The intrinsic value of bitcoin and the excessive price volatility

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Abstract

This paper formulates the intrinsic value of bitcoin in terms of hash rate (i.e. mining power consumption). In developing the intrinsic value of bitcoin, the profitability of mining hardware is formulated as the net present value of the revenue earned and costs paid by bitcoin miners, and the behavior of bitcoin miners is analyzed. Next, the relationship between mining by bitcoin miners and bitcoin price fluctuations is discussed. Finally, the future of bitcoin is discussed. JEL G14, G19, G40

1. Introduction

Bitcoin was created by a paper entitled "Bitcoin: A Peer-to-Peer Electronic Cash System" [1], published on the cryptography mailing list at metzdowd.com [2] in 2008. Bitcoin (BTC) is the first electronic currency to use the peer-to-peer network to prevent double spending without a central authority. Bitcoin's security system is called the blockchain, and it has been proven to work well without being breached. The result of this grand experiment shows that bitcoin could be a cheap and efficient payment system option. The blockchain is probably one of the reasons why bitcoin has attracted so much public attention since its inception. However, it has also become clear that bitcoin as money has many shortcomings. Currently, bitcoin is considered a commodity like gold. This suggests that bitcoin is fulfilling the function of money as a store of value. However, the number of goods and services that can be exchanged for bitcoin is still limited, and therefore bitcoin cannot be said to function as a medium of exchange (Baur and Dimpfl 2021)). The main reason why bitcoin is not used to exchange goods and services is due to excessive price volatility. The literature on the nature of bitcoin's high price volatility, and the factors that influence volatility, has grown very rapidly in recent years. (Dyhrberg (2016), Pichl and Kaizoji, (2017), Eom et. al. (2018), Nan and Kaizoji (2019), L'opez-Cabarcos, et. al. (2021), Bakas et. al. (2022), and Benhamed, et. al. (2023). This paper investigates the causes of the excessive price volatility of bitcoin. We focus on the intrinsic value of bitcoin to understand the excessive volatility.

The rest of the paper is organized as follows: Section 2 describes the intrinsic value of bitcoin while Section 3 discuss about mining cost. Section 4 shows the potential for mined bitcoins to be retired. Section 5 presents the mechanism for volatility in the market price of bitcoins. Section 6 provides concluding remarks.

2. The intrinsic value of Bitcoin

Bitcoins are created through a kind of computer game called mining. Bitcoins are paid out as a reward to the winner of the mining. The mining difficulty (hereafter referred to as "difficulty") is adjusted approximately every two weeks, depending on the mining software, so that a successful mining attempt is made every 10 minutes. Miners are rewarded with a certain number of Bitcoins for each successful mining attempt. The number of bitcoins paid as a reward is designed to be halved every four years. The final total number of bitcoins created in this way is set at 21 million, and if bitcoins are created at the current rate, the supply of bitcoins is expected to end around 2140.

This section focuses on the behaviour of minorities. There are several ways of mining bitcoin. One is by individuals mining on their own mining hardware. In the early days, many miners mined privately and earned revenue, but this is no longer a popular method of mining bitcoin, as it is no longer possible to successfully mine bitcoin without using a dedicated mining machine. Instead, individuals have taken to using cloud mining services provided by specialised mining companies as a way of mining. This method allows individuals to participate in mining by purchasing the Hash rate of cloud mining and does not require them to have dedicated mining hardware. It has the advantage of not incurring capital investment costs.

When a company operating a cloud mining operation successfully mines, individual miners participating in cloud mining receive a dividend of bitcoins in proportion to the Hash rate they own.

It is easy to know how much revenue can be earned from mining now or in the past. For example, Whattomine[1] offers a service on the web that calculates the bitcoins earned in the past day or the past seven days after setting the performance of the mining hardware.

However, what miners really want to know is the future mining revenue they will

[1] For more information on Whattomine, see webpage https://whattomine.com/.

earn. For example, how much bitcoin mining revenue there is at a Hash rate of a gigahash per second (Gh/s) depends on the difficulty of the bitcoin. In the history of Bitcoin so far, the difficulty level has continued to increase as a trend. Therefore, it is safe to assume that the bitcoins earned at the hash rate of a Gh/s will decrease over time; the total amount of bitcoins earned in the future at a Gh/s is written in discounted present value form. The discounted present value of the hash rate in bitcoin, $PV_{BTC,t}$, can be written by the following equation,

$$PV_{BTC,t} = \frac{BTC_{t+1}}{(1+R)} + \frac{BTC_{t+2}}{(1+R)^2} + \cdots + \frac{BTC_{t+T}}{(1+R)^T} + \cdots. \quad (1)$$

where BTC_{t+i} is the amount of bitcoin earned by mining at the end of period *t+i,* and is the borrowing rate for the cost of mining.

To consider the implications of this formula more concretely, consider *hashing 24*[2], which is a company that provided a major cloud mining service. As well as providing bitcoin miners with cloud mining services, *hashing 24* also operates an auction market called the *Trading Room*, where miners who bought hash rate can sell their hash rates to other miners. Hash rates are exchanged for bitcoins on the auction market. Sellers of hash rates will calculate the discounted present value of the Hash rate they hold and try to sell the hash rate at a price above the value. Buyers of hash rates would also predict the bitcoins they will get in the future using the discounted present value formula (1). If the auction market is efficient, the price of a GH hash rate should match the discounted present value of the hash rate. Hence, the following relationship holds.

$$HR_{BTC,t} \equiv PV_{BTC,t} = \frac{BTC_{t+1}}{(1+R)} + \frac{BTC_{t+2}}{(1+R)^2} + \cdots + \frac{BTC_{t+T}}{(1+R)^T} + \cdots \quad (2)$$

where $HR_{BTC,t}$ is the price of the hash rate in bitcoin on the auction market. The inverse of the discounted present value of the Hash rate, $1/PV_{BTC,t}$, represents the Hash rate consumed to mine one Bitcoin. This value is referred to as *the intrinsic value of bitcoin*.

Let's examine equation (1) using bitcoin's data provided by Nasdaq Data Link. As an example, a relatively early period (2013-2014) has been chosen. Figure 1 shows the number of bitcoins mined per day divided by the network hash rate (tera hashes per second) used by the mining network. The reward per mining success during this period

[2] For more information on hashing24, see the webpage https://hashing24.com/.

was 25 BTC. This can be thought of as the price of bitcoin per hash. As can be seen in Figure 1, the price of bitcoin per hash from the mining network has decreased exponentially over time. In other words, the intrinsic value of bitcoin has increased exponentially.

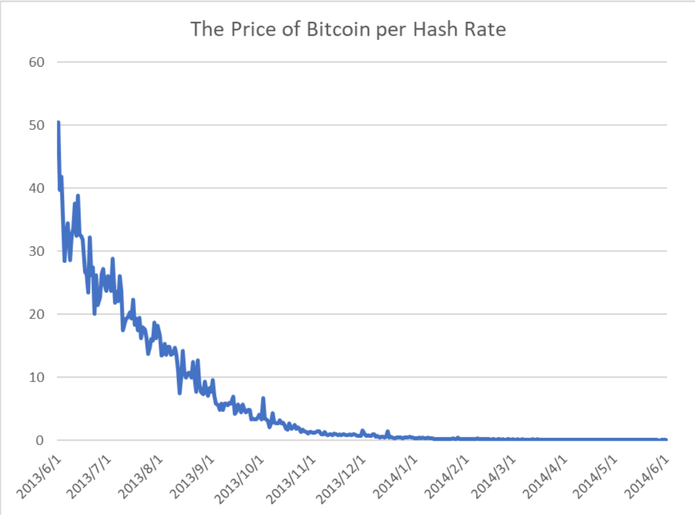
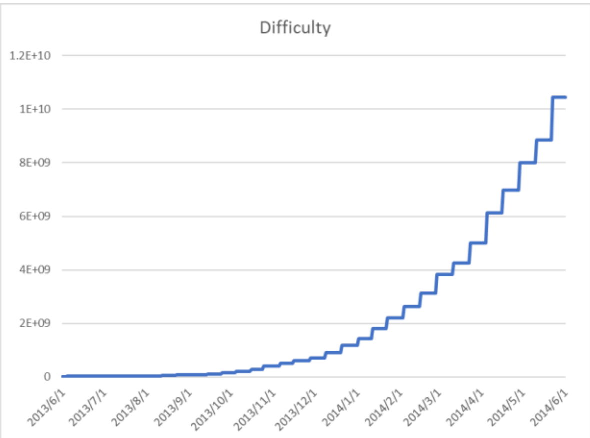


Figure 1: The Price of Bitcoin per Hash Rate. The period：2013/06/01-2014/06/01.

Prepared by the author from Bitcoin-related data provided by Nasdaq Data Link.

Figure 2 shows the evolution of *difficulty* and network hash rate over the same period as Figure 1, with difficulty increasing exponentially. The network hash rate is the estimated number of tera-hashes per second (trillions of hashes per second) performed by the Bitcoin network. It is clear to see that the difficulty increases in a staircase fashion every two weeks. While the increase in difficulty increases the network hash rate required for mining, the number of bitcoins mined is fixed, so the price of bitcoin per hash rate is likely to have decreased as the network hash rate increased.



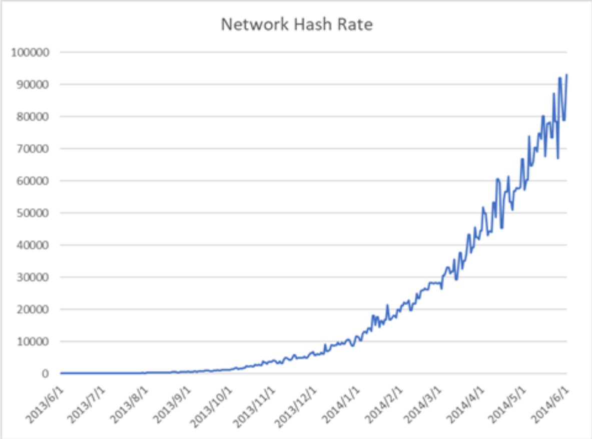


Figure 2：Difficulty and Network Hash Rate. The period：2013/06/1-2014/06/01.

Source: Nasdaq Data Link

To see more concretely how much an increase in difficulty reduces the discounted present value of hash rate, Figure 3 shows a scatterplot of the relationship between the two. The time period is from 18/08/2010 to 25/01/2023. Figure 3 is a log-log plot, so we can see that the price of bitcoin per hash rate decreases in a power-law fashion as difficulty increases.

$$PV_{BTC} = D^{-1.092}$$

where D is difficulty. The power index is calculated to be -1.092 using regression analysis. The coefficient of determination for the regression analysis is 0.9998.

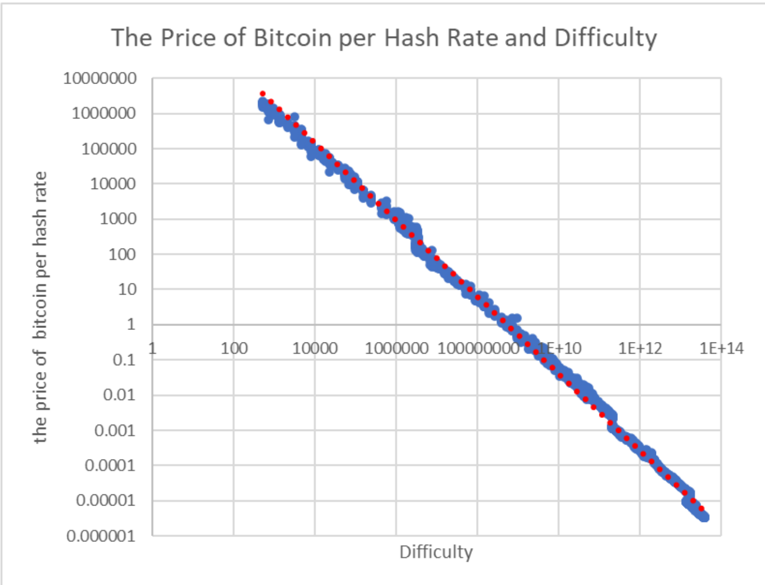


Figure 3: Difficulty and the discounted present value of hash rate.

The period: 2010/08/18-2023/01/25.

Prepared by the author from Bitcoin-related data provided by Nasdaq Data Link.

The power law is robust. It indicates that the inverse relationship between the discounted present value of hash rate and difficulty, shown in equation (2), holds for the mining network. Let's look at the relationship in equation 2 using the intrinsic value of Bitcoin and the difficulty level.

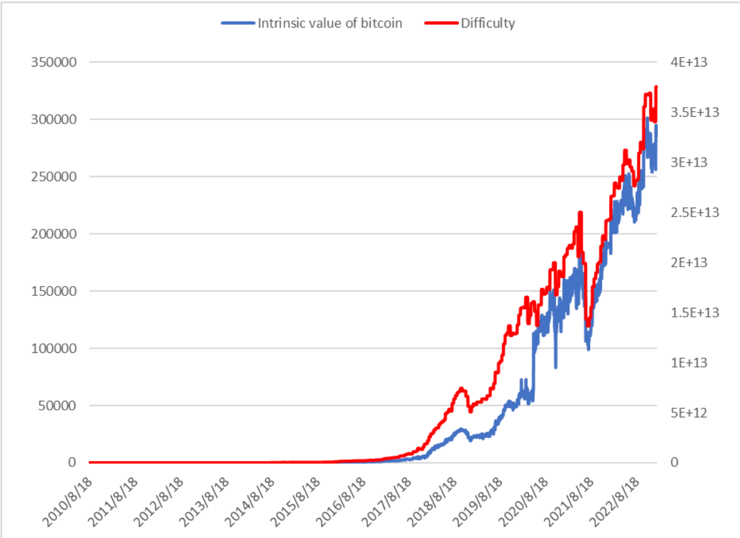


Figure 4: Difficulty (the red line) and the discounted present value of hash rate (the blue line). The period: 2010/08/18-2023/01/25.

Prepared by the author from Bitcoin-related data provided by Nasdaq Data Link.

Figure 4 shows the time series of difficulty and the intrinsic value of bitcoin. Taking 10 August 2010 as 1, the intrinsic value of bitcoin on 25 January 2023 is 567 billion times higher, indicating that bitcoin is being mined at a huge hash rate consumption.

If miners want to use bitcoins in the real economy, they must first convert bitcoins into another currency, such as US dollars in a cryptocurrency exchange. This is because bitcoin has little function as a medium of exchange. Then the present discounted value of the hash rate should be rewritten using bitcoin prices against dollars as follows,

$$PV_t = \frac{P_{t+1} \cdot BTC_{t+1}}{(1+R)} + \frac{P_{t+2} \cdot BTC_{t+2}}{(1+R)^2} + \cdots + \frac{P_{t+T} \cdot BTC_T}{(1+R)^T} + \cdots \quad (2)$$

Let's go back and consider the example of the hashing 24 miner again. The miner wants to convert the bitcoins earned from mining into dollars, so when he sells his

Hash rate in the trading room, he calculates the discounted present value of his Hash rate using equation (2). The buyer of the hash rate similarly uses equation (2) to calculate the discounted present value of the hash rate to be purchased. If the future price of bitcoin is predictable, the market-determined price of the hash rate in dollars and the discounted present value of the hash rate should match. This means that

$$HP_t \equiv PV_t \qquad (3)$$

where HP_t is the price of the hash rate measured in dollars in period *t*. The value, $1/PV_t$, is *the intrinsic value of bitcoin in USD*. Figure 5 compares the time series of the intrinsic value of Bitcoin expressed in Bitcoin and USD. It can be seen that the intrinsic value of bitcoin increases with difficulty and is predictable if the difficulty can be predicted, while the intrinsic value of bitcoin expressed in USD fluctuates wildly, influenced by changes in the market price of bitcoin The intrinsic value of bitcoin expressed in USD is appropriately described as being on a random walk and is unpredictable. This issue of uncertainty is discussed again in Section 5.

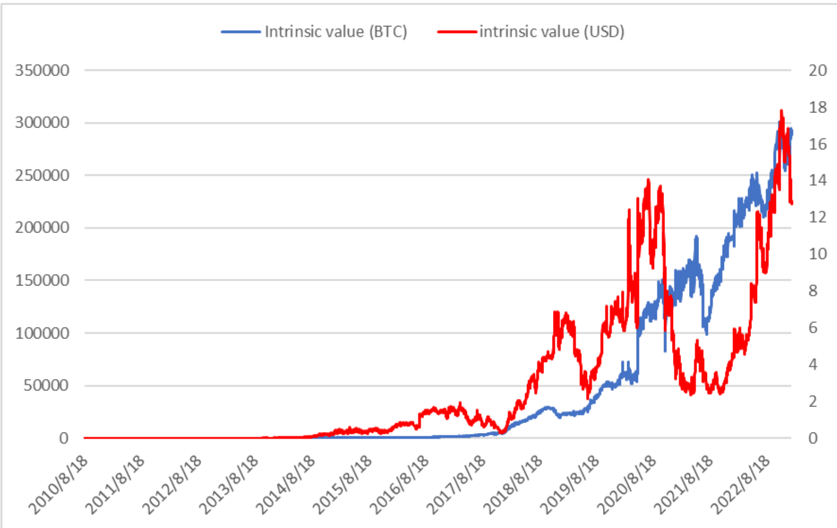


Figure 5: The intrinsic value of bitcoin (the blue line) and the intrinsic value of bitcoin in USD (the red line). The period: 2010/08/18-2023/01/25.

Prepared by the author from Bitcoin-related data provided by Nasdaq Data Link.

3. Cost of Mining

So far, we have considered the intrinsic value of bitcoin, focusing on miners who use cloud mining services to conduct mining. In Section 3, we consider the behaviour of miners mining using mining hardware. Miners have to purchase mining hardware and bear various costs associated with mining, such as electricity costs, maintenance costs, computer cooling costs, depreciation costs and labour costs. Let us consider the economic activity of the miner, taking into account Mining costs each period, including electricity costs and the investment costs of the mining hardware: the discounted present value equation (2) of the hash rate is rewritten in the net present value (*NPV*) of mining, taking into account the mining costs.

Equation (2) can be rewritten as follows.

$$NPV_t = -I_t + \frac{\left[P_{t+1}BTC_{t+1} - C_{t+1}\right]}{(1+R)} + \frac{\left[P_{t+2}BTC_{t+2} - C_{t+2}\right]}{(1+R)^2} + \cdots + \frac{\left[P_{t+N}BTC_{t+N} - C_{t+N}\right]}{(1+R)^N} + \cdots$$

(4)

where NPV_t is the net present value of mining in dollars. P_{t+1} is the dollar price of bitcoin in dollar in the period t+1, C_{t+1} is the mining costs in period t+1, and I_t is the investment cost of the mining hardware. The price is set by the cryptocurrency exchanges. Miners must calculate the *NPV* of mining by predicting the future movement of the market price of bitcoin and the amount of bitcoin they can earn from mining. Miners will try to choose a mining strategy that maximizes the NPV. If the NPV is positive, miners will mine Conversely, if the NPV is negative, the miner will not mine. If the market for mining hardware were competitive, the NPV would be zero. In other words,

$$I_t = \frac{\left[P_{t+1}BTC_{t+1} - C_{t+1}\right]}{(1+R)} + \frac{\left[P_{t+2}BTC_{t+2} - C_{t+2}\right]}{(1+R)^2} + \cdots + \frac{\left[P_{t+N}BTC_{t+N} - C_{t+N}\right]}{(1+R)^N} + \cdots \quad (5)$$

Since the miner's profit in each period depends on the market price of bitcoin in that period, whether a miner invests depends on the miner's expectation of the future price of bitcoin. This is the biggest factor that makes decision making difficult for miners: it is easy to imagine that the *NPV* calculations are difficult.

3.1. Mining hardware

It is an oligopolistic market with the three largest mining equipment manufacturers (Bitmain, Canaan Creative and MicroBT) holding more than 85% of the market share. These three companies launch new products every year, and the performance of their mining hardware improves every year. Currently, most bitcoin mining is done using application-specific integrated circuit ASICs optimised for bitcoin mining.

The Cambridge Centre for Alternative Finance (CCAF) lists more than 100 different bitcoin ASIC models designed for SHA-256 operations and publishes data on the mining efficiency of each model. Mining efficiency is expressed in Joules per Gigahash (J/Gh). The efficiency of a 1000 W mining device producing 10,000 gigahashes per second (Gh/s) is 0.1 joules per Gh (J/Gh). See https://ccaf.io/cbeci/index/methodology.

Figure 7 shows the mining efficiency of bitcoin ASIC models released since 2014. Let's take a look at the changes in the efficiency of mining hardware using this data as an example: the Bitmain Antminer S9 (11.5 Th) launched in 2016 had an efficiency of 0.1 (J/Gh); in April 2019, Bitmain launched the Antminer S17 Pro (53 Th) with an efficiency of 0.04 (J/Gh); in June 2022, the Bitmain Antminer S19XP (140 Th) was launched. The last machine has an efficiency of 0.02 (J/Gh). As efficiency increases, the price of mining machines also increases.

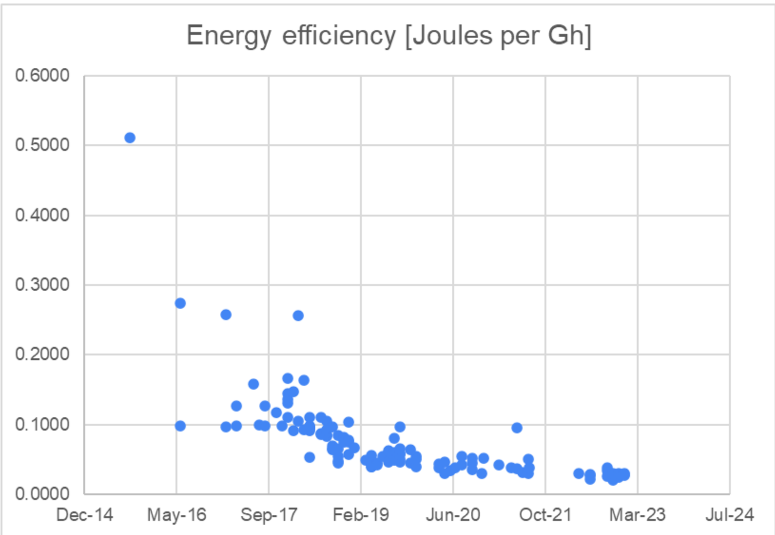


Figure 6: H Bitcoin mining equipment efficiency
Source: Cambridge Bitcoin Electriciry Consumption Index provided by
the Cambridge Centre for Alternative Finance (CCAF).
See CBECI http://sha256.cbeci.org

3.2. Electricity

Electricity costs account for a significant proportion of the cost of mining each period. Mining requires hash rate, which is the power of the mining computer. As the difficulty level increases, the hash rate required for mining increases, which means higher electricity costs. The electric cost is charged in a currency like dollars, not bitcoins. That is, while miners are rewarded in bitcoin, they must pay for their mining costs in dollars.

Cambridge Bitcoin Electricity Consumption Index (CBECI) provides the time series data of the total power used by bitcoin miners in gigawatts (GW) per day. *Cambridge Bitcoin Electricity Consumption Index (CBECI)* [3]calculates the total power from the network hash rate by 'assuming that all miners are mining using an equally weighted basket of hardware types that are profitable in terms of electricity prices'. To investigate whether the hardware can generate revenue from mining at current electricity prices and the market price of bitcoin, the *efficiency* of each mining hardware j is defined as

$$\theta_j E \leq SR$$

where θ_j : energy profitability of mining hardware [Joule/hash], E : electricity cost per joule [USD/Joule], and : SR :mining revenue per hash [USD/hash]. Note that a 1000W mining device that generates 10,000 Gigahashes per second (Gh/s) has an efficiency of 0.1 Joules per Gh (J/Gh), and that the cost of mining only considers electric power consumption, and do not include capital expenditures (e.g., acquisition and depreciation costs) and other operational expenditures (e.g., cooling, maintenance, and labour costs) in the cost. Figure 4 shows the total electricity consumed by the Bitcoin network, expressed in gigawatts (GW), over the period from 18 August 2010 to 25 January 2011. It is clear from the figure that the total mining power continues to increase with fluctuations. The reason why the total output fluctuates up and down despite the constant electricity price is that fluctuations in the market price of bitcoin change the behaviour of bitcoin miners. When the market price spikes, miners can generate revenue from mining even with older, less efficient mining hardware that they own, so when the price spikes, less efficient mining machines are used to mine and total power increases; conversely, when the price collapses, only efficient mining hardware is used, resulting in a decrease in total power.

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[3] Furthermore, for the calculations, it is also assumed that the PUE for all mining equipment is 1.10 and that the global average electricity price is constant over time, which corresponds to USD 0.05/kWh.

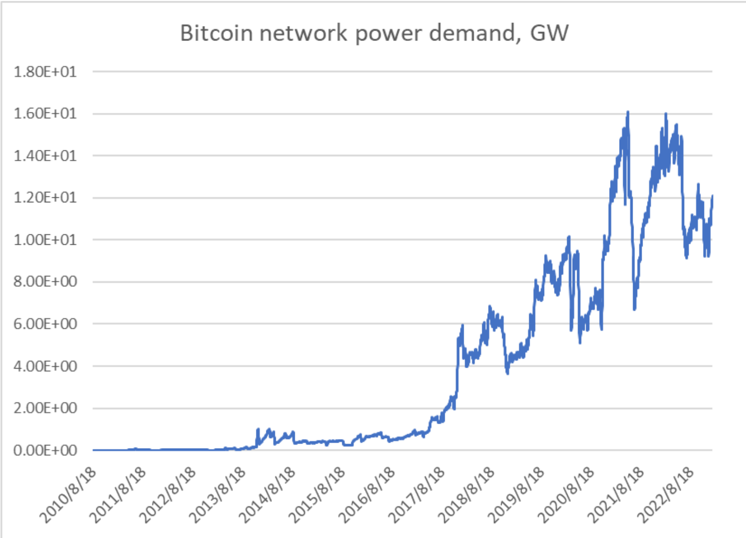

Figure 7: Historical Bitcoin network power demand (gigawatts (GW))
Source: Cambridge Bitcoin Electriciry Consumption Index provided by the Cambridge Centre for Alternative Finance (CCAF).
See CBECI https://ccaf.io/cbeci/index

As the difficulty of mining increases, the hash rate of mining networks continues to increase as the difficulty increases. Current observations indicate that the increase in mining difficulty is outpacing the increase in mining machine efficiency, so the total power consumed by mining continues to increase.

3.3 Profitability threshold

In addition to the efficiency of each mining hardware, CBECI publishes data on the *profitability threshold* of mining. The profitability threshold is calculated using the following formula,

$$\theta = \frac{SR}{E}$$

where θ denotes profitability threshold [Joule/hash], and E: electricity cost per joule [USD/Joule], and : SR :mining revenue per hash [USD/hash]. The following assumptions are made here.

・*Assumption 1*: the global average electricity price is constant over time and corresponds to 0.05 USD/kWh.

・*Assumption 2:* during time periods where no mining equipment is profitable, the model uses the last known profitable equipment.

・*Assumption 3*: all miners are assumed to use an equally-weighted basket of hardware types that are profitable in electricity terms[4].

The profitability threshold was above 1,000 until around 2011; it fell below 100 in 2014 and below 1 from around 2016; as of February 2023, the profitability threshold is 0.07. This means that unless mining hardware with energy efficiency below this value is used, mining revenues above the electricity price cannot be generated. Therefore, miners should use mining hardware that is above the threshold value θ to do their mining. Mining machines that also have an efficiency that falls below the threshold are either abandoned or discarded.

The figure shows a scatterplot of the relationship between profitability threshold and difficulty, written using a log-log plot. The dotted line is the expression for the power law,

$$\bar{\theta} \sim D^{-0.648}.$$

The power exponent is – 0.648. The coefficient of determination for regression analysis is 0.677. The power law shows a similar relationship to the power law representing the relationship between price and difficulty expressed in hash rate bitcoins, but the reason why the power law is less applicable for the profitability threshold is that the profitability threshold depends on the market price of bitcoins.

It can be seen that as the difficulty level increases, the profitability threshold decreases according to the power law. The increase in difficulty is indicative of increased competition in mining, but also of more energy-efficient mining hardware being deployed to win the mining game, pushing down the profitability threshold. Figure 5 shows a scatterplot of the relationship between difficulty and the number of bitcoins mined in a month divided by the total power in a month. It can be seen that the number of Bitcoins that can be mined with a GW of power decreases according to the power law as the difficulty increases. However, compared to the power law in Figure 3, which shows the relationship between the bitcoin that can be mined with a Gh/s and difficulty, the power law between the Bitcoin that can be mined with a GW of power and difficulty is not strict. This difference is thought to be due to the fact that, as mentioned earlier, power consumption is affected by the bitcoin price.

[4] For more information on Cambridge Bitcoin Electricity Consumption Index, see CBECI https://ccaf.io/cbeci/index/methodology.

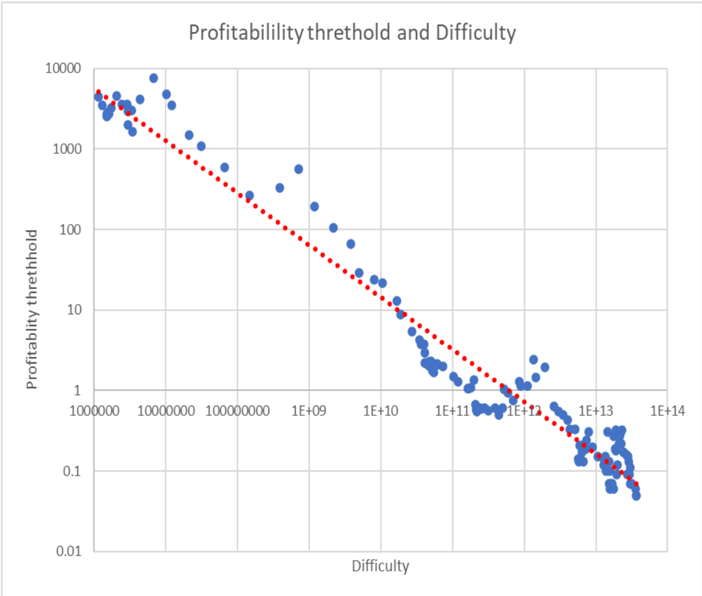

Figure 8: Profitability threshold and Difficulty

Prepared by the author from Cambridge Bitcoin Electricity Consumption Index provided by the Cambridge Centre for Alternative Finance (CCAF) .

See CBECI https://ccaf.io/cbeci/index

Write down the *NPV* of mining using the energy efficiency and profitability thresholds of the mining hardware *j*. A simple calculation yields the following relationship.

$$NPV_{j,t} = \frac{\left[(\bar{\theta}_{t+1} - \theta_{j,t+1})E_{j,t+1}\right]}{(1+R)} + \frac{\left[(\bar{\theta}_{t+2} - \theta_{j,t+2})E_{j,+2}\right]}{(1+R)^2} + \cdots + \frac{\left[(\bar{\theta}_{t+N} - \theta_{j,t+N})E_{j,t+N}\right]}{(1+R)^N} - I_{j,t}$$

(4)

Let us assume that mining hardware purchased in period t starts generating revenue from period t+1.

The profitability threshold tends to decrease as the difficulty increases. Miners need to calculate the *NPV* of the mining hardware *j* by estimating the trend in difficulty and bitcoin revenue. Period *N* is the period during which a machine can generate positive revenue from mining. That is, the period from t+1 to *t+N* is Period *t* to *t+N* is the period during which the mining hardware *j* can be used for mining.

From the previous discussion, it is clear that generating revenue from mining requires investment in high-performance mining hardware, but with increasing difficulty over the years, the time to renew mining hardware is becoming shorter and shorter. It is thought that miners are trying to invest in the latest hardware as quickly as possible, which lowers the profitability threshold and creates a spiral that further intensifies competition in mining. In addition, despite the increasing efficiency of mining hardware, the amount of electricity used for mining as a whole is on the rise.

The mining hardware market is a multi-company oligopoly. As such, the major mining hardware providers have pricing power over their products and are likely to generate significant revenues from the sale of mining hardware. (McCook (2018)). On the other hand, miners who invest in mining hardware have to anticipate future revenues, but face great uncertainty as future revenues depend on the future price of bitcoin.

4. Hoarding of Bitcoin

It has been observed that miners calculate the *NPV* of their mining (4) and make investment decisions. The miner's goal is to maximize the *NPV* of mining. One reason they may continue to mine is that they expect to receive future revenues from their bitcoin holdings due to the rising price of bitcoin. An increase in the bitcoin price raises the breakeven point because it increases the miner's revenue. Thus, in a situation where the bitcoin price is stagnant and the market price is below the price miners expect, miners who want to maximize their net present value will withdraw mined bitcoins in anticipation of a future price increase. Conversely, in a situation where the Bitcoin price is soaring and sufficient revenue can be generated, miners will sell their mined Bitcoins on the market and exchange them for hard currency. In general, miners who own mining hardware tend to retire mined bitcoins in anticipation of future price increases, as they need to recoup their investment in mining hardware through mining. Figure 9 shows that the time series of the total number of bitcoin mined and of the total estimated value in BTC of transactions on the blockchain. While the total number of bitcoins mined is continuously increasing, the number of bitcoins traded on the blockchain has not shown an increasing trend. This may indicate that a significant proportion of mined bitcoins are being retired.

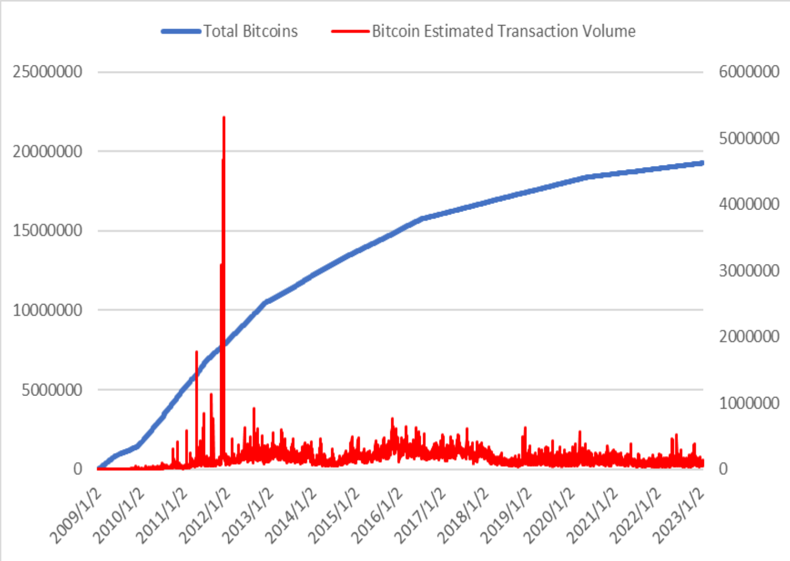

Figure 9: The total number of bitcoins that have already been mined (the blue line) and the total estimated value (BTC) of bitcoin transactions on the Bitcoin blockchain. (the red line). The period: 2009/01/012023/01/25.

Source: Nasdaq Data Link.

5. Excessive price volatility

The discussion so far has looked at the value of bitcoin from the miner's perspective. From the miner's perspective, it is the hash rate that creates bitcoins. Furthermore, it is the electricity that powers the hash rate that generates bitcoins. In this sense, bitcoin is a very expensive currency that requires enormous amounts of electricity to produce.

However, most investors on bitcoin exchanges value bitcoin in a very different way. Investors who view bitcoin as an asset are speculators who see the market price of bitcoin rising as it attracts public attention and becomes more popular, and who seek to profit from the expectation that the price will continue to rise. Bitcoin investor sentiment fluctuates and is influenced by a variety of information, including social media news, blog posts and tweets. It is also used as an asset to hedge the risk of assets such as equities. As bitcoins are rarely used to trade goods and services, investors do not care about the value of bitcoins themselves. Investors are more interested in making capital gains in fiat money, such as dollars, by exploiting the price fluctuations of bitcoin. Bitcoin investor sentiment fluctuates, influenced by a variety of information, including social media news, blog posts and tweets. It is also used as an asset to hedge the risk of assets such as equities. Bitcoin trading is unpredictable as it fluctuates under the influence of fickle investor psychology. See the price movement of bitcoin in Figure 10.

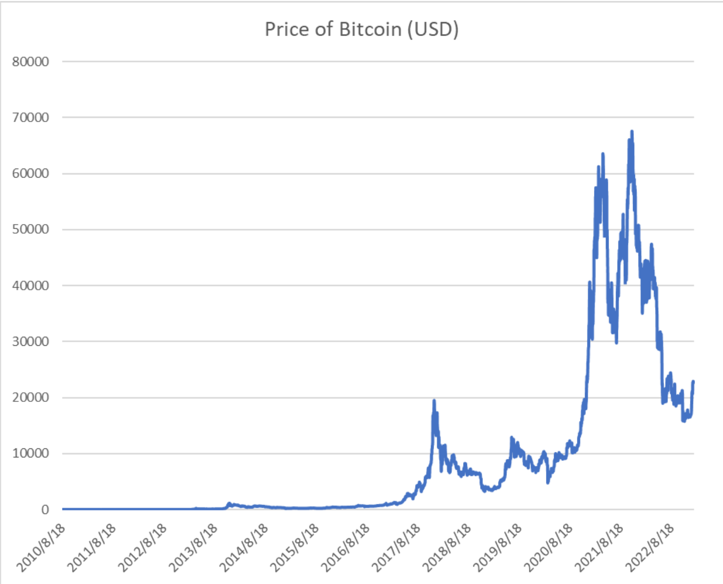

Figure 10: The Price of Bitcoin. The period: 2010/08/18-2023/01/25..

Prepared by the author from Bitcoin-related data provided by Nasdaq Data Link.

Miners tend to retire bitcoins in the hope that the price of bitcoins will rise, so if the price is stagnant, much of the mined bitcoins will be retired and the supply of bitcoins to exchanges will be limited. With limited supply, if demand increases for any reason, prices will spike. As the price spikes, miners will sell the bitcoins they have retired, causing the price to plummet. In this way, bitcoin transactions between speculators and miners are thought to cause bitcoin price fluctuations.

6. Concluding remarks

The total supply of bitcoin is set at 21 million coins and is expected to reach its limit in 2140. By 2022, more than 90% of bitcoins will have been mined. In order to protect the security of the blockchain, the degree of difficulty must increase. A significant decrease in difficulty would increase the likelihood that the most efficient miner would win the game and the blockchain could be breached. Bitcoin is a system that is sustained by increasing competition in the mining game. To be a winner in the mining game, miners must continue to invest in more efficient mining hardware and bear increasing power bills and other costs. Recent studies have highlighted the issue of CO_2 emissions from the vast amounts of electricity used in bitcoin mining as a cause of global warming

(Jones, et. al. (2022)). In addition, the market price of bitcoin must continue to rise in order for miners to absorb the inflated mining costs and generate revenue. Can the price of bitcoin continue to rise? It seems rather unreasonable to assume that the price of Bitcoin will continue to outweigh its increasing costs. It is known that there are large holders of bitcoin, known as *bitcoin whales*, many of whom are either miners who successfully mined large amounts of bitcoin in the early days or entrepreneurs involved in the bitcoin business. If many of them find it difficult to make a profit by continuing to mine, i.e. if they believe that the price of bitcoin will not rise enough to finance their mining costs in the future, they will convert their bitcoin reserves into fiat money such as US dollars on the cryptocurrency exchanges. Their action is likely to cause the price of bitcoin to plummet and could spell the end of bitcoin.

Acknowledgment

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