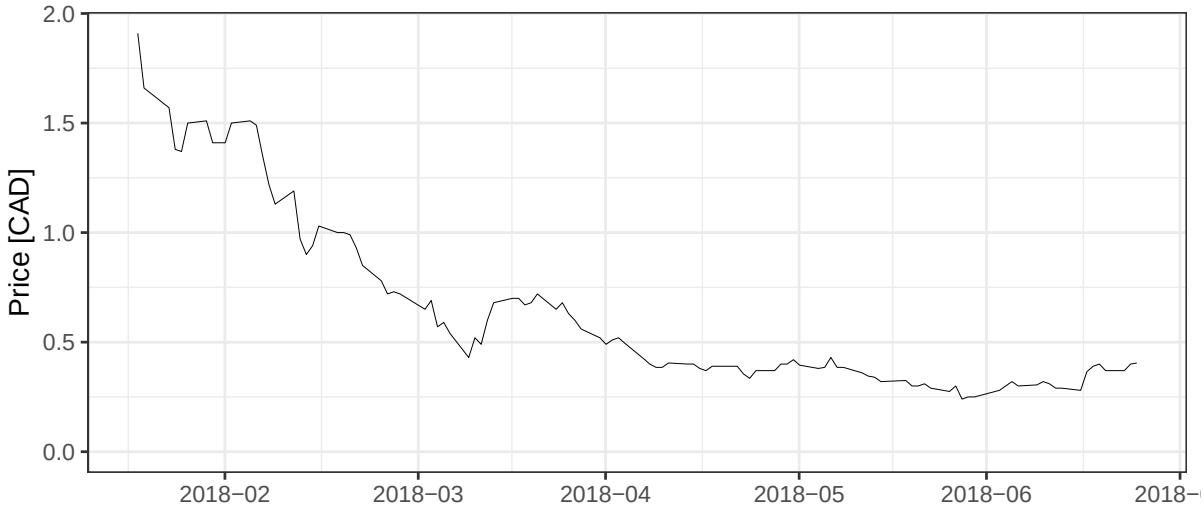
v. Neptune Dash (TSXV: DASH). The company is traded on Toronto Stock Exchange. Current share price is at the level of 0.18 CAD (data as of 2018/07/25).

Figure 2: The daily fluctuations of 360 Blockchain prices on CSE.



Source: https://finance.yahoo.com/quote/CODE.CN/history?period1=1469829600&period2=1532901600& interval=1d&filte r=history&frequency=1d (downloaded at 2018/07/30)

Figure 3: The daily fluctuations of DMG Blockchain prices on TSE.



Source: https://finance.yahoo.com/quote/DMGI.V/history?p=DMGI.V (downloaded at 2018/07/30)

vi. Argo Blockchain. An interesting initiative in the industry is created by the company Argo Blockchain (https://www.argomining.co). Their aim is to create an opportunity to invest in the cryptocurrency mining via the so-called "mining-as-a-service" (MaaS). Argo Blockchain planned to raise £ 20 m during the IPO in London Stock Exchange. If it manages to succeed it will be probably the first purely crypto-mining company listed on LSE.

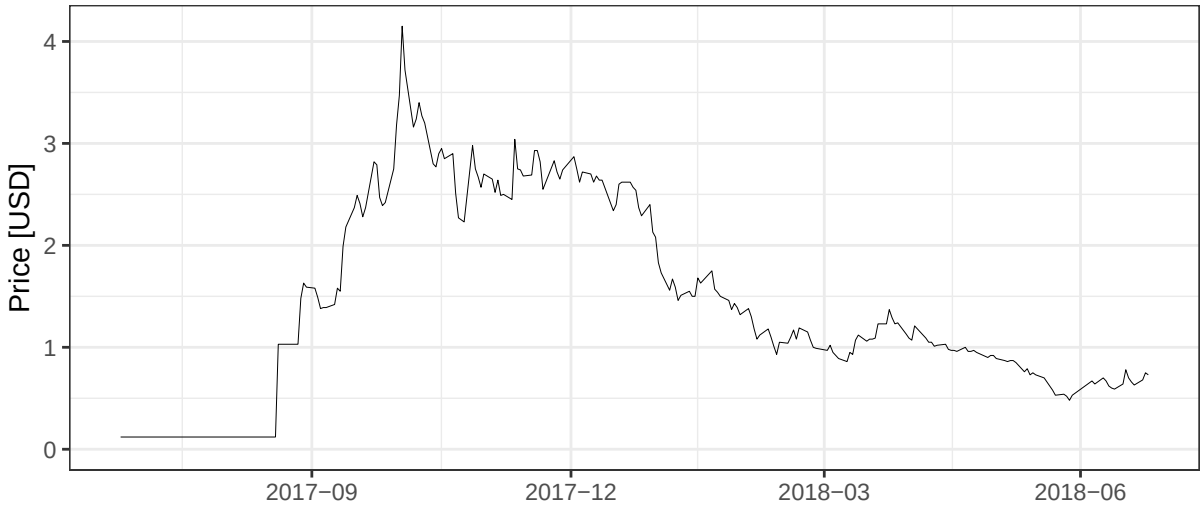
vii. Apart from the ICO founded mining companies and stock exchange trading ones, there are several other forms of attracting capital to the mining industry, including a particularly intresting one heading from Poland. The 'Pracownia Finansowa sp. z o.o.' via one of its daughter companies 'Pracownia Nowych Technologii sp. z o.o.' collects capital via limited partnership company structure where investors play a limited partner role. The company states that currently, cryptocurrencies mining is one of the most profitable and fastest growing businesses (https://www.pnt24.pl/oferta/inwestycja-w-kopalnie-btceth/ as of 2018-07-21). It also presents that the mining profitability ranges from 50% to 150% annually so far (https://www.pnt24.pl/oferta/inwestycja-w-kopalnie-btceth/ as of 2018-07-21) what in case of BTC mining is in strict contradiction with our main results showing that currently mining is not profitable.

Figure 4: The daily fluctuations of HashChain Technology prices on TSE.



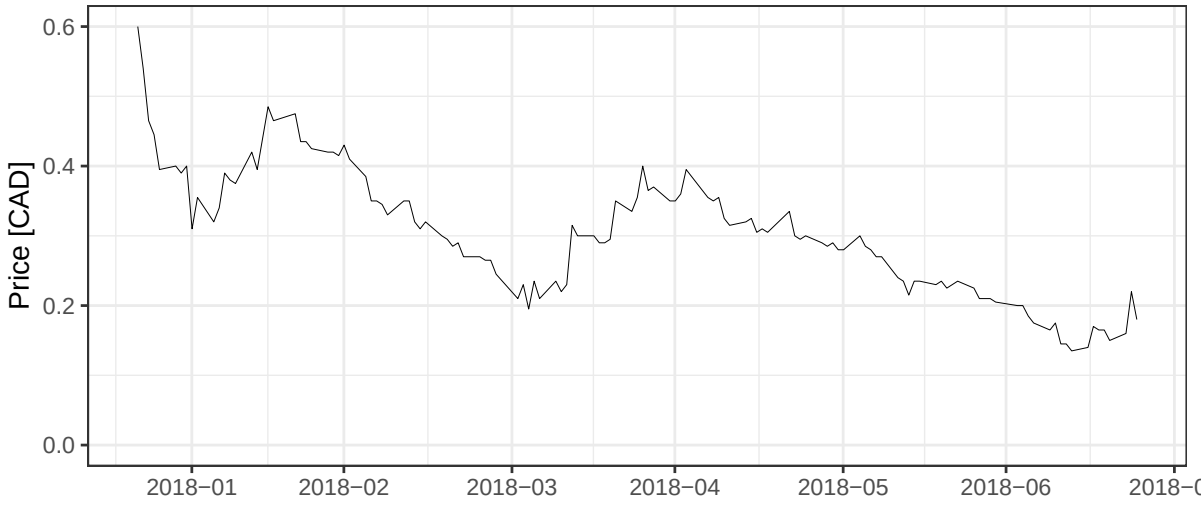
Source: https://finance.yahoo.com/quote/HSSHF/history?p=HSSHF&.tsrc=fin−srch−v1 (downloaded at 2018/07/30)

Figure 5: The daily fluctuations of HIVE Blockchain prices on TSE.



Source: https://finance.yahoo.com/quote/HVBTF/history?p=HVBTF&.tsrc=fin−srch−v1 (downloaded at 2018/07/30)

Figure 6: The daily fluctuations of Neptune Dash prices on TSE.



Source: https://finance.yahoo.com/quote/DASH.V/history?p=DASH.V&.tsrc=fin−srch−v1 (downloaded at 2018/07/30)

3 Crucial assumptions and data

Our methodology is based on thorough efficiency analysis and takes into account current conditions of BTC mining (as of 2018/07/25) in the main worldwide jurisdiction. In order to perform such analysis we have to make the following assumptions about our crucial parameters and clearly state our sources. The following analysis covers all this information.

3.1 BTC network hash rate

The monthly change of BTC network hash rate in the future will be on the level of its historical trajectory. In practice we assume one year average of monthly BTC hash rate change (1Y avg of monthly BTC hash rate change%).

Data source: https://api.blockchain.info/charts/hash-rate?format=csv (downloaded at 2018/07/25).

3.2 BTC network difficulty

BTC network difficulty is strictly connected with BTC network hash rate according to the following formula:

$$D = \frac{T \cdot HR}{2^{32}} \tag{1}$$

where: D - stands for BTC network difficulty, T - stands for the time of block mining, which is set to be about 10 minutes according to BTC white paper[4], HR - means BTC network hash rate.

Short-term departures from this equilibrium cause that difficulty of BTC network is adjusted in such a way that the required time of mining a single block will last the mandatory 10 minutes once again. The adjustment is made every 2016 blocks[5].

Data source: https://coinmetrics.io/data/btc.csv (downloaded at 2018/07/25).

3.3 The mining machine - Antminer S9

We assumed that Antminer S9 produced by Bitmain (https://www.bitmain.com/) is currently the most efficient and widely used BTC mining machine. We take into account the combination of its price, amortization period, hash rate and energy consumption. We would like to stress that it does not mean that there are no other mining machines[6] with similar cost/energy/hash rate efficiency profile, we have just picked the most popular one in our view.

i. Price + Taxes + Shipment costs

- The price of Antminer S9 is assumed on the level of 564 USD (https://bitmain.com/ as of 2018/07/25).
- PSU (power supply unit) is assumed on the level of 90 USD (https://bitmain.com/ as of 2018/07/25).
- Necessary taxes or shipment costs increasing the price of single mining machine (e.g. VAT, etc.) are assumed on the level of: 23%.

ii. Amortization

Amortization period was assumed on the level of 12 months. We are aware of the fact that in some cases when technological advancements occurs faster the amortization period could be shorter. Taking into account that during the last year there was no revolutionary change within the spectrum

[4] https://bitcoin.org/bitcoin.pdf as of date 2018/07/25

[5] https://en.bitcoin.it/wiki/Difficulty as of date 2018/07/25

[6] https://news.bitcoin.com/innosilicons-t2-turbo-bitcoin-miner-is-powerful-but-gmos-b3-is-still-the-champ/ as of date 2018/07/25

of the most efficient mining machines, we decided to keep 12 months to fix the attention as it is sufficiently precise assumption for purpose of this research.

The other approach to amortization period is to make this period conditional on the time which passes until the moment our mining machine will not be able to cover the sum of its monthly energy expenses and maintenance costs. The detailed analysis of this feature will be presented in the Results section (Section 5).

iii. Hash rate

Hash rate of Antminer S9, according to its producer, is 14 TH/s (https://shop.bitmain.com/product/detail?pid=00020180723150459602cN7UjRMv06B3 as of 2018/07/25) but based on the website reviews (https://99bitcoins.com/antminer-s9-review/ as of date 2017-07-25) its hash rate is not higher than 13 TH/s so we decided to assume this value for the calculation purposes on the level of 13 TH/s.

iv. Energy consumption

Power consumption of single mining machine is 1293 W per hour (https://shop.bitmain.com/product/detail?pid=00020180723150459602cN7UjRMv06B3 as of 2018/07/25)

3.4 Unit energy price

The average price of energy per kWh for institutional investor in the most common jurisdiction, i.e. China is 0.09 USD. Additionally, we take into account three other levels of unit energy costs: US (0.21), Poland (0.17) and minimum available (0.03).

Data source: https://www.statista.com/statistics/263492/electricity-prices-in-selected-countries/ (downloaded at 2018/07/25).

3.5 Maintenance cost

We assumed that maintenance should cover all costs connected to operational and logistic issues, e.g. paying rental, setting up the machine, its everyday maintenance and especially all periods when it is stopped due to hardware failures, overheating etc. The key component affecting this cost category are periods of downtime of our mining machine, therefore this cost is expressed as a percentage of the value of BTC mined per year. This cost was assumed on the level of 25% of the value of BTC mined per year (the amortization period).

3.6 BTCUSD price

In the base case scenario we assumed the price of 8379.66 USD for 1 BTC (https://coinmetrics.io/data/btc.csv as of 2018/07/25).

3.7 BTC transactions per day

This variable refers to the number of all BTC transactions which occured in all blocks during that day.

Data source: https://coinmetrics.io/data/btc.csv (downloaded at 2018/07/25).

3.8 BTC mined per day

This variable refers to the number of new coins that have been brought into existence on that day.

Data source: https://coinmetrics.io/data/btc.csv (downloaded at 2018/07/25).

3.9 BTC transaction fees per day

This variable refers to the value of all BTC fees paid in the network on the given day.

Data source: https://coinmetrics.io/data/btc.csv (downloaded at 2018/07/25).

3.10 BTC blocks per day

This variable refers to the number of blocks which were mined per day.

Data source: https://coinmetrics.io/data/btc.csv (downloaded at 2018/07/25).

3.11 Theoretical BTC blocks mined per hour

Based on the seminal paper of Nakamoto (2008) we assume that blocks are mined every 10 minutes what means that there are 6 blocks per hour.

3.12 Sensitivity analysis.

The evolution of mining profitability with regards to given factor or factors is presented and analysed ceteris paribus all other factors.

3.13 Break even analysis

We made the same assumption as in the sensitivity analysis section.

3.14 Additional variables

Based on the raw data described above we created the following new variables:

i. Monthly BTC hash rate change%

$$\text{Monthly BTC hash rate change\%} = \frac{\text{BTC network hash rate on the day } t}{\text{BTC network hash rate on the day } t-31} - 1 \tag{2}$$

ii. Monthly BTC difficulty change%

$$\text{Monthly BTC difficulty change\%} = \frac{\text{BTC network difficulty on the day } t}{\text{BTC network difficulty on the day } t-31} - 1 \tag{3}$$

iii. BTC transactions per block

$$\text{BTC transactions per block} = \frac{\text{BTC transactions per day}}{\text{BTC blocks per day}} \tag{4}$$

iv. Fees% - daily fees as % of daily block rewards.

$$\text{Fees\%} = \frac{\text{BTC transaction fees per day}}{\text{BTC mined per day}} \tag{5}$$

Table 1 presents the main descriptive statistics of our data downloaded in the form of time series. All our crucial assumptions set in order to present the final calculations can be found in Table 2 in Methodology section (Section 4).

As presented in Table 1, the maximum observable BTCUSD level was 19475.8. Average monthly BTC hash rate change% is at the level of 19.46% and 12.75% respectively for the last year and the last quarter. The shorter average shows lower values, however one should remember that the shorter the average period the more volatile is the variable. Nevertheless, this lower value of BTC monthly hash rate change% may be regarded as a sign of the fact that mining is less attractive after substantial decline of BTCUSD price.

Table 1: Descriptive statistics of the main important data.

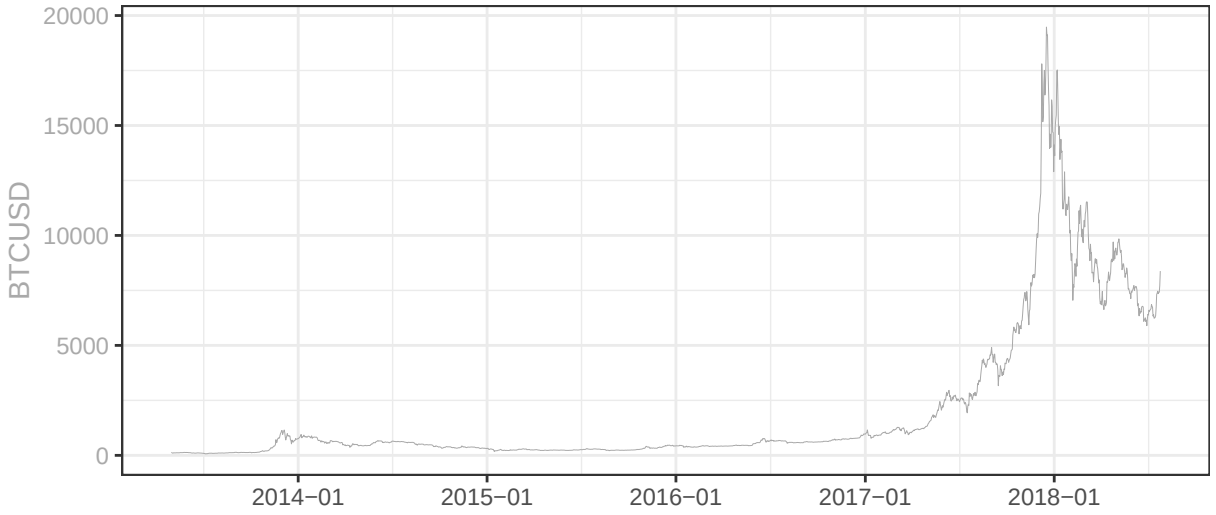
	BTCUSD	BTC network hash rate [TH/s]	Monthly BTC hash rate change%	BTC network difficulty	BTC mined per day [BTC]	BTC blocks per day	BTC transaction fees per day [BTC]	BTC transactions per block	Fees%
min	68.50	70.63	-37.36	1.01e+07	1000.00	80.00	8.05	162.20	0.18
Iq	291.29	186688.68	4.67	2.38e+10	1962.50	144.00	15.72	462.54	0.43
avg	2013.07	4670865.29	28.09	6.14e+11	3175.56	156.75	87.41	1075.85	4.17
median	576.00	654995.57	18.48	7.91e+10	3525.00	154.50	34.28	1062.30	1.01
IIIq	1187.93	3655114.73	39.62	5.00e+11	4025.00	168.00	80.77	1572.57	4.18
max	19475.80	46852830.60	244.76	5.36e+12	6500.00	260.00	1495.95	2721.62	77.21
standard deviation	3370.20	9055846.29	36.07	1.19e+12	1102.91	19.52	137.35	619.02	7.50
last year average	8106.64	20104609.83	19.46	2.64e+12	1921.39	153.72	195.65	1588.99	10.35
last quarter average	7534.62	35313358.10	12.75	4.69e+12	1889.90	151.20	31.12	1321.11	1.66

Note: Time period for this data is between 2013/05/01 and 2018/07/25.

The average number of BTC mined per day reached 1921.39 and 1889.9 for the last quarter and the last year respectively. Theoretically there should be 1800 BTC generated as a block reward. The gap between theoretical and realized values is produced by the fact that hash rate increase is close to continuous process while difficulty adjustment is strictly discrete process. Therefore, there is a lag between real time period between consecutive blocks confirmation and difficulty target adjustment.

In the remaining part of this section, graphical fluctuations of our main time series are presented in order to show main trends in our data and their dynamics.

Figure 7: BTCUSD historical prices.

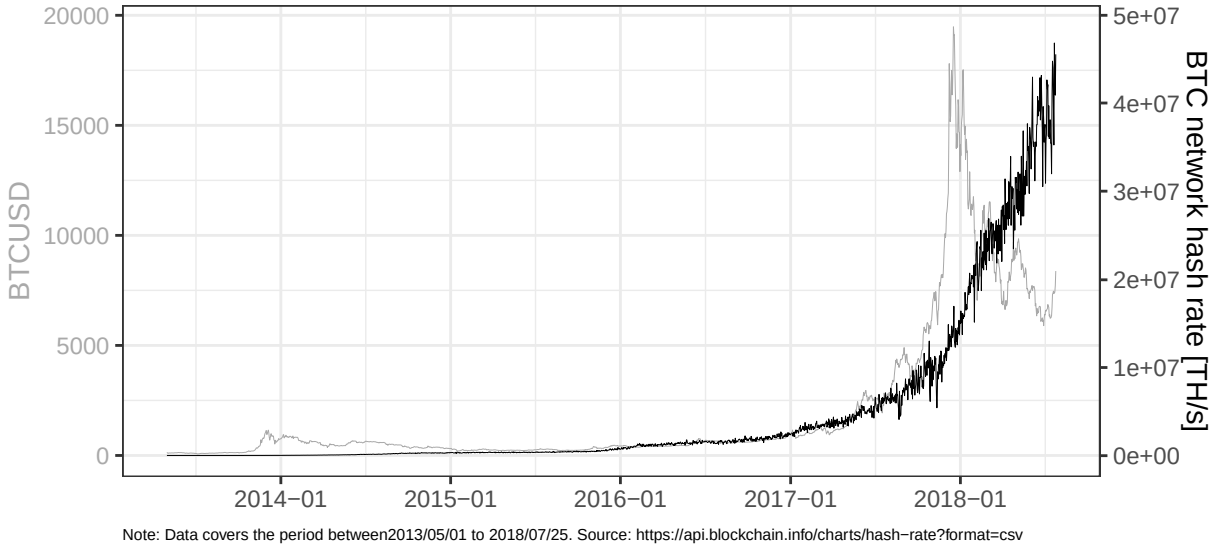


Note: Data covers the period between2013/05/01 to 2018/07/25. Source: https://coinmetrics.io/data/btc.csv

As can be seen in Figure 7 BTCUSD price remained below 1000 USD until the end of 2016 with very volatile period in the late 2013 and early 2014. The cryptocurrency gained on popularity in the late 2016 and strong increasing trend started in 2017. The late 2017 was characterised by enormous hype on BTC which lifted its price to the level of 20000 USD. Since beginning of 2018 there was a significant correction of upward trend but BTC did not go below 10000 USD until March 2018. The 2017/2018 peak is by some researchers attributed to the introduction of futures on BTC/USD on CBOE and CME (Hale et al. 2018) and entering the market by at least some institutional investors. However, in our opinion, the main and quite obvious reason for market correction observed in the first half of 2018 was normal adjustment of prices after abnormal departure from long-term trend, characterized by very volatile turmoils.

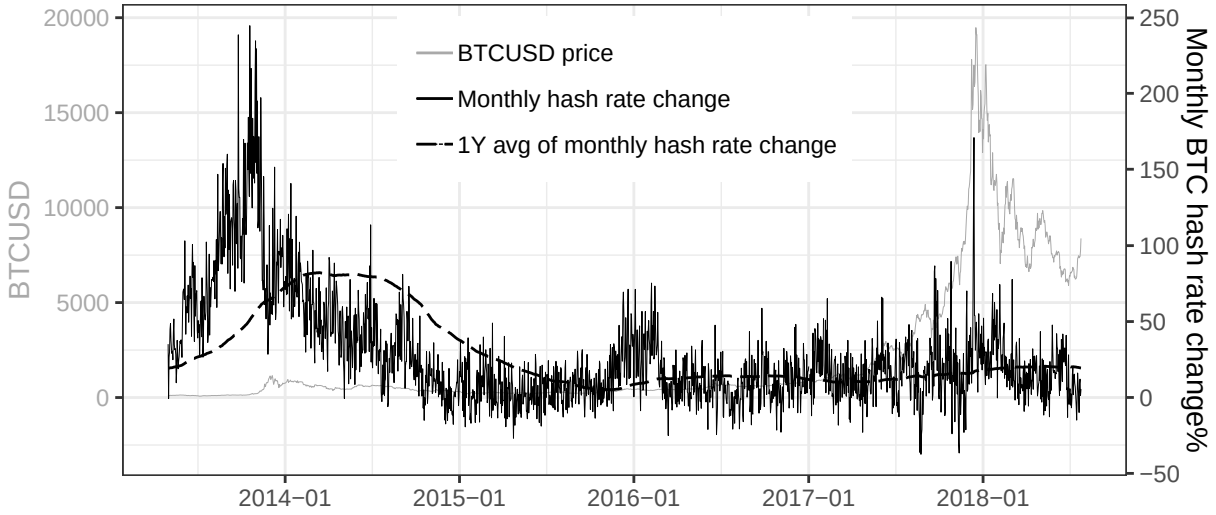
Figure 8 shows that BTC network hash rate has been in increasing trend almost all the time. Some exceptional periods with decreasing hash rate occurred historically, when BTC market was less mature e.g. August 2011 till October 2012. In the most recent history of BTC, i.e. since 2014, network hash rate developed close to exponentially. One can observe this phenomenon when plotting the hash rate with logarithmic scale.

Figure 8: BTC network hash rate.



Note: Data covers the period between2013/05/01 to 2018/07/25. Source: https://api.blockchain.info/charts/hash−rate?format=csv

Figure 9: Monthly BTC hash rate change% and 1Y average of these changes.



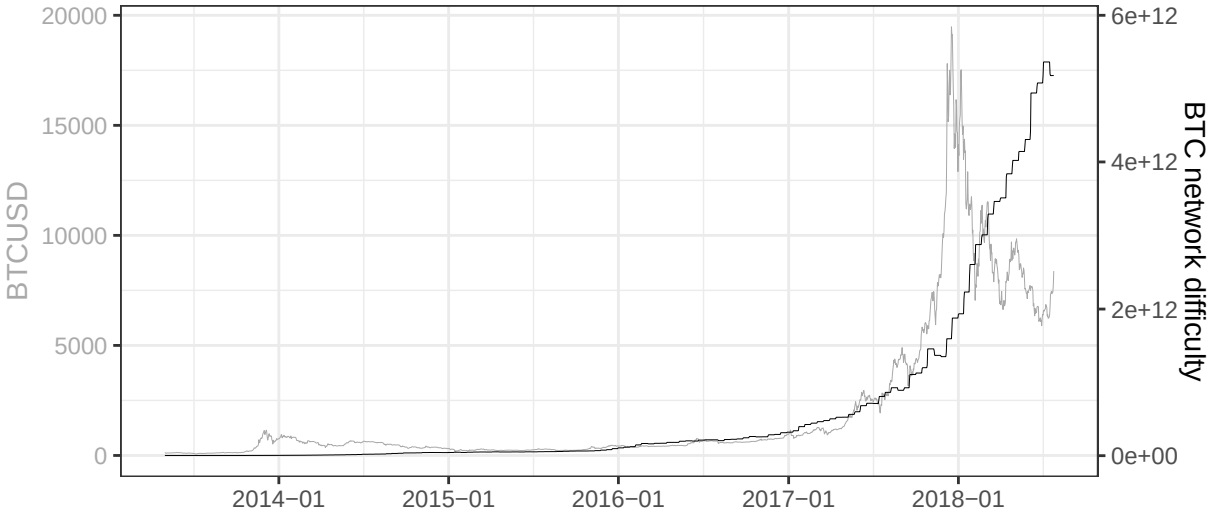
Note: Data covers the period between2013/05/01 to 2018/07/25. Source: https://api.blockchain.info/charts/hash−rate?format=csv

The long term increase in BTC network hash rate is confirmed by the analysis of monthly BTC hash rate change (calculated according to formula 2) which oscillates around 19% for the last year. In order to analyse long term trends the 1 year average of monthly BTC hash rate change% (later on referred to as 1Y avg of monthly BTC hash rate change%) was plotted alongside monthly BTC hash rate change% in Figure 9. The stability of this smoothed variable in the recent period confirms rationality of our assumptions of the future BTC network hash rate evolution for the purpose of mining profitability model presented in the further section.

Network difficulty presented in Figure 10 follows BTC network hash rate since there is linear relation between these two factors presented in the formula 1. The difficulty is periodically adjusted (every 2016 blocks) according to the real hash rate evolution in order to assure predefined intervals between confirmation of consecutive BTC blocks (10 minutes). Figure 8 and 10 can be treated as a depiction of the second research question stated at the beginning (Q2): *Is there strong positive relation between BTCUSD price and difficulty/hash rate of BTC network?* We can observe that such positive relation does not exist. This conclusion is based on two observations:

- There are almost no any downward movements in BTC difficulty or hash rate in the recent period, i.e. we observe very strong upward movements with quite rare corrections, no matter what happens on BTCUSD price,

Figure 10: BTC network difficulty.

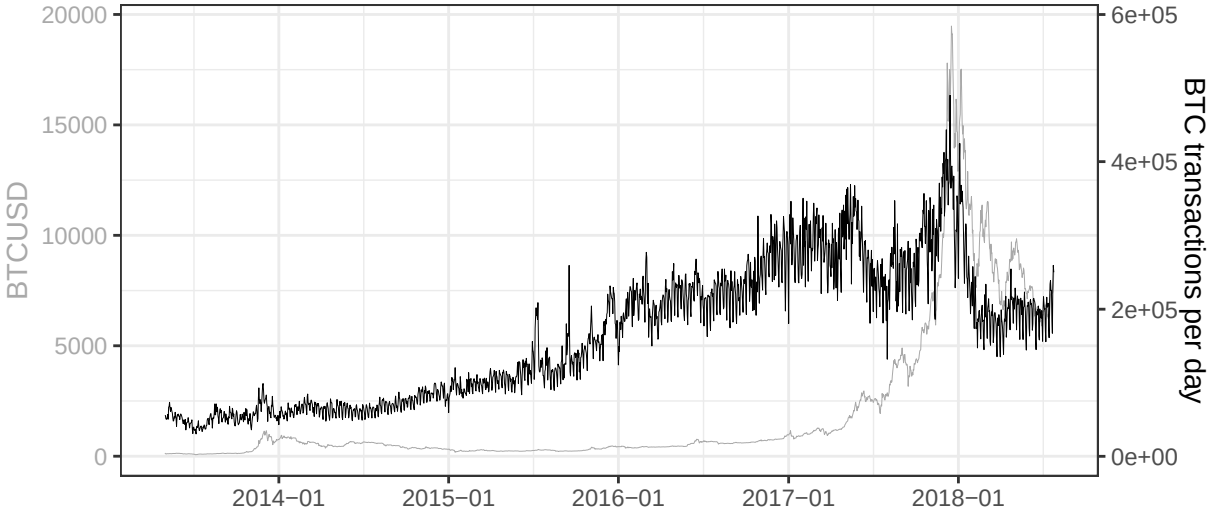


Note: Data covers the period between2013/05/01 to 2018/07/25. Source: https://coinmetrics.io/data/btc.csv

- A detailed analysis of very strong downward movements on BTCUSD price (2014 year and then first half of 2018) and both BTC network difficulty and hash rate shows that difficulty and hash rate grow significantly no matter what happens with BTCUSD price.

More formal analysis for this research question will be presented in Main results section (Section 5).

Figure 11: BTC transactions per day.



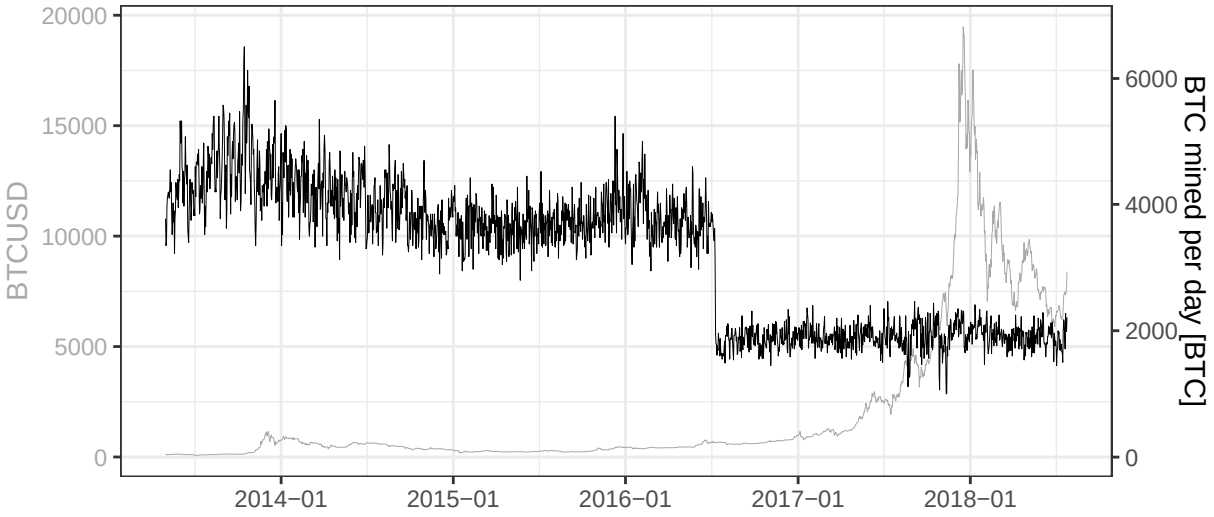
Note: Data covers the period between2013/05/01 to 2018/07/25. Source: https://coinmetrics.io/data/btc.csv

As seen in Figure 11, the number of transactions per day was increasing until mid 2017. After a short period of decline in mid 2017 it reached its high in the late 2017 to go down in December 2017 and January 2018. However the number of transaction could be biased in BTC network due to the fact that part of the payments are batched into combined transactions. The batch process is used mainly by industrial players like exchanges, mixers, payments processors and mining pools[7]. Nevertheless our profitability analysis is not affected by this fact since we base it on the transaction fee generated on daily basis rather than on number of transactions.

Number of daily mined BTC is presented in Figure 12. The values on the chart follows a rule embedded in the mining algorithm saying how many BTC coins are created once the block is confirmed and how often should it happen (apx. every 10 minutes). Since 2016/07/09 the block reward is 12.5 BTC while prior to this date the reward was 25 BTC. Reward halving happens roughly every 4 years (more precisely

[7]https://coinmetrics.io/batching/

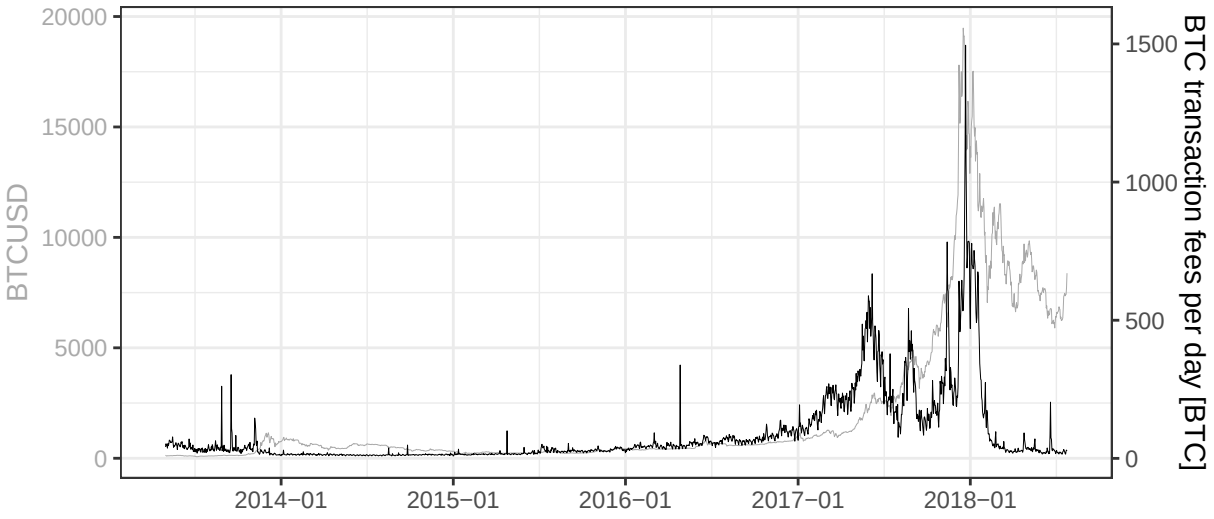
Figure 12: BTC mined per day



Note: Data covers the period between2013/05/01 to 2018/07/25. Source: https://coinmetrics.io/data/btc.csv

every 210.000 blocks) and the next one (to 6.25 BTC) is going to be in May, 2020[8]. Current theoretical BTC mined per day should be 1800 BTC ($=6 \cdot 24 \cdot 12.5$ BTC) but in practice it is slightly higher number (about 1920 BTC), because BTC network difficulty change is slower (every 2016 blocks) than BTC hash rate change (immediately after plugging in of new mining machine)[9].

Figure 13: BTC transaction fees per day



Note: Data covers the period between2013/05/01 to 2018/07/25. Source: https://coinmetrics.io/data/btc.csv

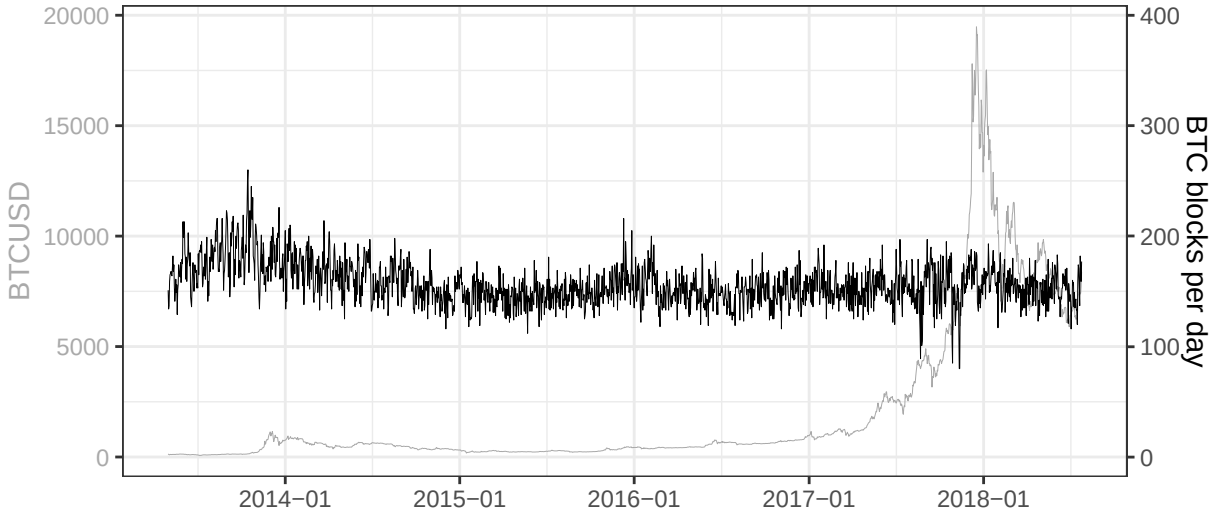
Figure 13 shows that the level of BTC transaction fees per day is characterized by high volatility, especially during 2017 and early 2018. The last surge in the transaction fees corresponds to the soaring prices and huge volatility of BTC and then steep decline of its price. The most recent values remain, for the last several months, on relatively low level.

Number of blocks confirmed every day is determined by the mining algorithm which says that, on average, a block should be confirmed every 10 minutes resulting with a theoretical value of ca. 144 blocks per day ($= 6 \cdot 24$). This interval may diverge from the target in the short period (see Figure 14) hence the network difficulty adjustment is performed to assure convergence to the target in the longer term period. This phenomenon is explained in more details in paragraph above describing Figure 12.

For the purpose of mining profitability calculation we decided to use BTC transaction fees presented as a

[8]https://www.bitcoinblockhalf.com/
[9]https://coinmetrics.io/on-data-and-certainty/

Figure 14: BTC blocks per day



Note: Data covers the period between2013/05/01 to 2018/07/25. Source: https://coinmetrics.io/data/btc.csv

Figure 15: Fees% and 1Y average of Fees%.



Note: Data covers the period between2013/05/01 to 2018/07/25. Source: https://coinmetrics.io/data/btc.csv

% of mined BTC coming from block reward for confirmation process (according to formula 5, referred further as Fees%). As one can observe in Figure 15 Fees% are highly volatile. The one year average of this ratio (referred further as 1Y avg of Fees%) is presented in Figure 15 as well. The current level of the average was taken as a current base case scenario for the further analysis of BTC mining profitability. This is rather conservative approach and may lead to the slight overestimation of the mining profitability when comparing to the actual market state, but we are aware of that fact.

The charts presented above gave us ability to rethink the most appropriate methodology for the purpose of this study and set the adequate values of our variables for the base case scenario.

4 Methodology

4.1 Model description

BTC mining profitability is calculated based on the following equation:

$$\text{BTC mining profitability} = \text{PnL\%} = \frac{\text{Amount earned} - \text{Amount invested}}{\text{Amount invested}}, \tag{6}$$

where:

$$\begin{aligned}\text{Amount earned [USD]} = {} & \text{Value of BTC mined per year [USD]} \\ & + \text{Transaction fees received per year [USD]} \\ & + \text{Residual value of hardware after one year [USD]},\end{aligned} \tag{7}$$

$$\begin{aligned}\text{Amount invested [USD]} = {} & \text{Energy cost per year [USD]} + \text{Hardware cost [USD]} \\ & + \text{Maintenance cost per year [USD]},\end{aligned} \tag{8}$$

$$\begin{aligned}\text{Value of BTC mined per year [USD]} = {} & \text{BTCUSD} \cdot \frac{\text{Theoretical BTC mined per year}}{12} \\ & \cdot \frac{\text{Hardware hash rate}}{\text{BTC network hash rate}} \cdot \frac{1 - \left(\frac{1}{1+d}\right)^{12}}{1 - \frac{1}{1+d}},\end{aligned} \tag{9}$$

and

$$d = \text{1Y avg of monthly BTC hash rate change\%}, \tag{10}$$

$$\begin{aligned}\text{Theoretical BTC mined per year} = {} & \text{Theoretical BTC blocks mined per hour} \\ & \cdot \text{BTC block reward} \cdot \text{Days per year} \cdot \text{Hours per day}\end{aligned} \tag{11}$$

$$\begin{aligned}\text{Transaction fees received per year [USD]} = {} & \text{1Y avg of Fees\%} \\ & \cdot \text{Value of BTC mined per year [USD]},\end{aligned} \tag{12}$$

$$\begin{aligned}\text{Residual value of hardware after one year [USD]} = {} & \text{\% of new Hardware cost} \\ & \cdot \text{Hardware cost [USD]},\end{aligned} \tag{13}$$

$$\text{Hardware net price [USD]} = \text{Mining machine net price [USD]} + \text{PSU net price [USD]}, \tag{14}$$

$$\text{\% of new hardware cost} = \frac{\text{estimated Hardware cost after 12 months}}{\text{current Hardware cost}} = \left(\frac{1}{1+d}\right)^{12}, \tag{15}$$

$$\begin{aligned}\text{Energy cost per year} = {} & \frac{\text{Hardware power consumption [W]}}{1000} \cdot \text{Unit energy price [USD/kWh]} \\ & \cdot \text{Days per year} \cdot \text{Hours per day},\end{aligned} \tag{16}$$

$$\text{Hardware cost [USD]} = \text{Hardware net price [USD]} \cdot (1 + \text{Taxes\&Shipment\%}), \tag{17}$$

$$\text{Maintenance cost per year [USD]} = \text{Maintenance ratio\%} \cdot \text{Value of BTC mined per year [USD]}. \tag{18}$$

4.2 Model assumptions

- Assumption 1. BTCUSD price in t months is the same as today.
- Assumption 2. USD energy prices during next t months is the same as today. For the base case scenario we assume China unit energy price.
- Assumption 3. Monthly changes in BTC network hash rate are approximated by their 1Y average.
- Assumption 4. Constant amount of BTC mined monthly by entire BTC network (specifically, halving of BTC block reward not assumed during time considered).
- Assumption 5. Maintenance cost is a fraction of Value of BTC mined per year [USD].
- Assumption 6. Residual value of our mining machine is based on the percentage decrease of monthly BTC mined in each consecutive month. In order to evaluate "% of new Hardware cost" we assumed that Hardware price will diminish according to its shrinking participation in increasing BTC network hash rate, what can be estimated mainly by factor d (1Y avg of monthly BTC hash rate change%) from formula 10.
- Assumption 7. We assume that amortization period for our hardware is 12 months.
- Assumption 8. Changes in Fees% are approximated by their 1Y average.

Table 2: Summary of all our crucial assumptions, types of data and data sources.

Single assumption	unit	Final value	Type of data	Data source
Mining machine net price (Antminer S9)	USD	564	static	https://shop.bitmain.com/
PSU net price	USD	90	static	https://shop.bitmain.com/
Taxes&Shipment%	%	23	static	Internal assumption
Amortization period	months	12	static	Internal assumption
Hardware hash rate (Antminer S9)	TH/s	13	static	https://shop.bitmain.com/ and https://99bitcoins.com/antminer-s9-review/
Hardware power consumption (Antminer S9)	W	1293	static	https://shop.bitmain.com/ and https://99bitcoins.com/antminer-s9-review/
Minimal unit energy price	USD/kWh	0.03	static	other sources[b]
China unit energy price	USD/kWh	0.09[a]	static	https://www.statista.com/statistics/263492/electricity-prices-in-selected-countries
Poland unit energy price	USD/kWh	0.17	static	https://www.statista.com/statistics/263492/electricity-prices-in-selected-countries
US unit energy price	USD/kWh	0.21	static	https://www.statista.com/statistics/263492/electricity-prices-in-selected-countries
Maintenance cost	% of total value of BTC mined per year	25	static	Internal assumption
BTCUSD	USD	8379.66	Time series	https://coinmetrics.io/data/btc.csv
BTC network hash rate	TH/s	4.56e+07	Time series	https://api.blockchain.info/charts/hash-rate?format=csv
1Y avg of monthly BTC hash rate change%	%	19.5	Time series	Own calculations
BTC network difficulty	TH/s	5.18e+12	Time series	https://coinmetrics.io/data/btc.csv
BTC transactions per day	number	250031	Time series	https://coinmetrics.io/data/btc.csv
BTC mined per day	BTC	2212.5	Time series	https://coinmetrics.io/data/btc.csv
BTC transaction fees per day	BTC	26.82	Time series	https://coinmetrics.io/data/btc.csv
BTC blocks per day	number	177	Time series	https://coinmetrics.io/data/btc.csv
Theoretical BTC blocks mined per hour	number	6	static	https://bitcoin.org/bitcoin.pdf
BTC transactions per block	number	1412.6	Time series	Own calculations
Fees%	%	1.2	Time series	Own calculations
1Y avg of Fees%	%	10.3	Time series	Own calculations
BTC block reward	BTC	12.5	static	https://www.blockchain.com
Theoretical BTC mined per year	BTC	657000	static	Own calculations

[a] This is our base case scenario.
[b] We have numerous sources on unit energy prices
https://www.forbes.com/sites/christopherhelman/2018/01/16/bitcoin-mining-uses-as-much-power-as-ireland-and-why-thats-not-a-problem/,
https://cryptocurrencynews.com/daily-news/mining/cheapest-places-mining-bitcoin/,
https://www.howtogeek.com/349033/why-it%E2%80%99s-nearly-impossible-to-make-money-mining-bitcoin/,
https://ca.reuters.com/article/businessNews/idCAKBN1F10BU-OCABS/

4.3 Values of variables as of 2018/07/25

All our assumptions for BTC mining profitability purposes can be found in the Table 2 presented below. The base case scenario in Section 5 will be presented based on this assumption.

5 Main results

In this section we wanted to tackle the base case scenario in which we consider our investment before the hardware is bought (Section 5.1) and the second variant in which we analyse BTC mining investment after all the necessary hardware was bought (Section 5.2). All analyses presented in this paper are based on the same assumptions as in the Section 5.1. Nonetheless, Section 5.2 was added in order to refer to the situation of an investor who is already engaged in BTC mining activity.

5.1 Base case scenario (the consideration before the hardware is bought)

This scenario assumes that we are before the decision whether to start mining operations and we try to consider all possible revenues and costs under current market conditions and make correct decision based on mining profitability.

Our main results show that BTC mining profitability is on the level of -56%, what means that during 12 months we would incur -0.56m USD of loss on each 1m USD invested in BTC mining. It means that referring to our main hypothesis (H1) we can say that BTC mining is not profitable under current market conditions.

What is more important, it could affect the state of BTC blockchain environment as a whole, taking into account that mining activity, as a necessary condition for block confirmation, is an essential part of BTC network. At this point we come to the fifth research question (Q5): *What are the consequences of BTC mining efficiency for future ability of blocks to be mined further?* and we would like to describe some scenarios.

To start with fundamental economic assumption, it is important to notice that the current state, when mining is not profitable, is not sustainable in a long term. Periodical divergence from equilibrium state, defined as a state negligibly close to break even point, may appear especially when the industry is not mature enough. However BTC ecosystem has to revert to the equilibrium if it is going to survive. We present six theoretical scenarios being an attempt to refer to Q5, nevertheless one may imagine a mix of these scenarios pushing BTC mining toward break even point. In scenarios from one to five we assume that BTC network will still exist and be able to evolve, while in the last one we take into account that current mining unprofitability could weaken and destroy the network as a whole.

The first scenario is connected with a sharp increase of BTCUSD triggered by current mining unprofitability. However it may create a simultaneous sociological effect attracting more miners to the network, thus postponing equilibrium further towards higher BTCUSD levels. The miners may decide to undertake currently not profitable mining in a hope of extraordinary BTCUSD increases would make their activity profitable. Assuming that miners behave like "homo oeconomicus" they should turn towards investing in BTCUSD derivatives instead of mining activity if they believe in a substantial growth of BTCUSD.

The second scenario is a substantial increase in the transaction fee level. This is a likely scenario as the reward halving day is due in 2020, and also a case considered by theoreticians and practitioners.

The third theoretical scenario is that a number of miners simply switch off their machines after suffering some losses due to persistent negative profitability (even not enough to cover OPEX), thus BTC network hash rate eventualy drops making mining profitable again. From this point we see two reasonable paths of how the situation develops further in this scenario. The first one assumes that miners may keep the hardware switched off during the period of negative profitability in a hope to switch them on when mining is profitable again. Alternatively, miners may sell the machines and invest the proceeds into BTCUSD derivatives if they still want to keep positive exposure on BTCUSD price.

The fourth scenario assumes that a major breakthrough in the hardware happens, e.g. a new generation of ASICs is introduced into the market. This scenario may change BTC mining landscape in the same way as CPU/GPU and GPU/ASIC migrations had before. Since the energy and hardware prices vary independently, they are not able to bring the industry to the break even point. Therefore, they should coexist with other drivers in a combined scenario.

The fifth scenario covers a change the block confirmation method connected with an enormous limitation of power consumption, i.e. the switch from Proof-of-Work to Proof-of-Stake, what could significantly change the main important conclusions of this analysis.

The sixth scenario is a catastrophic one for BTC network. It deals with a possibility that the mining profitability problems and any potential issues, e.g. with block confirmation, undermine credibility of the whole BTC blockchain and may be a cause of its downfall. We humbly assume this scenario is currently not the most probable one, but nevertheless we have to take it into account.

Table 3: Monthly USD profitability of mining of single Antminer S9 (13 TH/s) with adjustment of difficulty based on 1Y avg monthly BTC hash rate change.

	monthly mining of single Antminer S9 with adjutment of difficulty	USD value of mined BTC per month	USD monthly mining fees	USD energy costs per month	USD mainteanance costs per month	USD monthly profit
1M	0.0156	130.8929	13.5454	84.9501	32.7232	26.7649
2M	0.0131	109.5705	11.3388	84.9501	27.3926	8.5666
3M	0.0109	91.7215	9.4917	84.9501	22.9304	-6.6672
4M	0.0092	76.7801	7.9455	84.9501	19.1950	-19.4195
5M	0.0077	64.2727	6.6512	84.9501	16.0682	-30.0944
6M	0.0064	53.8027	5.5677	84.9501	13.4507	-39.0304
7M	0.0054	45.0382	4.6607	84.9501	11.2596	-46.5107
8M	0.0045	37.7015	3.9015	84.9501	9.4254	-52.7724
9M	0.0038	31.5600	3.2660	84.9501	7.8900	-58.0142
10M	0.0032	26.4189	2.7339	84.9501	6.6047	-62.4020
11M	0.0026	22.1152	2.2886	84.9501	5.5288	-66.0751
12M	0.0022	18.5127	1.9158	84.9501	4.6282	-69.1498
sum	0.0845	708.3869	73.3069	1019.4012	177.0967	-414.8041

Note: Above analysis assumes current mining conditions as of 2018/07/25 summarized in Table 2.

5.2 Base case scenario (the consideration after the hardware is bought)

Before we delve further into the sensitivity analysis of our results we would like to show how long should we mine BTC within our 12 months amortization period taking into account only operational costs (energy and maintenance) – under the assumption that our mining machine was already bought. This analysis assumes that our mining machine was bought in the past and currently we can make the decision to mine or not to mine considering operational expenses (OPEX) and excluding hardware costs (CAPEX). Table 3 shows the numbers for such analysis.

Table 3 and especially Figure 16 clearly show that, even if we do not take into account any hardware cost, after the third month we are not able to cover expenses for energy and maintenance costs because of diminishing monthly number of mined BTC due to the increase of BTC network hash rate.

This is very good place to refer to fourth research question (Q4): *What is the rational level of amortization period for our mining machines?* Based on the analysis of Table 3 and Figure 16 we can say that this period should not be longer that 3 months, i.e. until the moment our mining machine is useless, meaning that we will not even be able to cover OPEX costs. In the real life, if we take into account monthly amortization costs of our mining machine, we will realise that the profit even for the first month is negative. The above mentioned consideration clearly confirms our initial calculations of mining profitability presented in the point a of this section. Therefore, we reach a conclusion that one definetely should not start mining under the current market conditions. Hence, a rational level for the value of the amortization period does not exist in this specific case[10] (see Figure 23).

One can definitely argue that the horizontal trend assumption for future BTCUSD price or our assumptions concerning monthly change of BTC network hash rate are too rigorous or even arbitrary. Therefore, to address such a potential discussion, we present a very detailed and rigid description of these assumptions in sections 4 and 5 referring to current market conditions in order to avoid possible allegations concerning these issues.

5.3 Other research questions

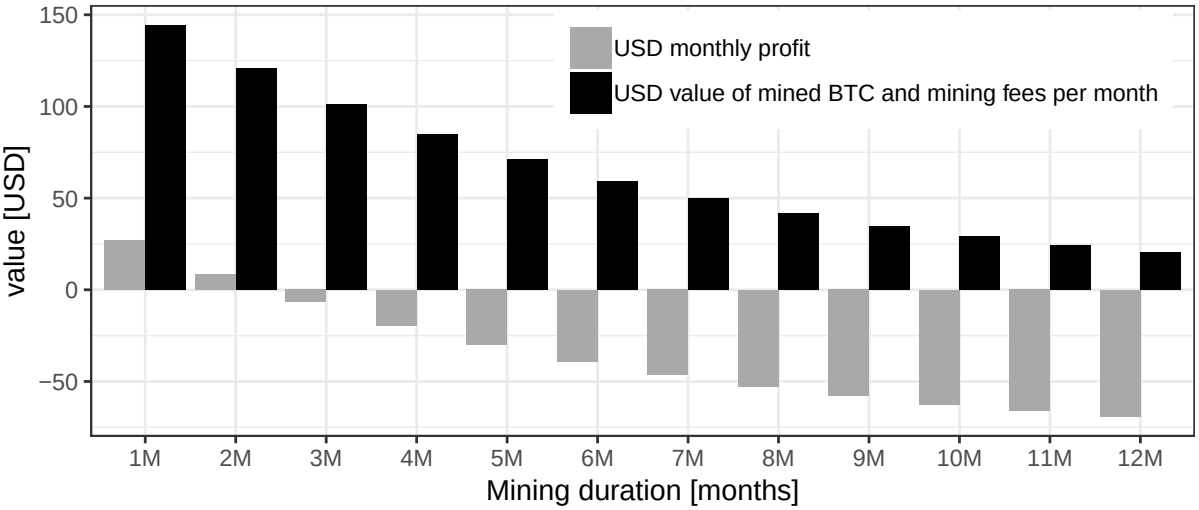
i. Q1: What is the sensitivity of BTC mining profitability to initial assumptions and future trajectories of main parameters? → we address this question in the Sensitivity analysis section.

ii. Q2: Is there strong positive relation between BTCUSD price and difficulty/hash rate of BTC network?

This question was already partially addressed in the third section. Nevertheless, below we try to present a more formal analysis based on the time series of BTCUSD and BTC network difficulty/hash

[10] We have to take in mind that in order to present any calculations concerning profitability we have to assume some level of amortization period. We decided to set it to 12 months but our results clearly show that the length of amortization period is strictly negatively correlated with %profitability of mining and that its optimal level should be set to zero, i.e. no mining activity should be undertaken, as is shown on Figure 23.

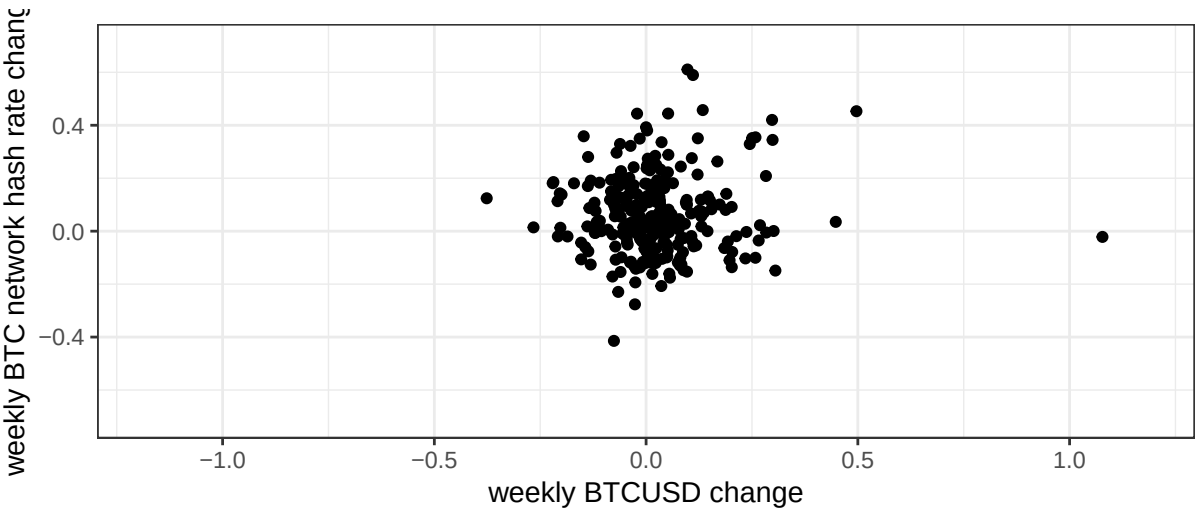
Figure 16: The profitability of mining in USD.



Note: Above analysis assumes current mining conditions as of 2018/07/25.

rate to gauge a potential relation between BTCUSD price and difficulty/hash rate of BTC network. As both the variables are nonstationary, we take 7 days returns in the historical values which allows us to calculate Pearson's correlation coefficient. The results does not confirm any relation between BTCUSD price and hash rate of BTC network. Pearson's coefficients are at the level of -0.06, 0.14 and -0.31 for the periods: 2013/05/01-2018/07/25, last 12 months, and whole 2018, respectively. Moreover, no visible correlation can be seen on Figure 17 which presents weekly BTCUSD change vs weekly BTC network hash rate change. Therefore, we can not confirm that there is any strong positive relation between BTCUSD price and difficulty/hash rate of BTC network.

Figure 17: Weekly BTCUSD change vs weekly BTC network hash rate change.



Note: Data covers the period between2013/05/01 to 2018/07/25. Own calculation based on the data from: https://coinmetrics.io/data/btc.csv, https://api.blockchain.info/charts/hash−rate?format=csv

iii. Q3: What are the breakeven levels of the main BTC mining parameters in order to make this activity profitable? → we refer to this question in details in the Breakeven section (Section 7).

iv. Q4. What is the rational level of amortization period for our mining machines? → we refer to this question in details in the Main results section in point 5.2.

v. Q5: What are the consequences of BTC mining efficiency for future ability of blocks to be mined further? → we refer to this question in details in the Main results section in point 5.1.

vi. Q6: Can we expect that blocks will not be confirmed if the efficiency of BTC mining is negative for an extended period of time?

This is one of the most important questions in this paper because this issue affects not only single mining endeavours but can influence the probability of BTC network to work properly as a whole. The answer is NO, at least for a longer period of time. Blocks will be mined unless there is trust in BTC blockchain protocol, regardless of BTCUSD price and other variables. BTC ecosystem has a feature to adjust itself accordingly to the observed parameters. Let us rephrase situation elaborated in a possible scenarios evolution. The long period of negative mining profitability motivates part of the miners to disconnect from the network thus pushing network hash rate down until the mining is profitable again. In such a situation there is a special case when blocks can be mined during much longer period of time especially if more miners would decide to stop mining at the same time. Nevertheless it will last only until next difficulty adjustment so not longer than until next 2016 blocks will be mined.

Another potential consequence is that a lower hash rate may make it easier for entities with a plenty of spare mining capacity to attack the network. However, we believe that BTC network at its current state of development limits substantially the probability of such an event.

vii. Q7: Should we invest in BTC mining if we expect very strong growth of BTC price?

The answer is quite straightforward: NO. If one expects BTC price to increase, they should rather invest directly in BTC spot or through BTC derivatives in order to capitalize on their predictions. Here we can provide a very simple analogy of BTC mining and GOLD mining. Should we really invest in gold mining embracing all potential equipment and operational issues if we think that price of gold will go up? Probably we would have higher operating leverage from such investment in comparison to direct investment in gold, but all the risks connected with setting up such activity would affect heavily our final profitability.

viii. Q8. Is it possible that technological advancements in the ASICs performance would change BTC mining landscape and make mining profitable?

All kinds of technical advancements, especially these focused on improving the hardware performance, could change the landscape of BTC mining industry. Breakthroughs in the efficiency, e.g. a new generation of ASICs, could make a difference, but the scale and direction of the change will definetely depend on the market price of new hardware. Should a new machine boost the profitability of the mining, then its price should be economically justified by the business models in the mining industry. Another thing is that technological improvements would probably once again push BTC network hash rate upward again and in spite of much higher efficiency of a single machine, nothing would change for the network as a whole.

ix. Q9: What kind of new financial instruments may stimulate BTC mining industry?

Cnalyzing the cost and revenue sources in mining industry on may conclude that part of the cost factors has its own, relatively well developed, derivatives market for hedging purposes. BTCUSD can be fairly easily hedged via futures contracts or options strategies. Energy prices have tradable commodity futures and forwards, even though we assume that the biggest miners have individual contracts with energy plants. The hardware and maintenance costs are exogenous (except for cases when big producers have their own mining subsidiaries, e.g. Bitmain), but not quite tradable. However, there is a one important and also exogenous driver of profitability – the hash rate. This part of the business case is nowadays not hegdeable. BTC hash rate may be treated as an index[11] and even be considered as an asset. Furthermore, an introduction of futures and options market for this commodity would without any doubt cause a tremedous stimulation of the industry creating an opportunity for further development of BTC network, along with an ability to stabilize performance and hedge mining industry against adverse scenarios.

[11] Aware of the technical problems that might arise in construction of such an index and derivatives based on it (due to its always growing nature) we advise that a basis instrument should be constructed as a departure from a projected long-term change of BTC network hash rate (1m, 3m, 6m, 1y, etc.). Introduction of derivatives on such index would enable to either speculate or hedge against adverse scenarios.

6 Sensitivity analysis

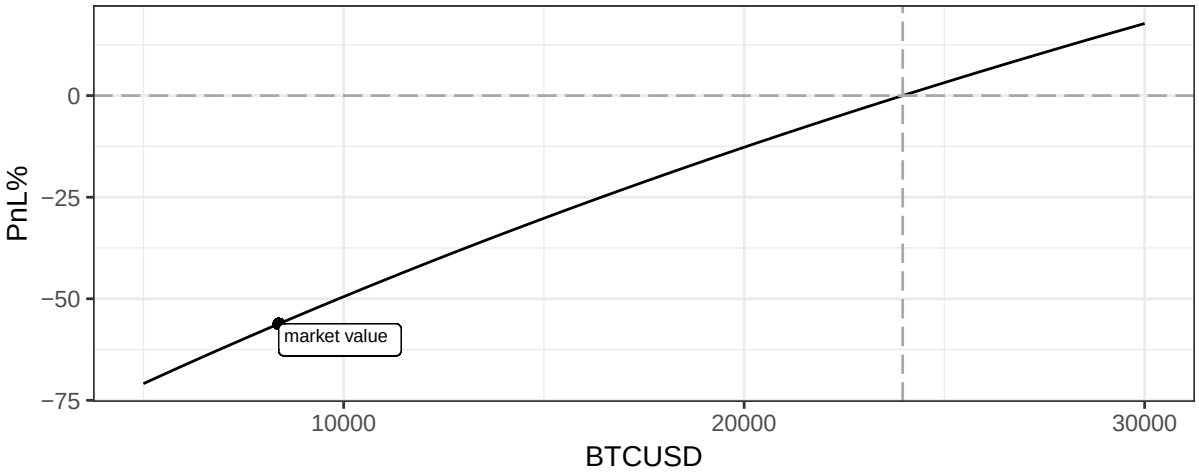
In this section, we present a detailed analysis of mining profitability assuming different trajectories of cost and revenue driving parameters. This analysis is presented in order to address the first research question (Q1): *What is the sensitivity of BTC mining to initial assumptions and future trajectories of main parameters?* The simulations are performed with ceteris paribus assumption i.e. changing only one variable at a time, while all other parameters remain constant.

One may raise an objection that such an approach is far from the real market dynamics. Nevertheless, we stick to this way of presentation as we see it as the most optimal description of the market possible states. We present the possible market evolution while simultaneously keep the analysis at a fairly simple level for the bussiness interpretation and conclusion sake. One- and two- factor sensitivity analysis allows us to present our results in a form of conclusive charts. A multi-factor simulation process has been also created and the results will be published in the next papers.

6.1 One factor analysis ceteris paribus all others

i. BTCUSD price

Figure 18: BTC mining profitability (PnL%) for different BTCUSD prices.



Note: PnL%, calculated according to the formula 6. BTCUSD hypothetical prices ranges from 5000 up to 30000 USD. Market value point describes current state of market mining efficiency assuming parameter outlined in the section Values of variables as of 2018/07/25. Source: own calculations based on data described in the section Crucial assumptions and data.

Figure 18 above presents an obvious positive relation between profitability of mining and the quotation of BTCUSD. One can easily make a conclusion on marginal profitability change for defined price of BTC. The slope of the line characterizes current market conditions for other variables. The change of the assumed level of other variables will move the position and slope of this line. These effects are presented further in this section.

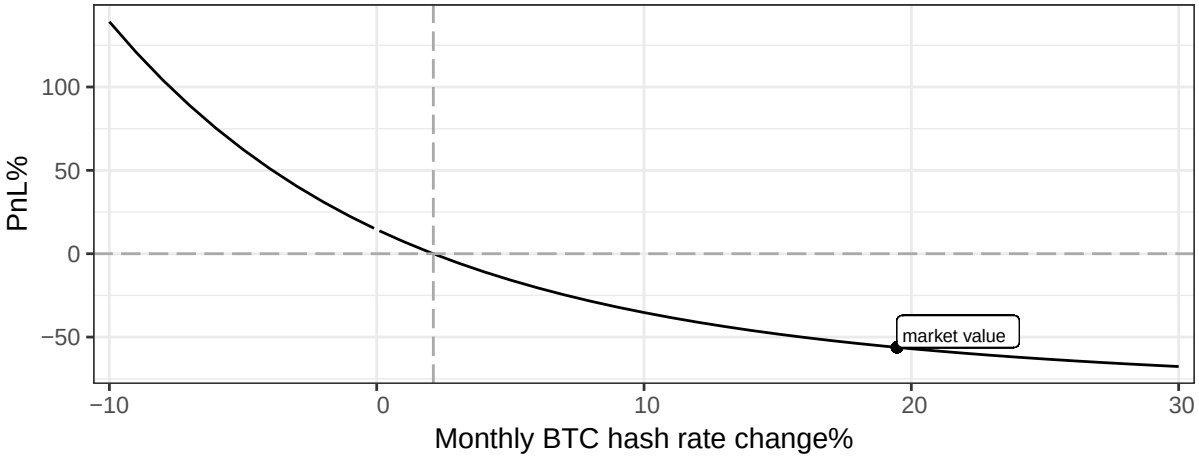
ii. Monthly hash rate increase

Figure 19 presents a negative relation between the dynamics of the monthly BTC network hash rate change and the mining profitability. This has to be a crucial part of the business case model when analysing the mining activity start-ups. Two main conclusions from Figure 19 are: (a) assuming that the monthly BTC network hash rate change is on the level of the last year average, the mining profitability is strongly negative, (b) the sensitivity of the business model to the monthly BTC network hash rate change rises once this variable is lower and profitability surges even faster once the network is shrinking. Under current conditions one may conclude that monthly BTC network hash rate change can not be higher than 2.1% if we want to stay with profitability of mining in the positive territory.

iii. Hardware total cost

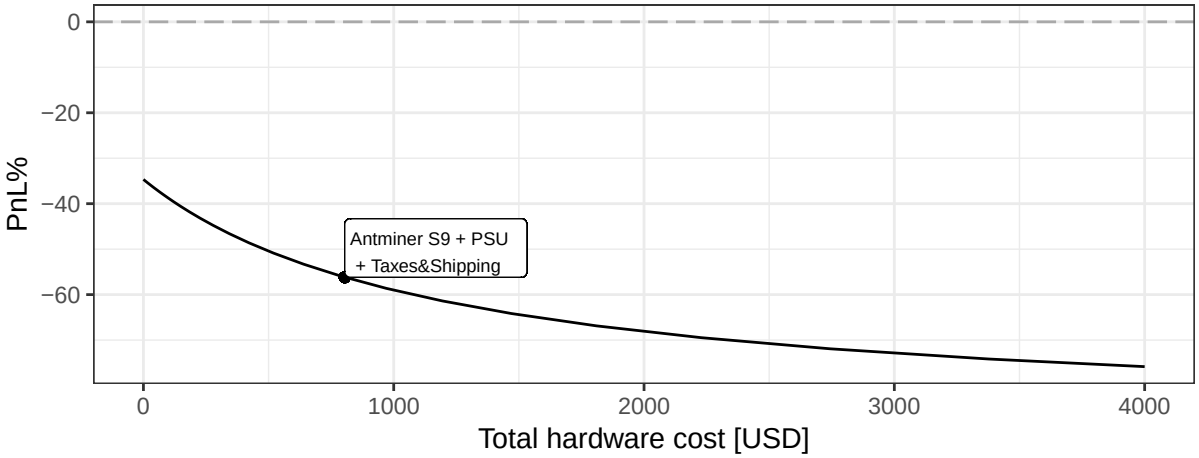
As presented on Figure 20, BTC mining efficiency is negatively linked with hardware costs which is an obvious conclusion, but one may also notice that this relation is not linear. The sensitivity increases with

Figure 19: BTC mining profitability (PnL%) for different evolution of network hash rate.



Note: PnL%, calculated according to the formula 6. Hypothetical monthly BTC hash rate change ranges from −10% up to 30 %. Negative values mean BTC network hash rate decreases, while positive describe increasing BTC network hash rate. Market value point describes current state of the market mining efficiency assuming parameter outlined in section Values of variables as of 2018/07/25. Source: own calculations based on data described in section Crucial assumptions and data.

Figure 20: BTC mining profitability (PnL%) for different cost of hardware.



Note: PnL%, calculated according to the formula 6. Hypothetical hardware cost ranges from 0 up to 4000 USD per unit. Since the Antminer S9 is defined as the most efficient for mining purposes (in terms of price vs. power consumption and hash rate), its cost is analysed on the charts. Market value point describes current state of market mining efficiency assuming parameter outlined in section Values of variables as of 2018/07/25. Source: own calculations based on data described in section Crucial assumptions and data.

the decrease of hardware costs. Current market state refers to the cost of hardware unit at the level of 804.42 USD. The most interesting conclusion is that mining remains unprofitable even for the zero hardware costs. As described in the previous sections – the 12 months mining revenues do not cover OPEX expenses i.e. electricity, maintenance and other variable costs, provided current market conditions.

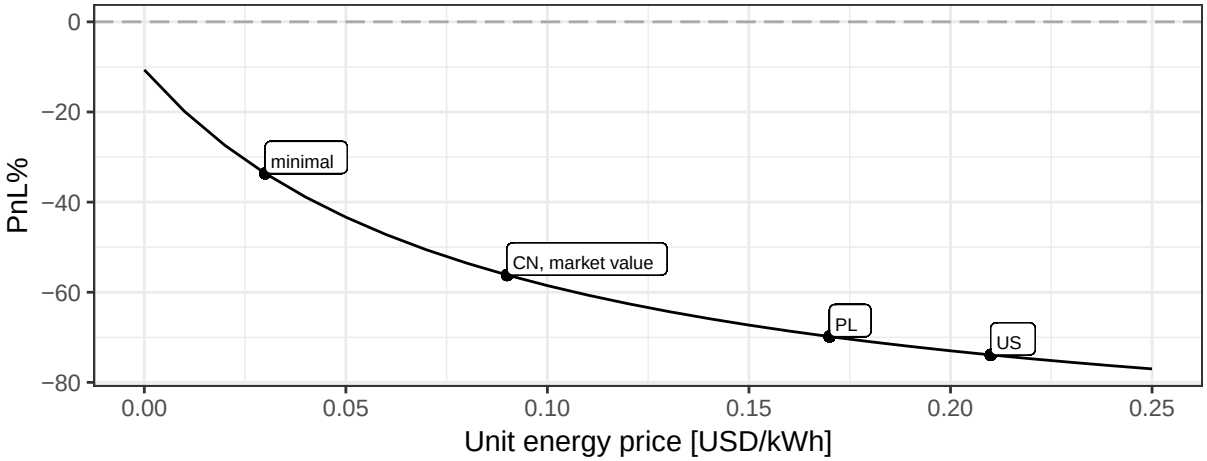
iv. Price of energy per kWh in USD

Figure 21 describes how mining efficiency depends on energy cost. Industrial energy prices are assumed for the sake of clarity. However, as described in the previous section, the supply of power for BTC mining industry comes mainly from renewable energy with dominance of hydro-generated power. Analysing Figure 21 one can easily conclude what would have been the mining profitability if the energy cost had reached the defined level. The main conclusion is that even for zero cost of energy supply the mining activity is still losing money. The reason for this is that the business case is not able to cover hardware cost, i.e. CAPEX, and maintenance costs. The minimal energy cost of 0.03 USD per kWh is assumed as well, but even for this value profitability is far negative.

v. Transaction fee as a percentage of mining reward (Fees%)

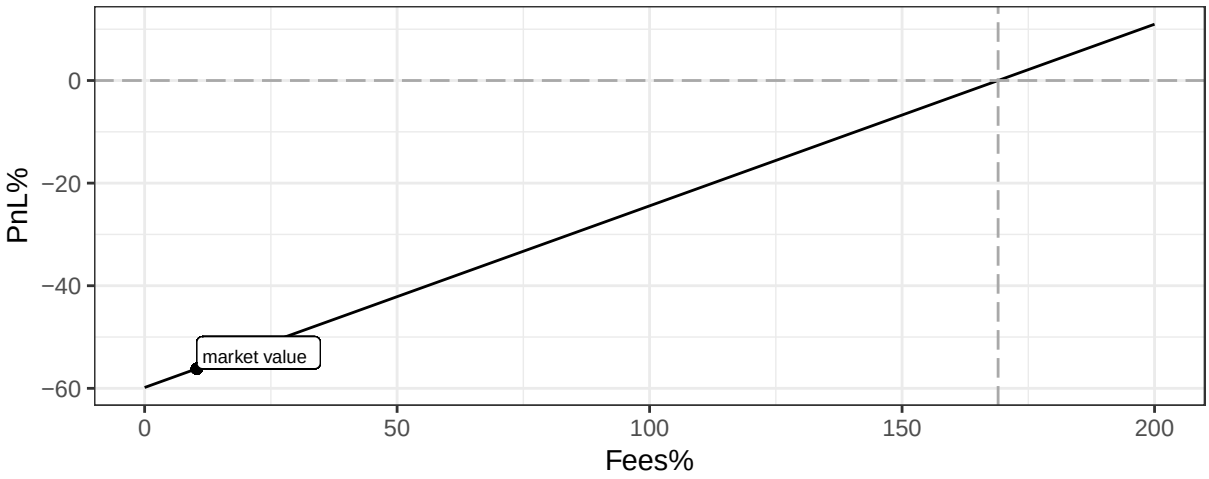
Figure 22 presents impact of the fees changes on the mining profitability. One can clearly see that the current contribution of fees to the revenues of the activity is very limited. Nevertheless, this part of the business is likely to change over time due to two main reasons: (a) the block reward is going to be halved

Figure 21: BTC mining profitability (PnL%) for different prices of electricity.



PnL%, calculated according to the formula 6. Hypothetical electricity prices ranges from 0 up to 0.25 USD per kWh. Minimal, CN, PL and US define respectively minimal world energy level, China, Poland and US located mining profitability corresponding to the local energy cost, provided that remaining parameters are equal. Market value point describes current state of market mining efficiency assuming parameter outlined in section Values of variables as of 2018/07/25, where energy cost is assumed to 0.09 USD per kWh. Source: own calculations based on data described in section Crucial assumptions and data.

Figure 22: BTC mining profitability (PnL%) for different levels of fees defined as % of BTC mined.



Note: PnL%, calculated according to the formula 6. Hypothetical transaction fees ranges from from 0% up to 200% of BTC mined. Market value point describes current state of market mining efficiency assuming parameter outlined in section Values of variables as of 2018/07/25. Source: own calculations based on data described in section Crucial assumptions and data.

in 2020 and there should be some substitute of reward revenue for miners, (b) current mining does not generate sustainable profit and one of the ways to assure the positive business output is to increase the mining costs. As one can see on the charts in the previous sections, historical periods with much higher contribution of fee revenue were observed. However, even if we assume historical highs we currently will not be able to reach the break even point. There is also research describing this issue in details (see Chepurnoy, Kharin, and Meshkov (2018)).

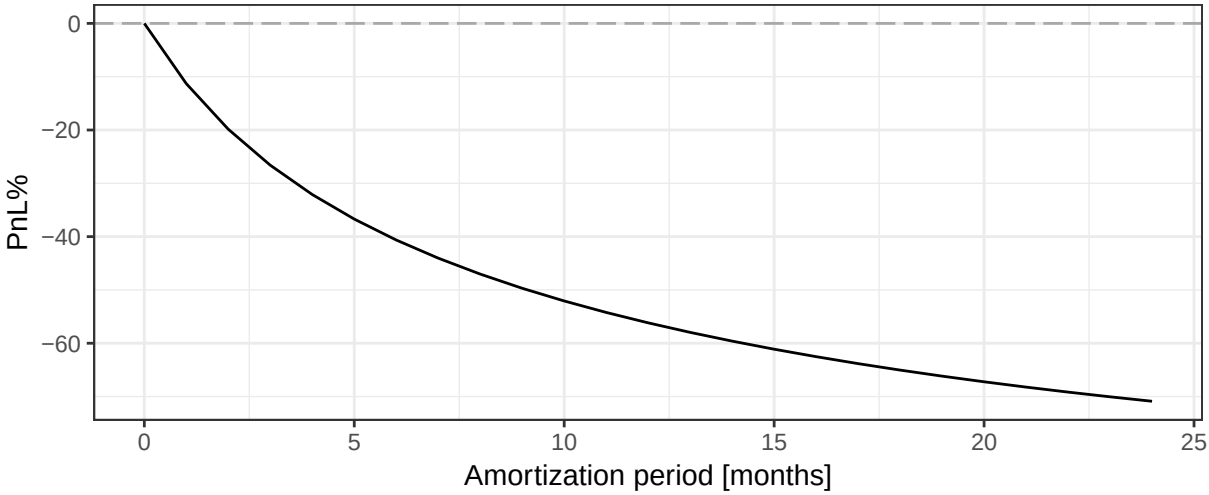
vi. Amortization period

Figure 23 presents relation between profitability and amortization period. The relation is monotonically decreasing which is a result of the fact that under current market conditions the mining is not profitable from the very beginning. The longer we keep machine working, the more of the invested capital we lose, mainly on OPEX. The story alters for higher levels of BTCUSD which is presented in the further part of this section.

6.2 Two factors ceteris paribus all others

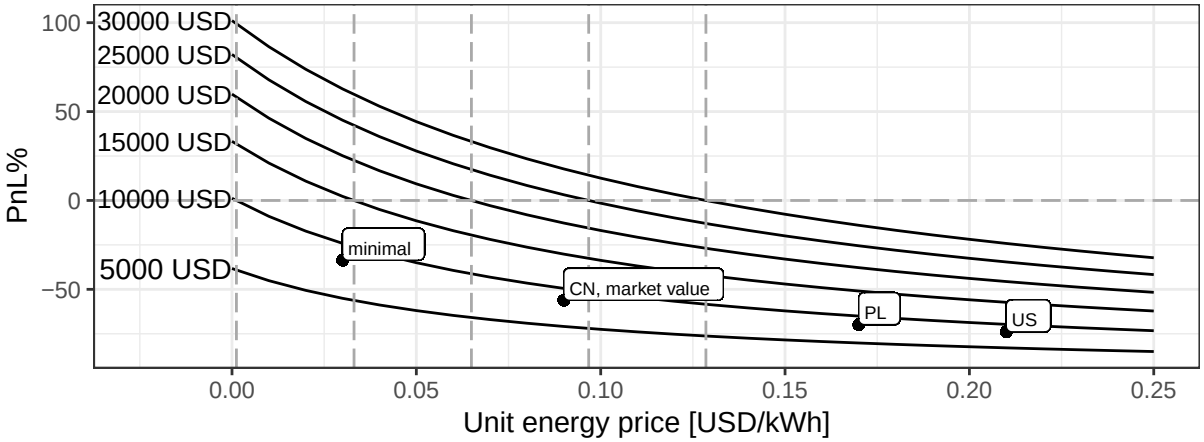
i. Price of energy per kWh jointly with BTCUSD price

Figure 23: BTC mining profitability (PnL%) for different levels of amortization period.



Note: PnL%, calculated according to the formula 6. Hypothetical amortization periods ranges from 0 up to 24 months. Other parameters are assumed as outlined in section Values of variables as of 2018/07/25. Source: own calculations based on data described in section Crucial assumptions and data.

Figure 24: BTC mining profitability (PnL%) for different levels of unit energy price and BTCUSD price.



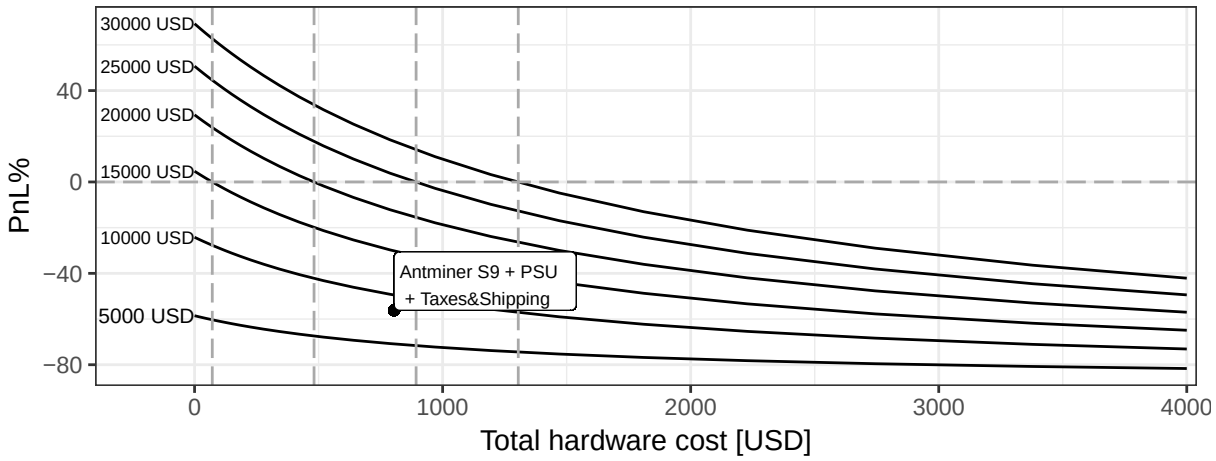
Note: PnL%, calculated according to the formula 6. Hypothetical unit energy price ranges from 0 up to 0.25 USD per kWh and BTCUSD price ranges from 5000 USD up to 30000 USD. Minimal, CN, PL and US define respectively minimal world energy level, China, Poland and US located mining profitability corresponding to the local unit energy price, provided that remaining parameters are equal. Market value point describes current state of market mining efficiency assuming parameter outlined in section Values of variables as of 2018/07/25, where energy cost is assumed to 0.09 USD per kWh. Source: own calculations based on data described in section Crucial assumptions and data.

Figure 24 presents relation between energy prices, BTCUSD and mining efficiency. The main observation is that reaching the break even point for the mining business case is virtually impossible while assuming stable BTCUSD and conventional energy sources. Taking into account assumed energy prices of 0.09 USD per kWh, it would have been hardly possible if BTCUSD prices had reached its historical highs. Unless there is no change in fees structure or a hardware efficiency breaktrough, the mining is not profitable under current BTCUSD price and BTC network hash rate dynamics. One can also conclude that the more efficient energy source is utilised the more sensitive is PnL% to absolute change of this price. There is also nonlinear sensitivity to energy price when assuming different BTCUSD levels: the higher BTCUSD prices are the more vulnerable mining is on the absolute change of energy price.

ii. Hardware cost jointly with BTCUSD price

As one can see in Figure 25 mining produces negative output in terms of PnL%. The higher BTCUSD is the more sensitive is PnL% on the hardware cost absolute change. Nevertheless, under current assumptions of BTCUSD price PnL% does not hit breakeven point even if the hardware cost is zero. This phenomenon is a result of a steep and sustainable increase of BTC network hash rate while productivity of the Antminer S9 remains constant since its release in 2016. Note that even though the nominal productivity of Antminer S9 is constant (13 TH/s), the relative productivity, i.e. contribution to the total network, is only 4.4% of its original productivity from the end of November 2016. Lower costs of the mining machine could

Figure 25: BTC mining profitability (PnL%) for different levels of hardware cost and BTCUSD price.

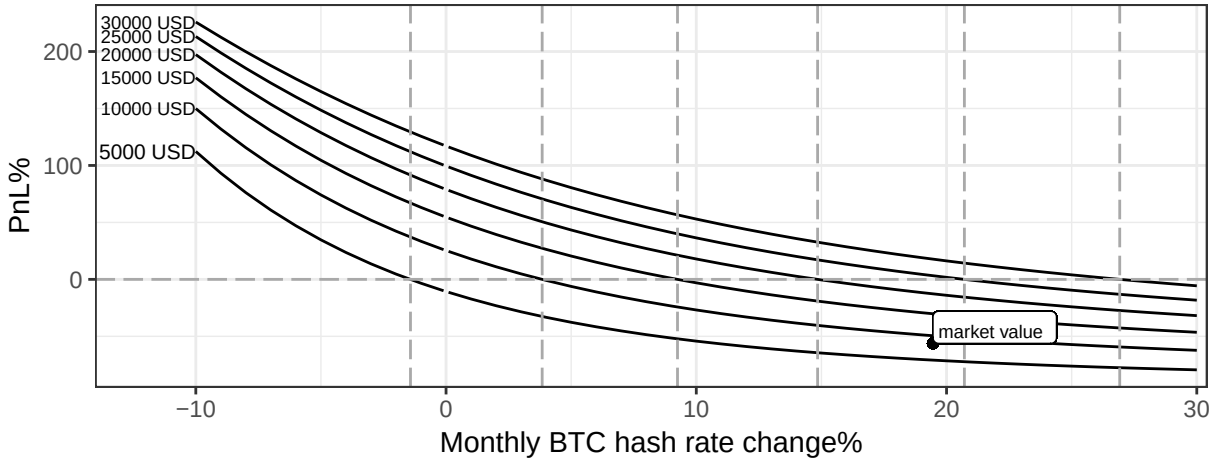


Note: PnL%, calculated according to the formula 6. Hypothetical hardware cost per unit ranges from 0 USD up to 4000 USD and BTCUSD price ranges from 5000 USD up to 30000 USD. Antminer S9 is assumed as the most optimal mining machine and its point describes current state of market mining efficiency assuming parameter outlined in section Values of variables as of 2018/07/25. Source: own calculations based on data described in section Crucial assumptions and data.

offset the decreasing contribution to the total mining power however it will not turn the final PnL% into positive territory taking into account current BTCUSD price.

iii. Monthly BTC hash rate change jointly with BTCUSD price

Figure 26: BTC mining profitability (PnL%) for different evolutions of BTC network hash rate and BTCUSD price.

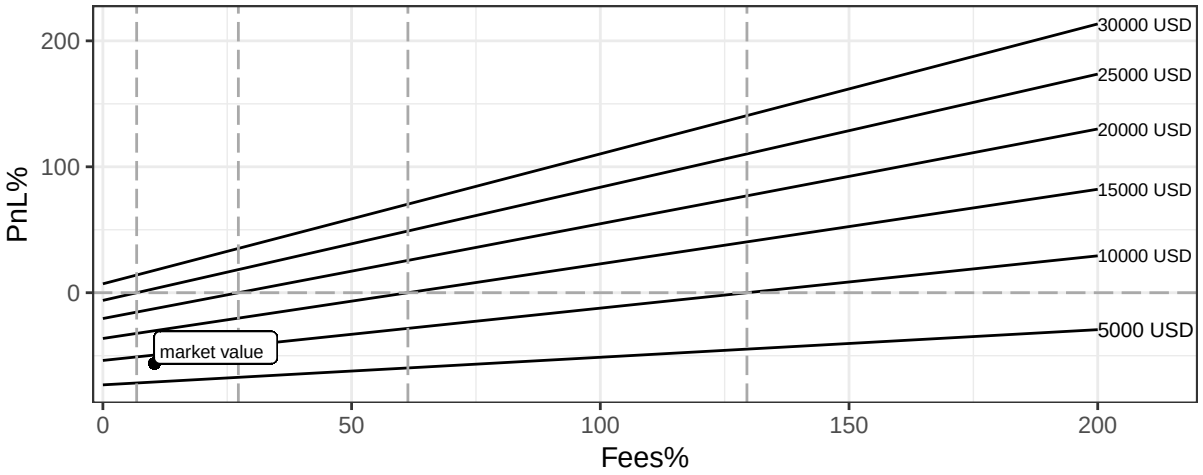


Note: PnL%, calculated according to the formula 6. Hypothetical monthly BTC hash rate change ranges from −10% up to 30% and BTCUSD price ranges from 5000 USD up to 30000 USD. Negative monthly BTC hash rate change means decreasing BTC network hash rate. Market value point describes current state of market mining efficiency assuming parameter outlined in section Values of variables as of 2018/07/25. Source: own calculations based on data described in section Crucial assumptions and data.

One of the key factors for profitability analysis is evolution of BTC network hash rate. The relation between this characteristic, BTCUSD price and mining PnL% are presented in Figure 26. Assuming current BTCUSD price, profit from mining would have appeared if BTC network increase rate had dropped to 0.021187. Shrinking BTC network hash rate gives a hope of a stable positive PnL%. Although theoretically one can imagine such situation, the historical evolution of BTC network hash rate does not give us any rationale for such expectation. Even if there were short term periods with decreasing BTC network hash rate, the mid- and long-term trend remains increasing with average monthly increase rate oscillating around 19% for the last 12 months. Next important conclusion is that the higher the average monthly hash rate change the less sensitive is PnL% on BTCUSD prices eventually making more difficult to reach break even point even for BTCUSD equal to 20000. It will require extraordinary changes in BTCUSD price or transaction fees level in order to make profit on BTC mining.

iv. Fees% jointly with BTCUSD price

Figure 27: BTC mining profitability (PnL%) for different levels of fees defined as % of BTC mined and different levels of BTCUSD price.



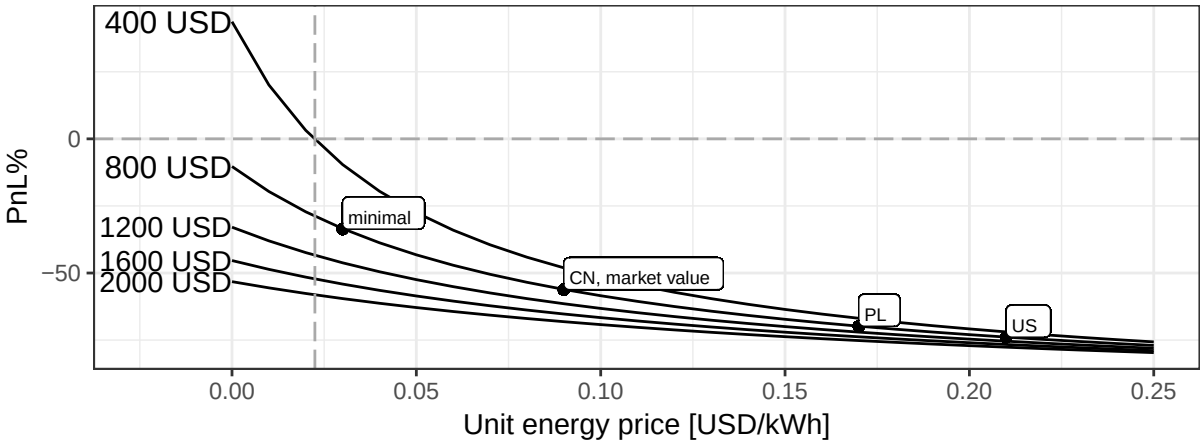
Note: PnL%, calculated according to the formula 6. Hypothetical transaction fees range from 0% up to 200% of BTC mined and BTCUSD price ranges from 5000 USD up to 30000 USD. Market value point describes current state of market mining efficiency assuming parameter outlined in section Values of variables as of 2018/07/25. Source: own calculations based on data described in section Crucial assumptions and data.

As it is shown in Figure 27 current market Fees% level, assumed in the analysis, do not produce enough revenue in order to make mining profitable. Worth mentioning is the fact that for the sake of integrity with other assumptions we defined the fee value at the level of its annual average. This makes the calculation conservative in terms of PnL% due to the fact that the most recent fees values stabilize during the last few months below 2% whereas annual average is 10.3%. Therefore, presented results are slightly better than these obtained using the most recent Fees% level.

As seen in Figure 27, the possible increase in Fees% create potential for mining to be profitable. Historically, fees have increased during the periods of substantial turmoils of BTCUSD prices. But even the highest historical levels will not assure positive PnL% under current conditions for other variables. Therefore fees composition and accompanying drivers are the field of current research in the crypto industry.

v. Hardware cost jointly with unit energy price

Figure 28: BTC mining profitability (PnL%) for different levels of unit energy prices and different levels of hardware cost.



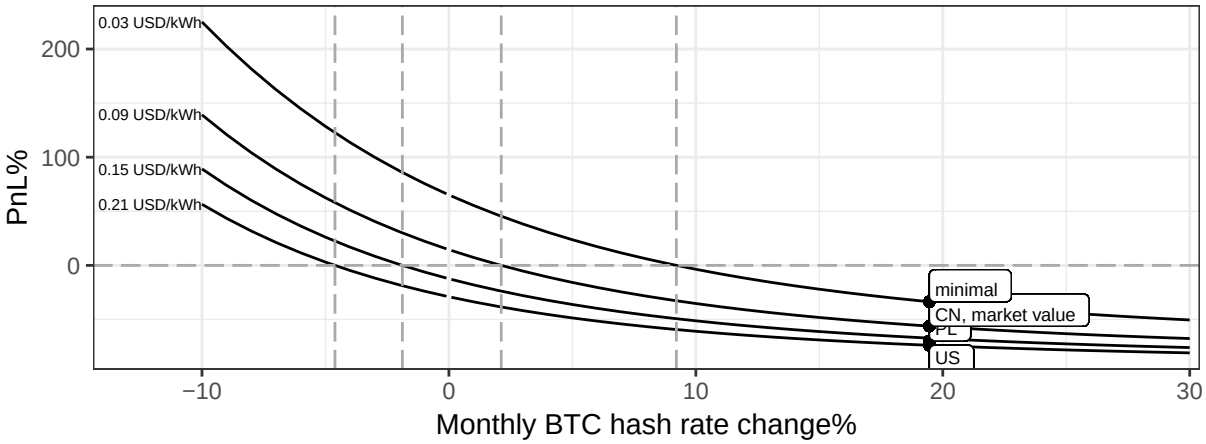
Note: PnL%, calculated according to the formula 6. Hypothetical unit energy price ranges from 0 up to 0.25 USD per kWh hardware cost per unit ranges from 400 USD up to 2000 USD. Antminer S9 is assumed as most optimal mining machine. Minimal, CN, PL and US define respectively minimal world energy price level, China, Poland and US located mining profitability corresponding to the local energy price, provided that remaining parameters are equal. Market value point describes current state of market mining efficiency assuming parameter outlined in section Values of variables as of 2018/07/25. Source: own calculations based on data described in section Crucial assumptions and data.

Two main conclusions from Figure 28 are that: (a) PnL% sensitivity to absolute energy price increases when hardware costs decrease and (b) PnL sensitivity to absolute hardware costs increases when energy price declines. Even though both conclusions are intuitive, the strength of dependence can not be assessed without comprehensive calculations. The results of these calculations are presented on Figure 28 so that

one can easily ascertain the shape and strength of relations. Note that the subject of the analysis is a unit of Antminer S9 which is believed to be the most efficient hardware under current market circumstances. The selection of the best available hardware can be seen as an additional 'degree of freedom in the model' of mining profitability. Apart from the specific parameters of a mining machine, one should consider current market condition affecting the selection of optimal hardware. However, this subject is not a part of our research.

vi. Monthly BTC hash rate change jointly with unit energy price

Figure 29: BTC mining profitability (PnL%) for different evolutions of BTC network hash rate and different levels of energy prices.

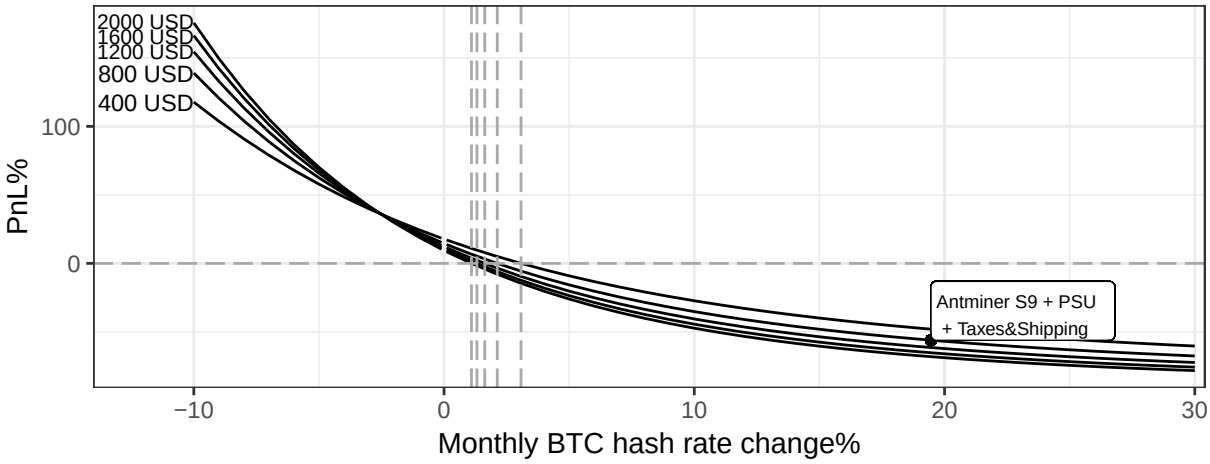


Note: PnL%, calculated according to the formula 6. Hypothetical monthly BTC hash rate change ranges from −10% up to 30% and energy price ranges from 0.03 up to 0.21 USD per kWh. Negative monthly BTC hash rate change means decreasing BTC network hash rate. Minimal, CN, PL and US define respectively minimal world energy price level, China, Poland and US located mining profitability corresponding to the local energy price, provided that remaining parameters are equal. Market value point describes current state of market mining efficiency assuming parameter outlined in section Values of variables as of 2018/07/25. Source: own calculations based on data described in section Crucial assumptions and data.

Figure 29 presents how sensitive the PnL% is to the evolution of BTC network hash rate. Should the trend in BTC network hash rate remains unchanged i.e. 19.5% monthly increase, the mining activity remains not profitable even assuming zero energy cost (as clearly seen also on Figure 21). Alternative interpretation of the chart is that the more efficient energy supply the more sensitive PnL% is to BTC hash rate change.

vii. Monthly BTC hash rate change jointly with hardware cost

Figure 30: BTC mining profitability (PnL%) for different evolutions of BTC network hash rate and different levels of hardware cost.



Note: PnL%, calculated according to the formula 6. Hypothetical monthly BTC hash rate change ranges from −10% up to 30% hardware cost ranges from 400 USD up to 2000 USD. Negative monthly BTC hash rate change means decreasing BTC network hash rate. Antminer S9 is assumed as the most optimal mining machine and its point describes current state of market mining efficiency assuming parameter outlined in section Values of variables as of2018/07/25. Source: own calculations based on data described in section Crucial assumptions and data.

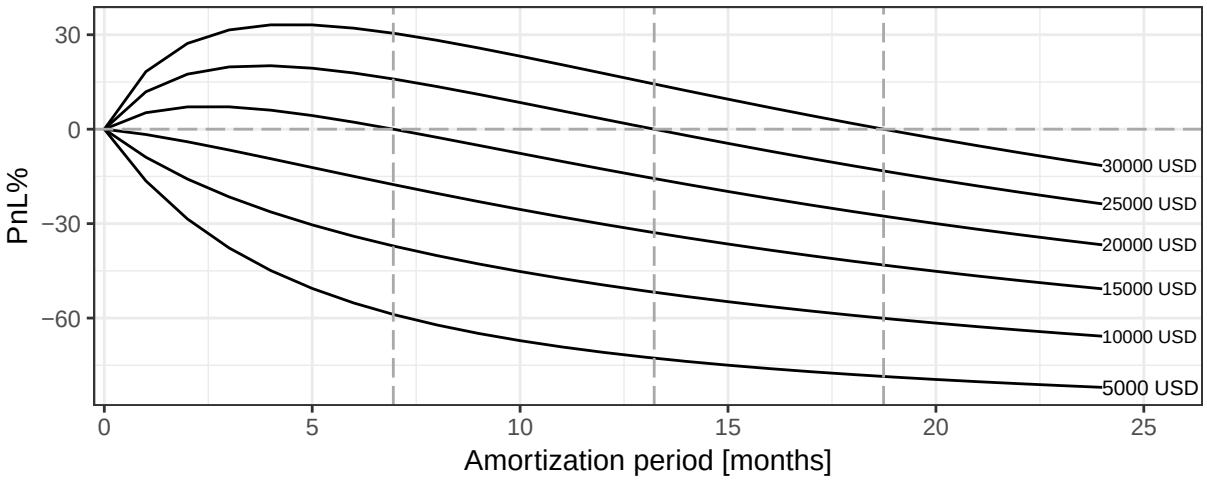
Figure 30 in the sensitivity analysis part shows the relation between PnL%, BTC network evolution and hardware costs. The negative relation between PnL% and monthly hash rate change is intuitive.

An interesting observation in Figure 30 is that the profitability curves cross. This means that for some scenarios of BTC network hash rate evolution the cheaper the hardware the higher the profitability, while for other scenarios the cheaper the machine the lower the profitability. Although the second part of the latter sentence seems counterintuitive it has its economic explanation. If the network hash rate decreases the contribution of a single unit of hardware to the network will increase thus it produces more coins each consecutive day. Consequently, assuming other variables constant, the residual value of mining machine increases over time.

Finally, the higher the initial hardware price, the higher the profit from selling the machine at the end of amortization period, making this component a substantial part of the revenue structure. This is of course only a theoretical consideration which is very unlikely to happen in the reality. Additionally, to get hardware residual value finite, the 12 months amortization period remains valid. Moreover, there is no chance to reach profitability just playing on hardware cost ceteris paribus other variables.

viii. Amortization period jointly with BTCUSD prices.

Figure 31: BTC mining profitability (PnL%) different amortization period and different levels of BTCUSD.



Note: PnL%, calculated according to the formula 6. Hypothetical amortization period ranges from 0 up to 24 months and BTCUSD price ranges from 5000 USD up to 30000 USD. Other parameters are assumed as outlined in section Values of variables as of 2018/07/25. Source: own calculations based on data described in section Crucial assumptions and data.

Figure 31 presents quite an interesting feature of the mining business model i.e. adependence of profitability on assumed amortization period for various levels of BTCUSD, with other factors held constant. One can easily see that for higher level of BTCUSD there is a local maximum of profitability. This means, at least theoretically, that the most profitable scenario is actually to buy a mining machine, utilise it until the maximum profitability point and then sell the hardware out on the market. The alternative scenario encompassing the full utilisation of the machine until the end of the amortisation period, i.e. until residual value is almost zero, produces much poorer business results. Of course, presented situation may work assuming: (a) ceteris paribus of remaining variables, (b) effective secondary market for trading hardware. It has to be stressed out that Figure 31 will show slightly different values if one assume different market parameters (e.g. other BTC network hash rate evolution). The other conclusions should be drawn if we assume that investor has some specific level of hurdle rate defined at the beginning.

This section, hopefully, has shed some light on the sensitivity of mining business to the various factors and market states. The most important conclusion is that if a company wants to be efficient in this industry (if it is only possible under current condition) it has to continuously perform multidimensional analysis on the evolution of the market, its impact on current business, its future prospects and adjust management decisions accordingly. In some cases it may be more profitable just to plug out mining machines and sell them out on the market.

As a summary of this part we have to point that the conditions under which mining starts to be profitable are nowadays barely reachable, but we would like to elaborate on this particular issue in a separate section as we regard it as a one of the most important results of this paper.

Table 4: Summary of breakeven values for all crucial parameters.

Parameter	Unit	Breakeven value
BTCUSD price	USD	23958.17
Energy cost	USD/kWh	NA
Hardware cost	USD	NA
Monthly BTC network hash rate change	%	2.12
Fees%	%	169.02

Note: Breakeven values presented here are set on the level which enable %profitability of BTC mining to reach zero ceteris paribus all other variables, assuming all other conditions as listed in Table 2. NA (not attainable) - means that under current market conditions (as of 2018/07/25) for all other variables it is impossible to reach breakeven value for unit energy price and separately for hardware cost.

7 Breakeven conditions for BTC mining profitability

After detailed analysis of mining profitability and proving that BTC is not profitable under current market conditions we would like to take under consideration what actually should happen with crucial variables in order to make such activity profitable. We define the break even point as a state when the net mining profitability reaches zero.

7.1 BTCUSD price

Taking into account a holistic model of BTC mining profitability i.e. covering CAPEX as well as OPEX expenses and all the sources of revenue, one may reach a conclusion about the exact BTCUSD price corresponding to the break even point. This level is defined at 23958.17 USD per BTC. This conclusion may seem to be in contradiction to information presented in several sources where so called 'mining cost' or 'marginal cost' are defined at far lower level. Please note that this break even is affected by crucial assumptions that make our research more realistic, which are: (a) inclusion all the costs in the analysis, especially hardware costs and its amortization over time, (b) assumption on BTC network hash rate evolution which impacts tremendously the forecasted revenue. We believe that thanks to this approach our study gained a practical aspect.

7.2 Unit energy price

As described in the previous section, current market parameters do not satisfy the break even point at any unit energy price. Therefore, even if we assume zero cost of electricity, the output from the mining activity does not produce positive results. In other words – BTC mining does not cover sum of hardware costs and non-energy related maintenance cost, assuming other factors constant over the next 12 months. The only case when it makes sense to keep mining machines switched on is the strong conviction that the market will significantly rebound and exceed previous highs in a short period of time.

7.3 Hardware cost

A similiar situation as for energy cost can be observed for hardware cost. It is not possible to reach the break even point even for zero hardware cost scenario provided that remaining variables are constant over next 12 months. This means that the potential revenue is not able to cover the sum of energy and maintenance costs. As a consequence one can conclude that current ASICs are not efficient enough, in terms of TH/s vs. energy consumption, to satisfy equilibrium state defined as break even mining activity point.

7.4 Monthly BTC hash rate change%

BTC network hash rate evolution assumption is of crucial importance for mining profitability. Majority of naive web profitability calculators assume no increase in BTC hash rate while historical trends do not

permit such assumption. Therefore, after the analysis of hash rate development and its monthly increase ratio we decided to assume a constant monthly increase ratio (at the level of 19%). This presumption affected our model heavily and brought it closer to the real world. A detailed analysis allowed us to define the state of BTC hash rate dynamic that may support reaching break even point at the level of 2.12% of monthly change in the hash rate. This is more a theoretical consideration than a practical forecast as this is quite an unrealistic value for a longer period of time.

7.5 Fees%

Transaction fee is the area of probable future adjustments if BTC mining is to regain profitability. Even though we do not place this part in the center of our research, we can derive a rough conclusion on the fees level corresponding to the break even point ceteris paribus. The mining would have turned into profitable territory if the fee had increased to 169% of BTC mined, i.e. 21.1BTC per block. This area remains of interest of developers and scientist, especially in the context of upcoming halving reward day in 2020.

8 Conclusions

The research we have presented allows us to tackle our main hypothesis and additionally to answer several research questions. With no doubt we can refer to our main research hypothesis (H1): *Is BTC mining profitable under current mining conditions?* Under current market condition mining is not profitable. Detailed calculations which enable us to formulate such answer are presented in previous sections. The problem is that such answer raises many other questions connected with overall blockchain and cryptocurrency environment which require further research. Below we will refer to all of them one by one.

- Q1: What is the sensitivity of BTC mining profitability to initial assumptions and future trajectories of main parameters?

There is a strong positive correlation between BTCUSD and Fees%. Simultaneously there is negative sensitivity of BTCUSD to the monthly BTC hash rate change, energy price, hardware cost, and amortization period. Even though the relations are in most cases intuitive, there are several interesting, and some time surprising, conclusions like non-monotonic relation of PnL% and amortization period or hardware cost. They are presented in details in the section Sensitivity Analysis (Section 6).

- Q2: Is there strong positive relation between BTCUSD price and difficulty/hash rate of BTC network?

Based on the presented analysis one can not say there is a strong positive relation of BTCUSD price and difficulty/hash rate of BTC network. Especially in the recent months in the period since December 2017 the relation is opposite i.e. negative.

- Q3: What are the breakeven levels of the main BTC mining parameters in order to make this activity profitable?

Assuming ceteris paribus all other variables one can conclude that 23958.17 USD per BTC turns mining into profitable. Alternatively, either decrease in the average monthly BTC network change to 2.12% or increase of Fees% to 169% may satisfy break even point. More theoretical considerations are presented in the section Main Results (Section 5).

- Q4: What is the rational level of amortization period for our mining machines?

Since the mining is currently not profitable the answer is 0. However for various scenarios of the market evolution the optimal amortization period may be on different levels. One of the conclusion is that miners should consider utilising the hardware up to some point and then sell out the machine instead of mining until the full utilisation of the machine. This approach may increase business results and is explained in section b of Main results.

- Q5: What are the consequences of BTC mining efficiency for future ability of blocks to be mined further?

We present six theoretical scenarios being an attempt to refer to Q5, nevertheless one may imagine mix of these scenarios pushing BTC mining toward break even point. In scenarios from one to five we assume that BTC network will still exist and is able to confirm blocks and evolve while in the last one we take into account that current mining unprofitability could weaken and destroy the network as a whole.

- Q6: Can we expect that blocks will not be confirmed if the efficiency of BTC mining will be negative for an extended period of time?

This is one of the most important questions in this paper because this issue affects not only single mining endeavours but can influence the probability of BTC network to work properly as a whole. The answer is NO, at least for a longer period of time. Blocks will be mined unless there is trust in BTC blockchain protocol, regardless of BTCUSD price and other variables. Since BTC ecosystem has its own immune mechanism that helps to sustain the protocol healthy, we assume that appropriate adaptation will take place to bring BTC blockchain to the equilibrium state in the long term.

- Q7: Should we invest in BTC mining if we expect very strong growth of BTC price?

The answer is NO once again, unless you are a hardware mining producer thus having a synergy effect. The better option for miner is to turn toward BTCUSD spot or derivative market.

- Q8. Is it possible that technological advancements in the ASICs performance would change BTC mining landscape and make mining profitable?

Introduction of faster ASIC chips, will definitely change BTC mining landscape, at least for the company that will be the first to introduce the new hardware. Mainly because the most likely scenario is that such company will leverage on the new technology for its own mining activity and then supply ASICs to the market. The additional factor is the price of new hardware.

- Q9: What kind of new financial instruments may stimulate BTC mining industry?

Introduction of futures and options market for the monthly (quarterly, yearly, etc.) BTC network hash rate change could stimulate the mining industry, creating opportunity to stabilize performance and hedge against adverse scenarios. Therefore it may strengthen BTC as a digital currency ecosystem.

Even though our paper is relatively long, what was caused by the fact that we tried to refer to the subject of BTC mining profitability with the highest scientific and practical rigidity at the end we found that there are still several issues which should be resolved especially when we treat the subject of cryptocurrency mining more broadly. These questions can be summarized as follows:

- What is the mining profitability of other cryptocurrencies?
- Proof-of-stake versus Proof-of-work. Should we go this way in case of BTC network?
- What is the future shape of transaction fees?
- The reward halving challenge and its consequences.
- To prepare analysis of historical BTC mining conditions in order to answer the question if undertaking of BTC mining activity was reasonable in the past.

We are sure that they can be treated as a subject of future scientific investigations or practical reports.

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