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# The Economics of Mining

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# 15.S68 Economics of Mining Bitcoin

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**Abstract**

The economics of mining Bitcoin are investigated from the perspective of the miner. First, the profitability of the entire ecosystem is studied. For this, global estimates of hardware price, electricity rates, depreciation expenses, and mining rewards are derived and the global profits arising from mining Bitcoin are calculated. According to the estimates used, Bitcoin mining has not been profitable since mid 2018, even with a depreciation schedule as long as 24 months. In addition, the overall hashrate of the Bitcoin network is studied and its relationship to the BTC/USD exchange price is analysed. It is observed that there is a lag between the hashrate and the exchange price of the order of about 200 days. Moreover, a linear model is constructed to reproduce the hashrate from lagged information on the top-pools mean hashrate and the BTC/USD exchange price.

# Contents

# 1 Introduction


Figure 1: Bitcoin Mining; Credit to Osato Avan-Nomayo

*To mine or not to mine?* Some may not mind, but this is a puzzling question. At the beginning of this project, we placed ourselves in the shoes of a miner wanting to manage mining operations. The main objective was to try and understand the dynamics that make miners mine and attempt to find ways to make this decision more rational by creating a model that would somehow resemble a net-present-value approach.

The particular angle of this research was to study how miners make profits, if any, and how much these represent in absolute terms over the past couple of years. This is a complex issue that necessitates a lot of data, much of which can be secretly guarded and therefore not available, and that requires many predictions to be made about a very volatile future where certainty is pie in the sky.

## 2 Facts

**Network Development and Marginal Cost** As mentioned by Christopher Bendiksen, Samuel Gibbons and Eugene Lim in their paper *The Bitcoin Mining Network*, "from May 2018 to November 2018, the hashrate of the Bitcoin network has increased from approximately 30 EH/s to approximately 40 EH/s. During this period the Hashrate grew faster than the two-year average but slower than the all-time average." [1]

**Hardware Development** As the paper *The Bitcoin Mining Network* pointed out, The second half of 2018 has also seen "the introduction of several next-generation mining units with significant improvements in both GH/J efficiency and investment cost per TH/s." [1]

## 3 Global estimation of mining costs

In this section, we interrogate the change of global miner unit, the global mining power consumption, and the global device purchase, in order to help us identify the cost of hardware and electricity. To begin with our interrogation, we first set up certain boundaries and assumptions for our global estimation.

$$BitcoinMiningCost_{Total} = HardwareCost + ElectricityCost$$

### 3.1 Time Boundary

The time boundary we look at is from January 2014 to February 2019 (62 months). We use 1 month as our time interval for this exercise. The first assumption we make is that **the Hashrate is constant during each month**. The number of Hashrate is the same number as recorded by the 00:00:00, the first day of each month [2].

### 3.2 Miner

We determine the dominant mining technology and miners based on the report released by Jing Data and Node Capital [3]. According to this, we have summarized the important milestones of mining technology's development from December 2013 to now.

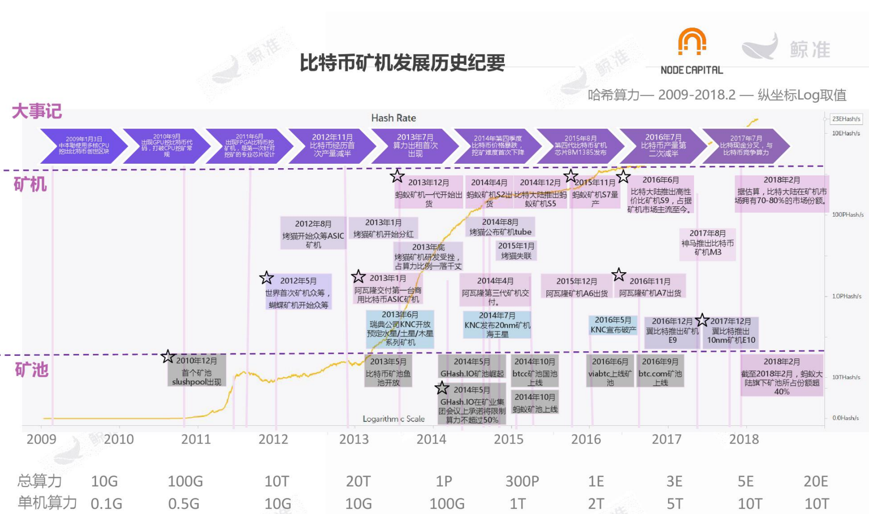



Figure 2: The evolution of the miners

- 12/2013, Bitmain released Antminer S1;

- 08/2014, Bitmain released Antminer S3;
- 12/2014, Bitmain released Antminer S5;
- 09/2015, Bitmain released Antminer S7;
- 12/2015, Avalon released Avalon A6;
- 06/2016, Bitmain released Antminer S9, which is still one of the major miners on the market;
- 11/2016, Avalon released Avalon A7;
- 12/2016, EBIT released EBIT E9;
- 08/2017, WhatsMiner released M3;
- 12/2017, EBIT released EBIT E10;
- 11/2018, Bitmain released Antminer S11;
- 04/2019, Bitmain released Antminer S17.

In order to determine the units of the miners in the global network, we also documented the parameter of the different miners and listed them chronically.

Hence, when considering the parameter of the miner, we assume that 1) the increased/decrease network Hashrate is **due to the application/abandon of the most updated miner**. For example, according to our documentation, the network Hashrate increased 36000T Hash from August 2015 to September 2015. We assume the increased amount of the Hashrate is all due to the new

| Miner | Release time | Hashrate per unit/G | Power consumption per unit/W |
|---|---|---|---|
| Antminer S1 (using S1-115.2G) | 12/2013 | 115.2 | 115.2 |
| Antminer S3 | 08/2014 | 440 | 332 |
| Antminer S5 | 12/2014 | 1150 | 590 |
| Antminer S7 | 09/2015 | 4050 | 1042 |
| Avalon A6 | 12/2015 | 3650 | 1100 |
| Antminer S9 (using S9-14) | 06/2016 | 14000 | 1375 |
| Avalon A7 | 11/2016 | 7300 | 1150 |
| EBIT E9 | 12/2016 | 6300 | 882 |
| WhatsMiner M3 | 08/2017 | 12000 | 2100 |
| EBIT E10 | 12/2017 | 18000 | 1620 |
| Antminer S11 (using S11-21) | 11/2018 | 21000 | 1470 |

Figure 3: Different miners' parameters

implementation of the Antminer S7, which was first introduced to the market in September 2015. This demonstrates the concept of cumulative units.

We also assume that **2) each miner has a depreciation duration of 2 years**. This means that after 2 years, the old miner will no longer exist on the market.

## 3.3 Number of active units

Based on our previous assumption of the miner, we assume that all the unit in the network used the same miner until the new mining technology was released. Therefore, these assumptions enable us to calculate the global miner units. The calculation process is shown in the following graph.

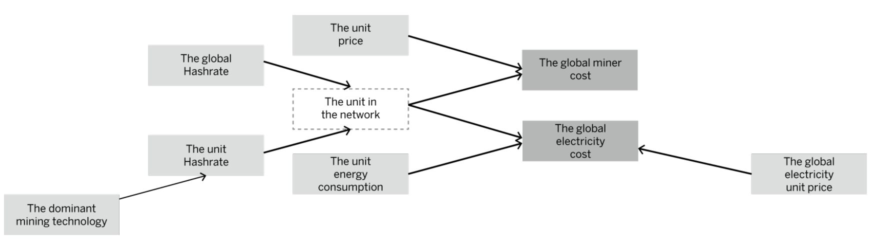



Figure 4: Calculation process

Based on our previous assumptions, we calculated the different miner units in different time sections. They formed a step function as shown in the following table (figure 6). With the help of this table, we are able to track what is the market share of different miners' units at different stages.

### 3.4 Hardware cost

After identifying the quantities of different miners at different sections of the market, we use the following formula to calculate the total hardware cost of bitcoin mining along different time period.

$$HardwareCost_{Total} = \sum HardwarePrice_{unit} * Unit$$

We have collected the price change for each miner we have selected previously. Here, we **1) use the average of the neighbor values to fill the missing value.** We also get rid of the abnormal values (e.g. the unit price of 999999 USD of the individual miner). Hence, we get the following graph tracing each miner's price change (Figure 7).

After performing the calculation, we come to the conclusion of the cost change as the following figure of the cost of mining devices along the time globally (Figure 8).

### 3.5 Global electricity price

Since electricity price is highly locality dependent, it is extremely difficult to collect all the price information and connect with corresponding electricity con-

| Time | 2013/12 | 2014/01 | 2014/02 | 2014/03 | 2014/04 | 2014/05 | 2014/06 | 2014/07 | 2014/08 | 2014/09 | 2014/10 | 2014/11 | 2014/12 | 2015/01 | 2015/02 | 2015/03 | 2015/04 | 2015/05 | 2015/06 | 2015/07 | 2015/08 | 2015/09 | 2015/10 | 2015/11 | 2015/12 | 2016/01 | 2016/02 | 2016/03 | 2016/04 | 2016/05 | 2016/06 | 2016/07 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Antminer S1 | 72703.534 | 130968.15 | 210188.35 | 303040.16 | 457897.29 | 624532.49 | 915681.25 | 1146554.7 | 1146554.7 | 1146554.7 | 1146554.7 | 1146554.7 | 1146554.7 | 1146554.7 | 1146554.7 | 1146554.7 | 1146554.7 | 1146554.7 | 1146554.7 | 1150000 | 1150000 | 1150000 | 1150000 | 1150000 | 1150000 | | | | | | | |
| Antminer S3 | | | | | | | | | 94909.259 | 226791.71 | 298615.26 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 | 355075.12 |
| Antminer S5 | | | | | | | | | | | | | -1058.887 | 16058.74 | 35367.058 | 47611.687 | 45719.663 | 49107.724 | 56997.491 | 73455.43 | 89487.89 | 89487.89 | 89487.89 | 89487.89 | 89487.89 | 89487.89 | 89487.89 | 89487.89 | 89487.89 | 89487.89 | 89487.89 | 89487.89 |
| Antminer S7 | | | | | | | | | | | | | | | | | | | | | | 8832.7929 | 13498.546 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 |
| Avalon A6 | | | | | | | | | | | | | | | | | | | | | | | | | 47202.29 | 133355.7 | 205368.65 | 222416.4 | 247209.28 | 281649.32 | 281649.32 | 281649.32 |
| Antminer S9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5821.7125 | 6047.3789 |
| Avalon A7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EBIT E9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| WhatsMiner M3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EBIT E10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Antminer S11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Time | 2016/08 | 2016/09 | 2016/10 | 2016/11 | 2016/12 | 2017/01 | 2017/02 | 2017/03 | 2017/04 | 2017/05 | 2017/06 | 2017/07 | 2017/08 | 2017/09 | 2017/10 | 2017/11 | 2017/12 | 2018/01 | 2018/02 | 2018/03 | 2018/04 | 2018/05 | 2018/06 | 2018/07 | 2018/08 | 2018/09 | 2018/10 | 2018/11 | 2018/12 | 2019/01 | 2019/02 | 2019/03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Antminer S1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Antminer S3 | 355075.12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Antminer S5 | 89487.89 | 89487.89 | 89487.89 | 89487.89 | 89487.89 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Antminer S7 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | 29305.501 | | | | | | | | | | | | | | | | | | |
| Avalon A6 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | 281649.32 | | | | | | | | | | | | | | | |
| Antminer S9 | 11756.117 | 32867.385 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | 42219.632 | | | | | | | | | |
| Avalon A7 | | | | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | 19946.796 | | | | |
| EBIT E9 | | | | | 42944.99 | 134369.65 | 210436.82 | 251649.87 | 298939.82 | 391713.26 | 501988.24 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | 658209.18 | | | |
| WhatsMiner M3 | | | | | | | | | | | | | 25043.97 | 158554.68 | 278757.16 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | 346001.65 | NA |
| EBIT E10 | | | | | | | | | | | | | | | | | 181503.98 | 480888.29 | 726740.06 | 875897.22 | 1073135 | 1240356.5 | 1565489.4 | 1730994.7 | 2234540.6 | 2384129.3 | 2380882.1 | 2380882.1 | 2380882.1 | 2380882.1 | 2380882.1 | NA |
| Antminer S11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | -320198.4 | -609761.8 | -247295.9 | -156047 | NA |

Figure 5: Bitcoin Miner Unit

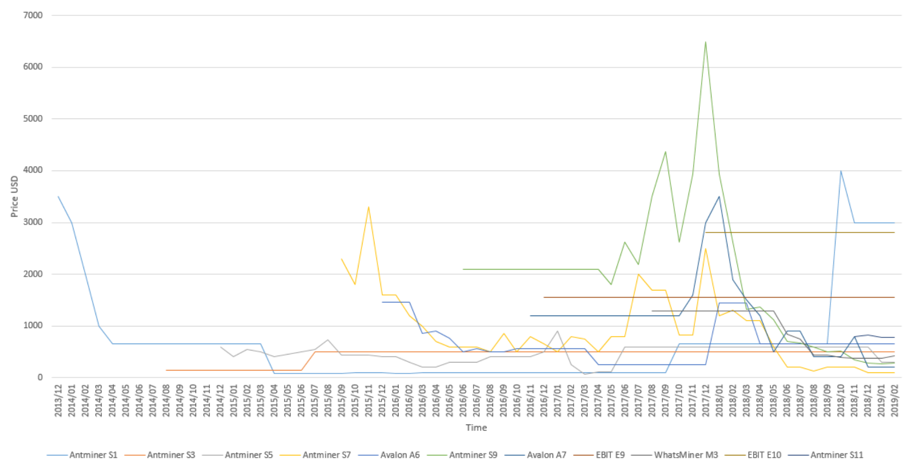



Figure 6: Miner Price Change USD

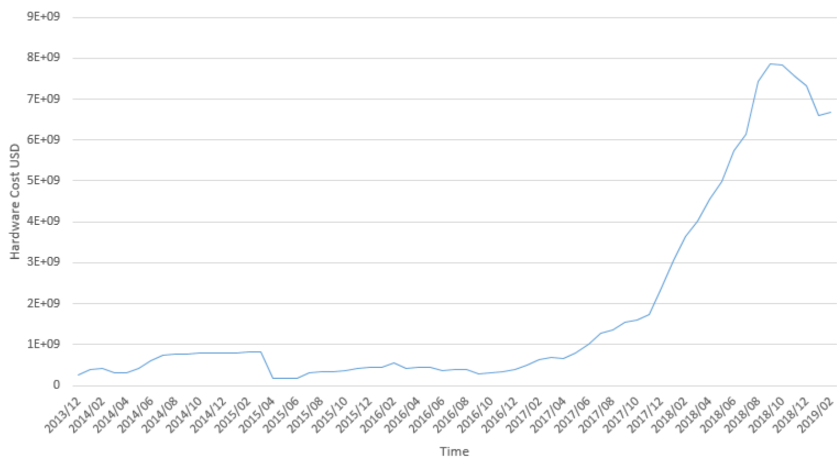



Figure 7: Global Miner Cost USD

sumption. Hence, in order to identify the global electricity cost, we adopt the methodology of the weighted average for implementing our estimation. We assume that **1) 50 percent of the global electricity used for mining comes from China** [4]. In terms of the rest 50 percent of the electricity used for mining, we assume that **2) the among is evenly distributed among the**

**countries of OECD (Organisation for Economic Co-operation and Development)**, based on the electricity price data we collect from Internationa Energy Agency [5]. That said, our weighted global electricity price can be calculated as the following formula.

$$Price_{Global} = 0.5 * Price_{China} + 0.5 * Price_{OECDAverage}$$

Since our data spectrum is available until 2017 at a yearly base, we use the data from 2013 to 2017 to estimate the price. We assume that the **3) electricity price among the same year is constant**. We assume that **4) both the electricity price of China and OECD countries are designated according to the industrial category and for industrial users**. The data is then aggregated as the following table.

| Time | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|
| China Industry | 0.11 | 0.11 | 0.1 | 0.1 | 0.1 | 0.11 |
| OECD Industry | 107.803 | 111.6607 | 115.197 | 107.16 | 102.5521 | 104.8025 |
| Weighted Electricity Price | 53.95648 | 55.88536 | 57.6485 | 53.63 | 51.32606 | 52.45624 |

Figure 8: Global Electricity Price

## 3.6 Global mining electricity cost

We use the miners we have previously determined in different time sections as the objectives to identify the total global electricity cost along time. By implementing the calculation like the following.

$$Electricity_{Total} = \sum Electricity_{unit} * Unit$$

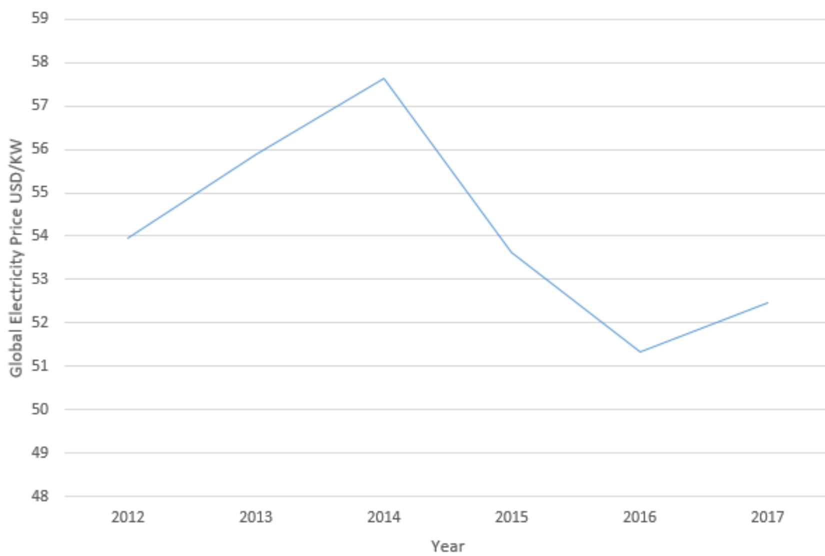



Figure 9: Global Electricity Price Change (USD/MWh)

We will be able to find the different global energy consumption in specific time series. The different unit electricity consumption of the dominant mining technologies we have identified are documented in figure 4. The result of the electricity consumption across time series is shown as in the following figure.

Based on the calculation of energy consumption, we will be able to identify the corresponding energy cost according to the time variable using the following formula.

$$ElectricityCost_{Total} = \sum Electricity_{unit} * Unit * ElectricityPrice$$

The total electricity cost across different time series is calculated as the

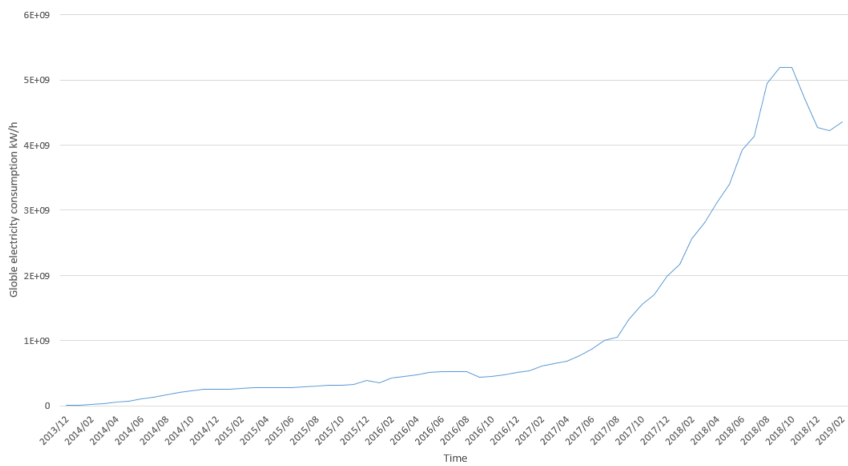



Figure 10: Global Electricity Consumption kW/h

following.

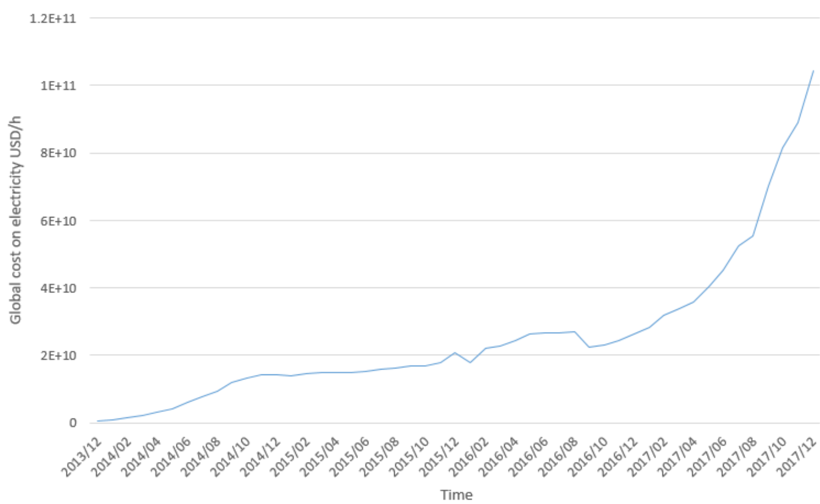



Figure 11: Global Electricity Cost USD/h

# 4 Global profitability of mining

From the miner's perspective, the profitability of its operations arises as the difference between its revenues and costs. The revenue sources of the miners arise from selling the Bitcoin rewards obtained from the mining operations. On the other hand, the costs incurred by the miners can be divided into capital expenses (CAPEX) and operational expenses (OPEX). The former is linked to the cost of acquiring the hardware and facilities necessary to mine, whereas the second relates to the cost of operating the mining facilities and includes the electricity price, salaries, cooling expenditures, etc. The important difference between CAPEX and OPEX is that operational expenses can be largely reduced at any point in time by not mining, whereas this is not the case for the capital expenditure. As an example, it may be not profitable to mine using some hardware that was expensive to purchase, but once the equipment is in the facility, it is still beneficial to mine as long as the operating expenses are lower than the mining revenues.

## 4.1 Mining reward

The revenues of miners are comprised of the block reward (for mining a new block) and a transaction fee. For a single miner, there can be a significant effect of the choice to mine in a pool (and if so what pool, with what compensation scheme). The main reason for mining in pool is that it allows miners to reduce the volatility of their revenues by receiving a portion of the mining of a large number of miners. Pool economics do play an important role in how miners are rewarded for the work they produce, but as a first estimate, this reports focuses on the global profitability without incorporating the pool economics. As a consequence, the fees captured by the pool operators are not separated from the miners' revenues.

The number of blocks mined *per day* can be calculated from the time required to find a block as

$$N_{\text{block}} = \frac{60 \cdot 24}{\text{Block time}} \tag{1}$$

and is shown in fig. 12. The daily transaction fees were directly downloaded from BitcoinVisuals.com are shown, expressed in BTC, in fig. 13.

The total daily mining revenues (in BTC) are calculated from the block reward multiplied by the number of blocks mined in a day, plus the transaction fees:

$$\text{Daily revenues} = \text{block reward} \times \#\text{ of blocks mined/day} + \text{transaction fees} \tag{2}$$

which is shown in fig. 14. Note that the block reward is currently 12.5 BTC and varies over the period considered in this study.

## 4.2 Costs

The mining costs (namely consisting of CAPEX and OPEX), are calculated as follows:

- The depreciation horizon is assumed to be **24 months**.

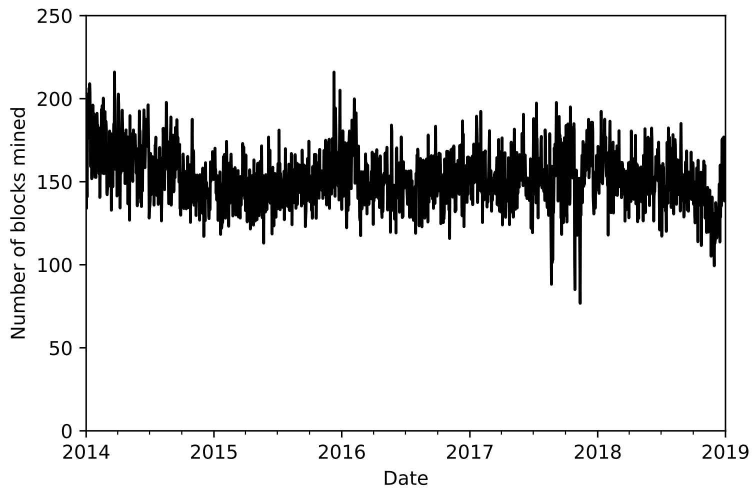



Figure 12: Number of new blocks mined per day.

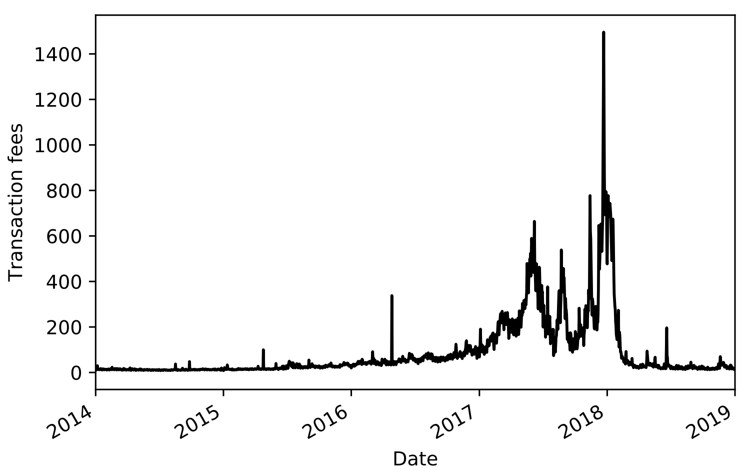



Figure 13: Transaction fees per day (in BTC).

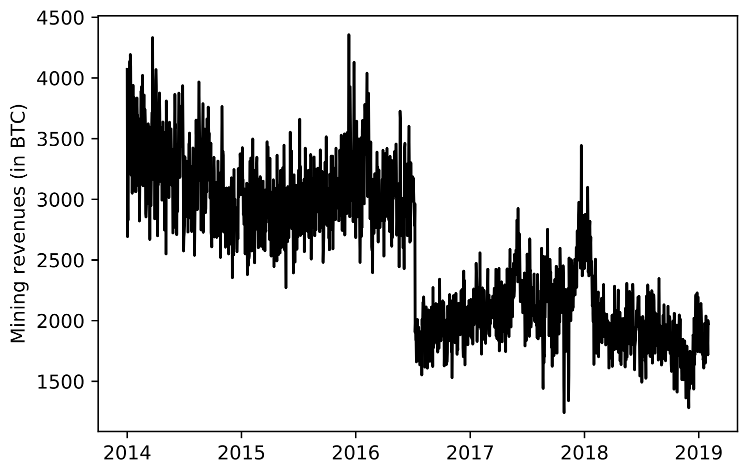



Figure 14: Mining revenues, composed of the block reward and the transaction fee, expressed in BTC.

- The hardware costs, hardware consumption, and hardware hashrate (per unit of hardware) are taken from the estimates in section 3.
- The number of active mining units is calculated from the hashrate, divided by the hashrate of one unit.

From the above quantities, the CAPEX is calculated as

$$\text{CAPEX} = \frac{\text{hardware cost} \times \text{number of units}}{\text{depreciation horizon}} \tag{3}$$

Next, the electricity price is taken from section 3 in order to calculate the daily operating expenses as

$$\begin{aligned} \text{OPEX} =& \text{operational factor} \times \\ & (\text{hardware consumption} \times \#\ \text{units} \times \text{electricity cost} \times 24), \end{aligned} \tag{4}$$

where the operational factor is taken to be equal to 1.1. This factor is meant to incorporate the other operational costs such as maintenance, cooling, employees, etc. by assuming that these expenses scale linearly with the size of the mining operations. The hardware consumption is in kWh while the electricity cost is expressed and taken from the estimate derived in section 3.

### 4.3 Profitability of mining

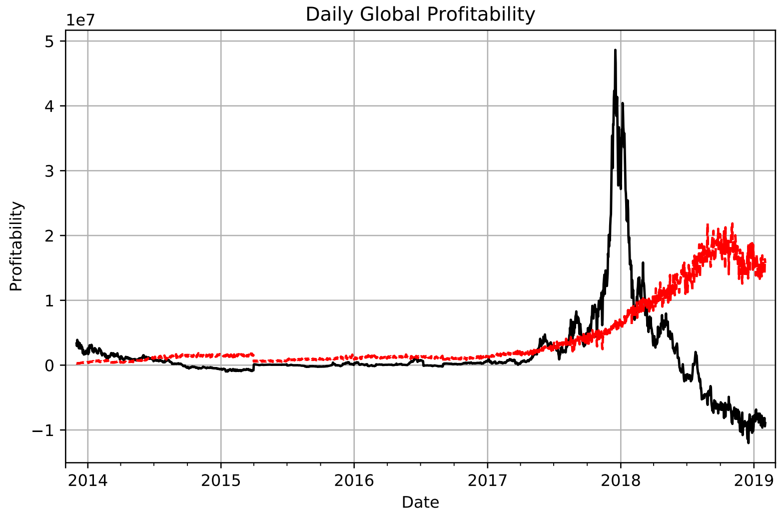
In order to evaluate the global profitability of Bitcoin mining, it is assumed that each day the miners convert the proceeds of the day into USD and do not hold Bitcoins.

Next, the net profits are calculated by subtracting the costs to the mining revenues

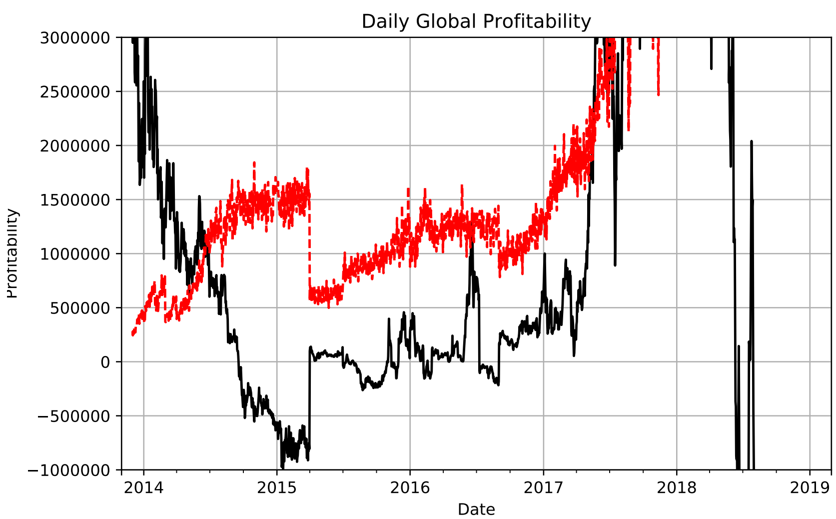
$$\text{Daily profits} = \text{Daily revenues} - (\text{CAPEX} + \text{OPEX}), \tag{5}$$

the result is shown in fig. 15.

It is interesting to observe that the profitability has historically been quite low until 2017. After a period during which it was significantly negative spanning from the end of 2014 until the beginning of 2015, the profitability remained




(a)




(b)

Figure 15: Estimation of global daily profits of Bitcoin mining with the assumptions of the empirical model. Black line: profits, red (dashed) line: costs. (b) is the same as (a) but with a zoom to focus on the period 2014 – 2017.

alternating around zero for a year or so until 2017. The bull market made the price of Bitcoin very attractive for miners and therefore the profitability of mining skyrocketed, however, in the recent times, this estimation yields losses for miners.

Over the period considered (2014 to 2019), the total profits sum to about \$2.9 Bn whereas the total CAPEX is estimated at about \$4.6 Bn with a total OPEX of \$3.1 Bn. As future work, it would be interesting to compare these figures to other reports and in particular the CAPEX to the revenues of ASICs producers (e.g. Bitmain) and chip manufacturers.

Despite the estimation that the global Bitcoin mining network operates at a loss, there are a couple of remarks that may be worth elaborating on:

- Increasing the depreciation schedule would increase the profits. From our discussion with some miners, we were told that some mining hardware had been in use profitably (supposedly from an OPEX perspective) for over 4 years, which suggests that as the mining industry matures the depreciation horizon may become longer.
- At the moment, according to some miners, it is not worth it to try and improve the operating efficiency by using the heat produced by the miners for other purposes, mostly because for the size of operations where it could be interesting, the added complexity is not justified by the margins already achieved
- Following the previous point, it is reasonable to expect that large actors

operate at much more advantageous rates, be it electricity rates or hardware costs. As far as electricity prices are concerned, one way of lowering the cost to about $0.02/kWh is to act as a utility and purchase the electricity from hydro generation or other means of bulk production. There are other means to obtain cheap electricity: by political favours (also sometime called bribery), or by contractual arrangement whereby close-to-free electricity can be accessed (e.g. some employees of electricity providers do not pay for electricity, or only pay a fraction of the costs). As far as the hardware is concerned, getting cheap and rapid access to new mining hardware can make a significant difference. Indeed, new mining hardware can provide orders of magnitude of mining efficiency improvements which in turn gives a competitive advantage in order to capture more of the total mining rewards.

- In the race to obtain contracts providing cheap electricity, the previous observation on the OPEX may be void: often such contracts can specify a minimum power usage which prevents miners from ceasing operations even if it is no longer profitable for them to mine.

# 5 Mining network hashrate and Bitcoin price

If instead of considering the entire global mining network a local miner who wishes to understand whether it is in their economical interest to purchase some mining hardware and start mining is considered, most of the reasoning that has been laid out still holds. They will have to evaluate exactly the same costs and revenues, and unlike for the estimates given in the previous section, the miner will more precisely know at what price they can buy the hardware and how much their electricity costs. However, they will need to make a set of predictions. These predictions will include the Bitcoin price[1] and also importantly the network hashrate: leaving aside the pool economics, the individual miner is only capable of capturing a portion of the total reward which is linked to its share of the working power. If the total hashrate increases significantly, then the relative share on the rewards of the miner decreases, which may hinder their profitability.

For this reason, this section gathers a number of observations that may help a miner in making those predictions. In addition, although this would necessitate further work, the results given in this section could be used in conjunction with section 4 in order to train a model estimating the profitability of ones operations. Instead of taking the global quantities for hardware costs, electricity prices, etc. these would be substituted by the miner's costs (which they know more precisely). Next, the miner can define a model for how they make predictions in order to decide to mine or not (this can be mining as a starting decision, i.e. involving supplementary CAPEX, or alternatively a decision to turn on/off mining hardware). Finally, the procedure of section 4 can be used to backtest the miner' strategy or to train a model tailored to their mining costs and constraints.

[1]It may be interesting to note that some of the miner's risks in that respect could be hedged using futures, however this has not transpired in our conversations with practitioners.

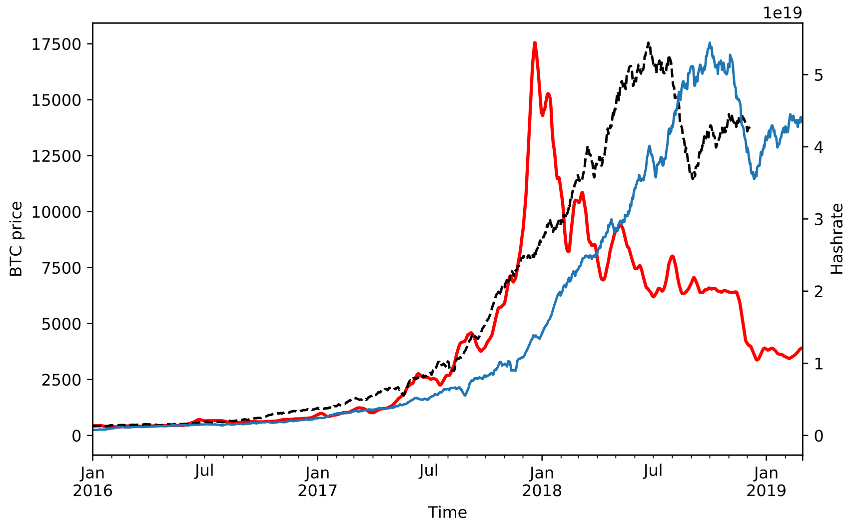



Figure 16: Comparison between the movements of the Bitcoin price and those of the hashrate over the period 2016 − 2019. Red continuous line: BTC price (see left axis), blue continuous line: hashrate (see right axis), black dotted line: hashrate shifted by 100 days.

## 5.1 Hashrate and Bitcoin price

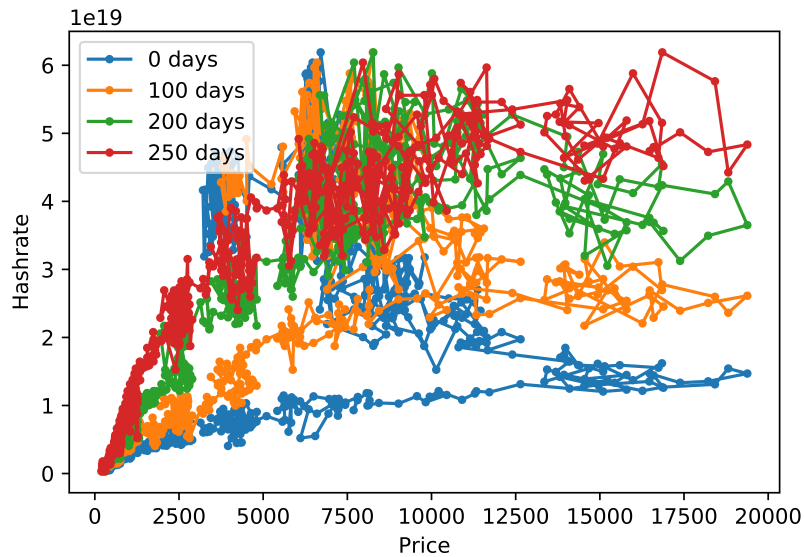
As the price of Bitcoin increases, it would seem natural from what was seen in section 4 that this creates incentives for more miners to start mining and input work into the system. The consequence of this is that increases in price may push miners to install new mining facilities, which is not an instantaneous feat. On the contrary, there exists an asymmetry in the fact that taking a miner of the network is instantaneous: it only needs to be forced offline.

As a first intuitive observation, fig. 16 shows on the same plot the hashrate, the bitcoin price, and the hashrate lagged by a hundred days.

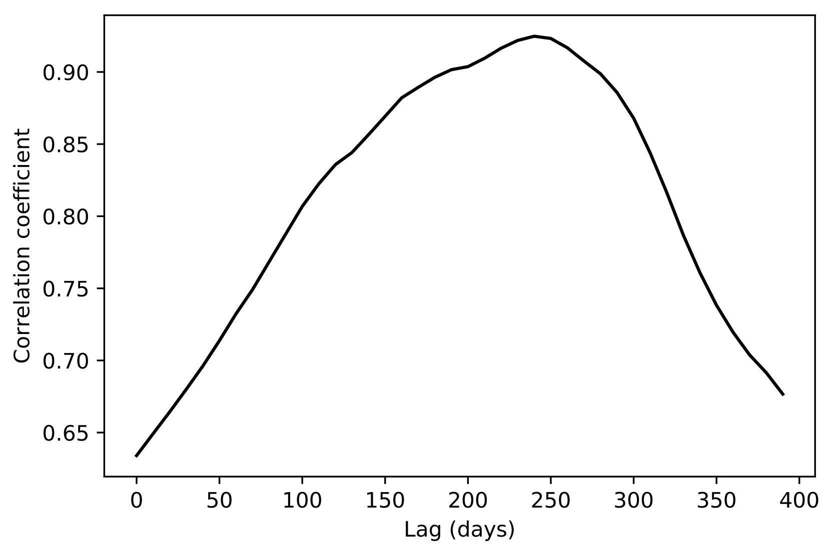
Next, the qualitative observation made on fig. 16 is further studied and analyzed more quantitatively. Figure 17 shows that there is a significant correlation between the price of bitcoin and the network hashrate. An important observation is that for a lag of about 250 days, the scatter plot collapse, and this is evidenced by a stronger correlation coefficient between the hashrate and the price for lags in the vicinity of 250 days.

Based on the observation that the relationship between the hashrate and the price on fig. 17 was somewhat concave, the same procedure was repeated with the square root of the price which might perhaps be seen as some utility rooted in some degree of risk aversion from the miners. The results, shown in fig. 18, confirm that the correlation is higher when the square root of the price is considered, and overall the relationship is qualitatively more linear when comparing fig. 17(a) to fig. 18(b).

The previous analysis was performed over an extended period. Therefore, it may be interesting to investigate if there are departures from this behavior (while still retaining some degree of statistical significance). One particular period where there were intensely strong drivers to drive the installation of miners faster and start mining operations was during the bull market of 2017. Figure 19 shows the price of Bitcoin, networksh hashrate, and the correlation between the hashrate and the price depending on the lag for the period between January 2016 until end of March 2018. Interestingly, the correlations are much stronger for shorter lags than what was observed in fig. 17. This could be an indication that the changes in incentives relating to the economics of mining can significantly incentivize and speed up the installation of new mining hardware

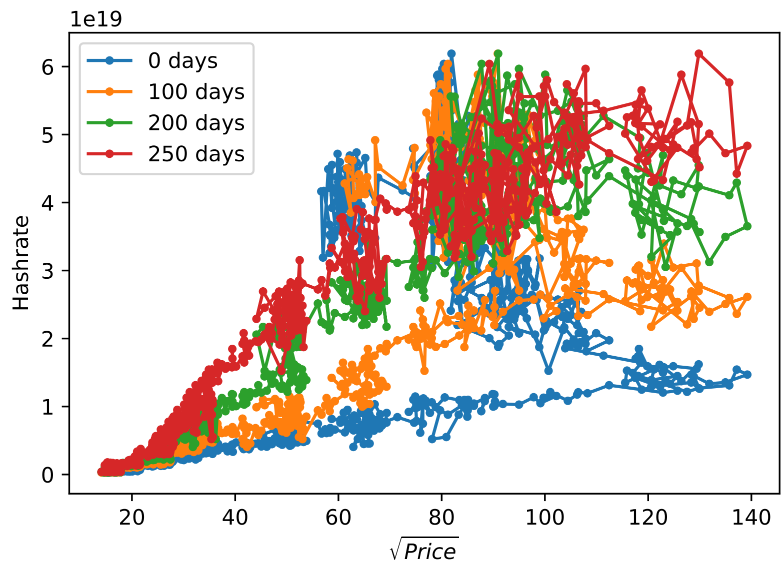



(a)

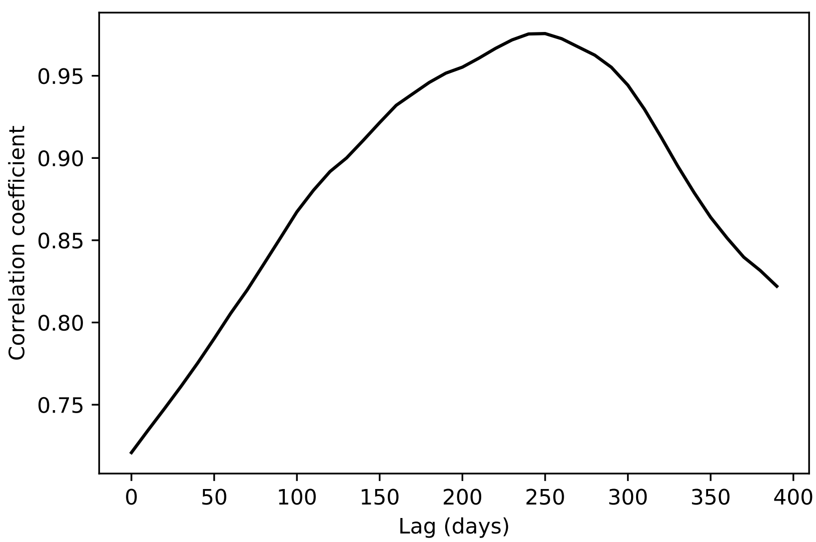



(b)

Figure 17: Lag between hashrate and Bitcoin price for the period of Jan 2015 – Jan 2019. (a) Scatter plot of the hashrate as a function of the price for different values of the lag ranging from 0 days to 250 days; (b) correlation coefficient between the hashrate and the price as a function of the lag.




(a)




(b)

Figure 18: Same as fig. 17 but with the square root of the Bitcoin price instead of the price itself.

which as a consequence increases the network hashrate.

## 5.2 Trends

Another element that was considered in order to understand what drives the miners' decisions are search trends. Data from Google trends were gathered on search terms like "mining," "Bitcoin," "ASIC," etc. One striking observation was that Google trends indices on "Bitcoin" and "mining"-related keywords are particularly strong in a handful of African countries[2]

Figure 20 shows that there is a strong correlation between the Google trend index for the word "mining" and the price of Bitcoin, in particular during the peak of 2018.

## 5.3 A simple model of the network hashrate

For miners need to make predictions and because the hashrate is an important variable they need to consider when deciding to mine, attempting to model the hashrate can be valuable for miners.

First, the hashrate is modeled by using a linear approximation based on only the price of bitcoin:

$$\text{Hashrate}_t = a \cdot \text{Price}_{t-\Delta t} \tag{6}$$

Second, some information is introduced about the lagged hashrate by adding a factor that corresponds to the average hashrate of the top four mining pools:

[2]Those are quite correlated to the ones cited in https://bitcoinafrica.io/bitcoin-in-africa/. Also see https://www.coindesk.com/bittrex-crypto-exchange-valr-south-africa-bitcoin for complementary information.

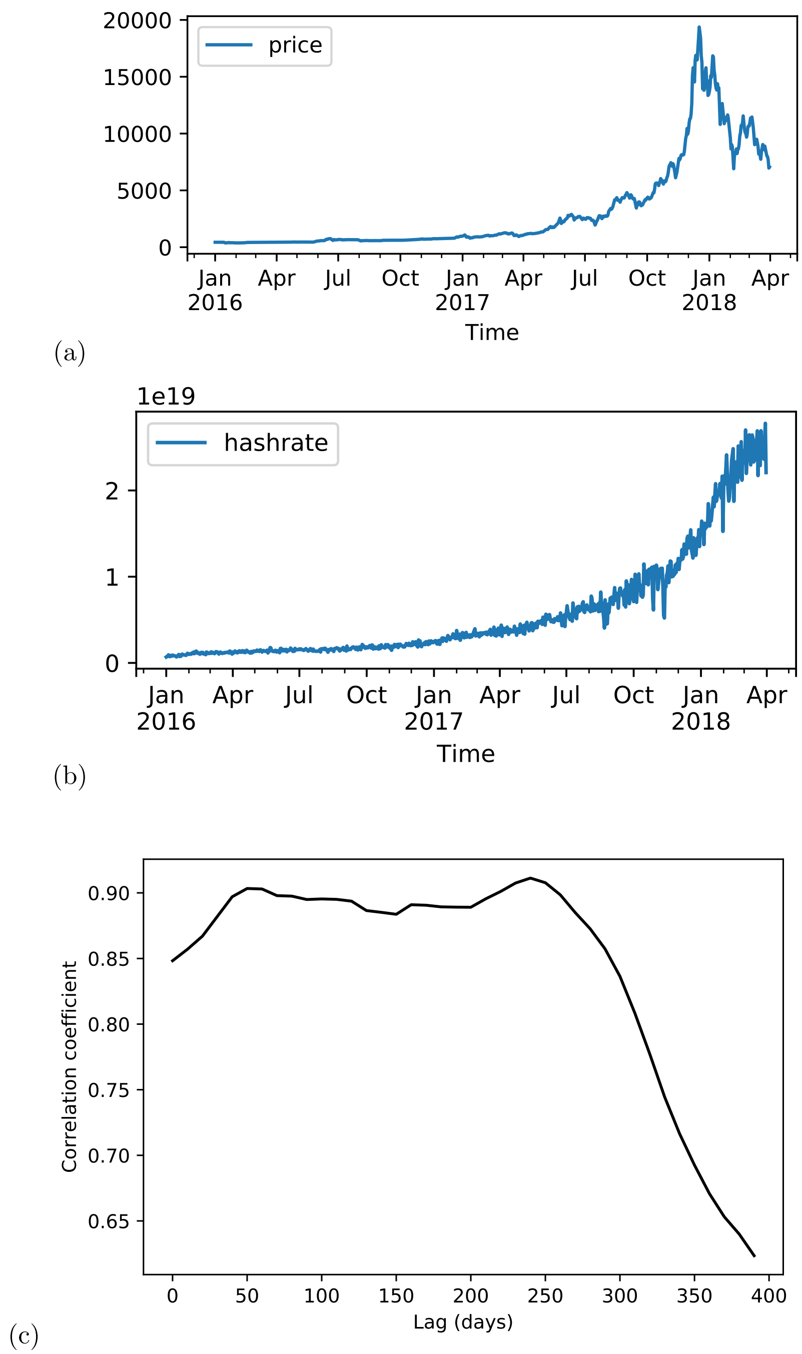



Figure 19: Correlation coefficient between the hashrate and the bitcoin price **over the period Jan. 2016 – Mar. 2018**. (a) and (b) show the price of Bitcoin and network hashrate, respectively.

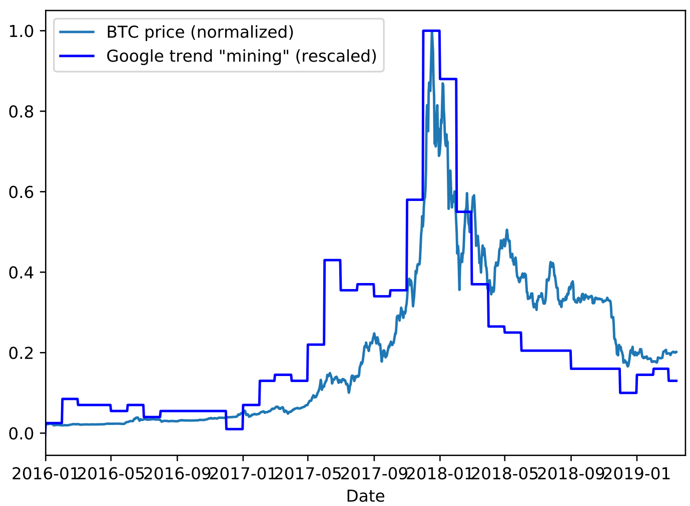



Figure 20: Comparison between the Bitcoin price and the Google trend index associated with the keyword “mining”.

AntPool, BTC.TOP, ViaBTC, and SlushPool.

$$\text{Hashrate}_t = a \cdot \text{Price}_{t-\Delta t} + b \cdot \overline{\text{Sub Hashrate}}_{t-\Delta t} \tag{7}$$

The results from the expression in eq. (6) (i.e., with the price only) are shown in fig. 21. Although the model has a reasonably good performance over the beginning of 2018, it does not capture the dynamics of prior dates by orders of magnitude. Upon introducing the second factor in eq. (7), the model shown in fig. 22 captures much more of the hashrate evolution. However, it should be noted that there are strong problems of collinearity since many of these variables are correlated. The lag $\Delta t$ was selected in order to have an $R^2$ as high as possible in the linear regression, which yielded $\Delta t = 175$. Note that this is

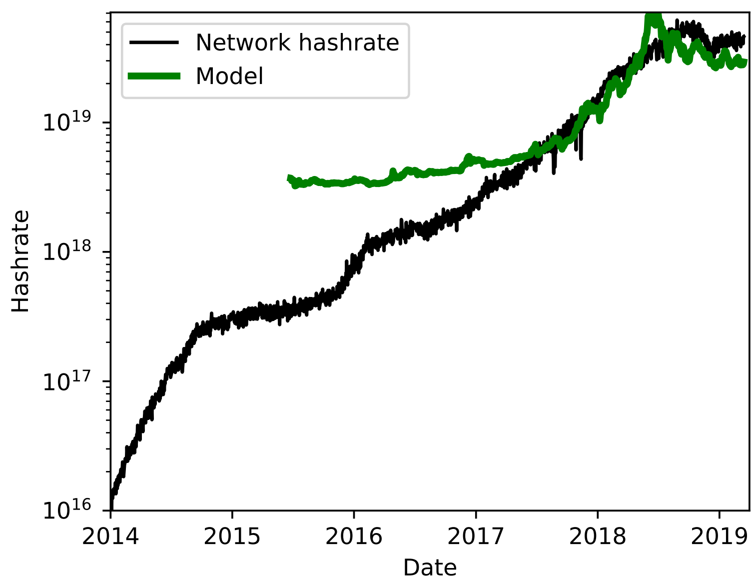



Figure 21: Comparison between the network hahsrate and a linear single-factor approximation of the hashrate based on the Bitcoin price.

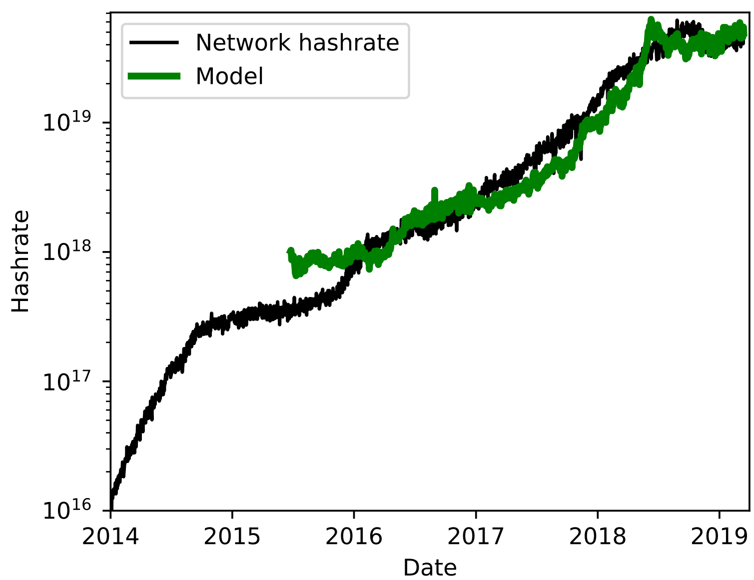



Figure 22: Comparison between the network hahsrate and the two-factor linear model.

lower than the lag of 250 days that was previously identified.

An interesting feature that is captured by the model, as shown in fig. 22, consists of the recent increase in hashrate despite the fact that the price of Bitcoin had been going down.

## 6 Conclusions

The economics of mining Bitcoin have been investigated from the viewpoint of miners. Data were aggregated to describe the operation parameters of the miners such as the cost of electricity and cost of hardware. The repartition of the miners was simplified and the total hashing power was converted to a number of units running on the network in order to more intuitively size the total hashing power.

As new hardware is introduced in the market, this creates pressure for the miners to upgrade so that their share of the hashrate remains large enough for their operations to retain enough of the network mining rewards and be profitable.

Based on the data collected and estimated, an empirical model of the mining profitability was constructed. The outcome indicates that with a deprecation horizon of 24 months, Bitcoin mining has not been profitable in the recent times. This may be an indication of the strong disparity between the miners where only top-tier miners are able to make profits, or indicate that our estimates are too far away from the actual costs miners are able to obtain in reality. The next year will be interesting to watch in this regard with new mining hardware hitting the market with significant improvements (e.g. the Antminer S17 was released recently by Bitmain).

The lag between the price of Bitcoin and the network hashrate was studied with the rationale that increasing prices would incentivize mining—resulting in hashrate increases—and vice versa. Then, high correlation between the lagged values may be representative of the time required to install the mining facilities and begin operations.

As miners are deciding whether to mine or not, they need to make various projections on how the market is going to evolve in order to assess the profitability of their investment. A linear model was built in order to evaluate the network hashrate based on the 175-lagged Bitcoin price and top-pool-average hashrate. Despite the sheer simplicity of the model, the increase of the hashrate in spite of diminishing price in 2019 is captured.

# A Appendix for miners' parameters

Below are gathered links to data sources relating to mining hardware that were used in this report.

1. Antminer S1 (using S1-115.2G)

   Parameter; Prize

2. Antminer S3 (using S3-440G)

   Parameter; Prize

3. Antminer S5 (using S5-1150G)

   Parameter; Prize

4. Antminer S7 (using S7-4T)

   Parameter; Prize

5. Antminer S9 (using S9-14)

   Parameter; Prize

6. Antminer S11 (using S11-21)

   Parameter; Prize

7. Avalon A6

   Parameter; Prize

8. Avalon A7

   Parameter; Prize

9. EBIT E9

   Parameter; Prize

10. EBIT E10

    Parameter; Prize

11. WhatsMiner M3

    Parameter; Prize

# References

[1] E. L. Christopher B., Samuel G., "The bitcoin mining network - trends, marginal creation cost, electricity consumption & sources," 2018.

[2] Bitcoinity.org, "Bitcoin network hashrate," 2019.

[3] N. C. Jing Data, "The evolution of the miners," 2018.

[4] B. Research, "Electricity price for industrial users in china," 2019.

[5] I. E. Agency, "Electricity information," 2018.

[6] J. Kühnen, B. Song, D. Scarselli, N. B. Budanur, M. Riedl, A. P. Willis, M. Avila, and B. Hof, "Destabilizing turbulence in pipe flow," *Nature Physics*, vol. 14, pp. 386–390, Apr. 2018.