Impact of the 2020 Bitcoin Halving: A Mathematical, Social, and Econometric Analysis

Jered Masters, November 2019

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Abstract

Bitcoin (BTC) [1] is a decentralised crypto currency where transactions are made by broadcasting the intention to transact to volunteer "miners" around the world. These miners then compete to create a cryptographic signature which proves the transaction (and others) is valid and was initiated by a party in control of the funds. This signature and the transactions are then permanently committed to history on the blockchain. These miners are rewarded for the work of creating the signature with a fixed quantity of Bitcoin, the amount of which halves approximately every four years. This called a "Halving" or "Halvening". The next is predicted to occur in May 2020, and will result in the block reward reducing from 12.5 BTC per block to 6.25 BTC. This could have significant impact on mining profitability, the price of Bitcoin, liquidity and global transaction volume as this event will reduce the global revenue of mining by $7.3M USD (equivalent) per day. Some experts, analysts, and popular commentators speculate this will result in a significant increase in the price of Bitcoin, possibly more than doubling it over 12 months. This could add $146.6B USD equivalent at the current Bitcoin market capitalization.

The Bitcoin experiment has thus far been an interesting study into the viability of an unregulated, unbacked currency. The consequences of this Halving are likely to give hints about the long-term future of Bitcoin as this is the first Halving which puts a significant percentage of miners into a non-profitable state.

This study explores consequences of the Halving with a methodical approach and draws the conclusion that the price of Bitcoin could decrease in the short-term and increase in the medium-term, although unlikely to the same extent which previous Halvings have seen. Briefly discussed is the long-term utility and security of Bitcoin and how this potential future could also impact the price during the Halving.

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1.0 Introduction

1.1 Purpose

The intent of this study is to document and discuss in detail the various professional analyst statements, as they currently appear in the public domain, regarding of the impact of the 2020 Bitcoin Halving, and using these concepts to establish theoretical bounds for prediction by applying mathematical models to recent data.

1.2 Scope

Considerations in this study are restricted to extant literature and will discuss what is possible. In order to remain objective, it will refrain from adding speculative commentary, critical appreciation or interpretation. This study in no way should be interpreted as investment or financial advice. *Please conduct proper due diligence before making any investment decision.*

1.3 Audience

This study is primarily intended for principle stakeholders, but is written to be easily understood by those with a more general interest in the crypto-currency ecosystem.

1.4 Acknowledgements

The following people have lent their time and expertise to review, provide feedback and/or inspire the work presented in here. This study would not be what it is without their assistance:

- Dr Anthony O'Sullivan
- Richard Hodges
- Mark Hammond
- Charl Sparks
- Jon Myers

1.5 Summary of Results

While opinions differ on whether Bitcoin has an inherent value, the strong correlation between mining expenditure and the price of Bitcoin does not prove a cause-effect relationship which would act to inflate the value of Bitcoin after the Halving. Rather a percentage of mining effort may switch to other, more profitable alt coins (5.2 Market and Mining Reaction (Projection), p26).

Following the Halving, it is possible the price of Bitcoin will decrease in the short term, caused by the mempool congestion as a result of the reallocated mining efforts. This reallocation could cause the global Bitcoin Hashrate to drop by up to 41% (6.1 Mempool Congestion, p28), resulting in increased mining time per block, up to 24 minutes, an effect which could last up to 12 days. The consequence of this congestion is the decreased utility of the currency and increased transaction fee on the network.

After this potential period of congestion, the price of Bitcoin could return to, or surpass, its pre-2020-Halving price, although this may not be to the same extend as previous halvings. The increase in price would be a result of the reduced downward pressure on the price of Bitcoin, due to the reduction in liquidation of mining revenue (6.2 Reducing Downward Price Pressure, p30). The state of the market going into the 2020 Halving is different to the previous two Halvings in a few critical ways, possibly causing the reaction to be different. The market now anticipates this halving and its impact (3.0 Market Speculation, p13), and have likely begun hedging or taking positions; a market configuration which has historically resulted in similar opportunities being attenuated and/or protracted over a longer period.

2.0 Literature Review

Despite the significant impact of the Halving on mining revenue and speculated price increase, most of the literature concerning the impact of the Halving is casual and popular in nature with very little emanating from the academic sector.

2.1 Inherent Value of Bitcoin

Establishing an inherent value for Bitcoin has been a controversial exercise. Jamie Dimon, CEO of investment bank JP Morgan Chase, argues (2017, [2]) that the value of Bitcoin is zero and the entire pursuit is at best fool's errand, and at worst a fraud akin to the Dutch tulip bulb bubble in 1637 [3]. Cheah and Fry similarly limit its value in their 2015 study [4]. They used models developed by Johansen et al (1998, [5]) and concepts from Shiller (2000, [6]), derived from their extensive work on understanding traditional market bubbles, to analyse cryptocurrencies and Bitcoin value inflation. This work presents an empirical investigation, disputing an inherent value, arguing the primary source of value is speculation.

These ideas have been disputed by several hypotheses to establish a fundamental value for Bitcoin [7], or at least lower and/or upper bounds [8]. Hayes in 2015, proposed a model looking at the cost of production to evaluate the price of Bitcoin [9]. In 2018 Hayes back tested the model on recent data [7], shown in the graph below, concluding investment in mining Bitcoin creates the inherent value.

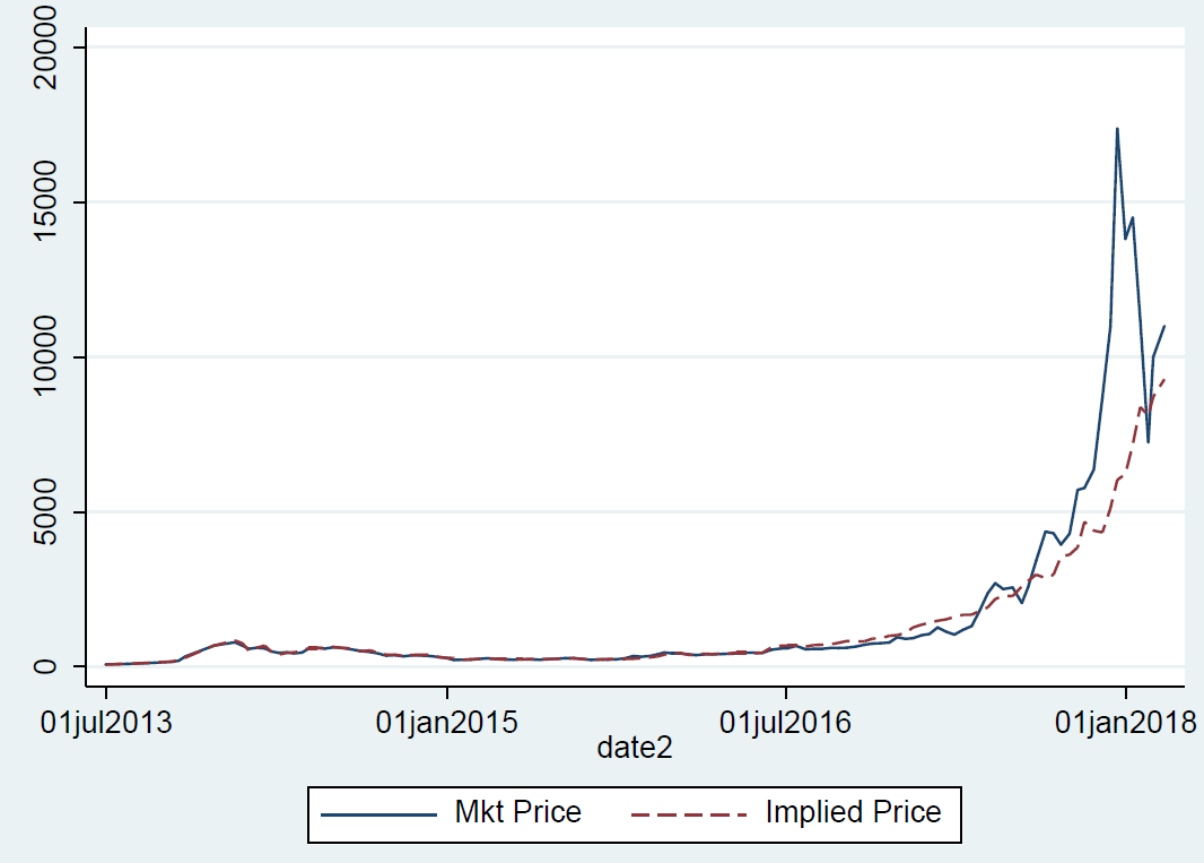

Figure 1 - Price of Bitcoin vs Production Cost Implied Price. Source [7]

These conclusions have been informally disputed without a specific correction [10]. It is also possible that this finding merely proves that the investment in mining has an equilibrium relationship to the value of Bitcoin, which is slow to respond; as opposed to the value returning to the fundamental value.

Another attempt to establish an inherent value for cryptocurrencies in general (including Bitcoin) by Bhambhwani et al (2019) [11] considers both the global Hashrate, and the size of the network (i.e. number of users and active users). Bhambhwani asserts the price of crypto currencies depends on the dedicated mining effort and the number of users in the network. The team also points out other factors such as regulatory supervision and political risk may influence the price.

2.2 Bitcoin Price Factors

An article in Risk and Financial Management journal by Frode Kjærland et al [8] finds the (global) Hashrate to be irrelevant in modelling Bitcoin price dynamics. This was contracted by Hayes in 2015 [9] who found the Hashrate to be a significant factor of Bitcoin price. Kjærland counters that the underlying protocol requires adjustments in the mining difficulty to effect a consistent and deterministic supply of Bitcoins, and therefore has no market impact, going on to prove this via statistical correlation.

2.3 Mining Cost and Energy Efficiency

In his 2015 paper, Hayes evaluated the average energy cost of mining [9]. This evaluation sheds light on the significant performance increases given by advancing hardware technologies applied to mining.

The graph below shows the energy consumption per giga-hash, which trends steeply downwards over time as new technologies are developed. The development and adoption period of these new technologies are marked on the graph.

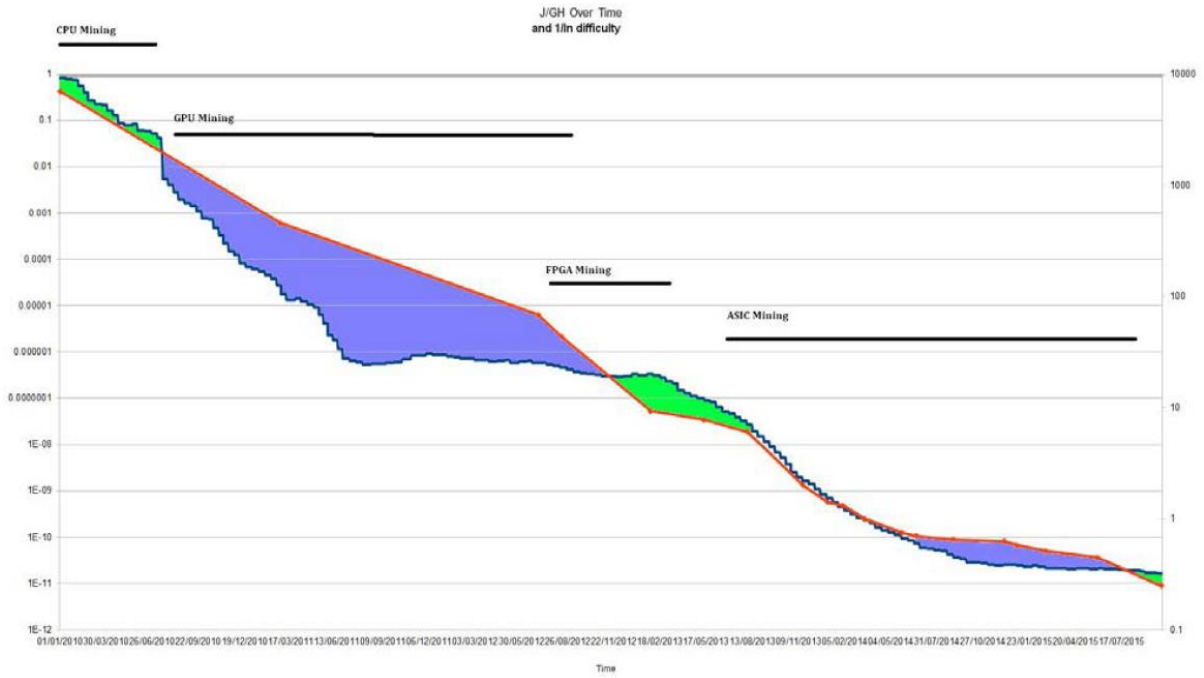

Figure 2 - Bitcoin mining difficulty vs mining energy efficiency over time [9]

This data (when combined with the global hash rate over time) corroborates the data presented by the Cambridge Center for Alternative Finance in their ongoing work to find the global energy cost of mining [12].

2.4 Global Mining Efforts

Until recently optimum returns in Bitcoin mining were determined by possession of the latest hardware and software [13]. The former could change every few months and so prove challenging for miners to keep pace without capital investment. The contemporary environment, however, is no longer subject to these same pressures which have shifted instead to a constant downward pressure on operating costs [13] [14].

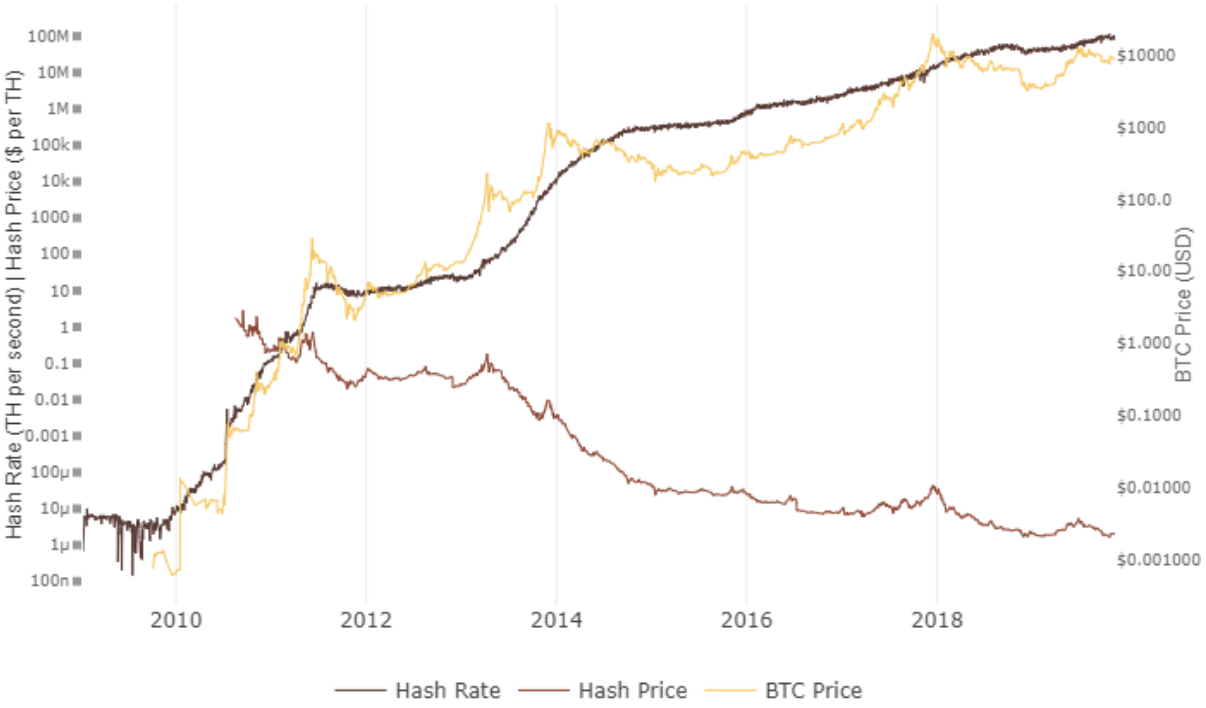

Figure 3 - Hash rate, Hash cost and Bitcoin Price [15]

2.5 Non-Economic Trade Volume on Exchanges

In a presentation to U.S. Securities and Exchange Commission in 2019, Bitwise CEO Teddy Fusaro and Global Head of Research Matt Hougan reports that up to 95% of all reported trade volume is fake or non-economic in nature [16]. An in-depth study by Alameda Research suggests a slightly lower figure of 86% [17].

2.6 Altcoin Value Correlation to Bitcoin Value

In his 2015 paper, Hayes describes an equation for BTC denominated price of the top 66 altcoins (by trading volume).

$$ln(CoinPrice) = \beta 1 + \beta 2 ln(GH/s) + \beta 3 ln(CoinsPerMin) + \beta 4(\%CoinsMined) + \beta 5(Algo) + \beta 6(DaysSince) + e$$

where:

PRICE : is the Bitcoin-denominated market price

GH/s : is the computational power in GigaHashes per second

COINS_PER_MIN : average number of coins mined per minute

%COINS_MINED : Percentage of coins mined thus far

ALGO : 0 when using SHA256 and 1 when using scrypt

DAYS_SINCE : the number of calendar days since the altcoin inception

Equation 1 - Least Squares multiple regression for price correlation [9]

The beta coefficients were found to be as follows:

- β1 = -9.68
- β2 = 0.67
- β3 = -0.98
- β4 = -0.57
- β5 = 7.43
- β6 = 6.7 x 10^{-4}

This results in a historic correlation (for data up to September 18, 2014) of R^2=0.844. This suggest that approximately 84.4% of the variation in BTC equivalent value is caused by the variables described above.

2.7 Previous Halvings

Commentators have suggested that the observed short-term boom (and subsequent correction) following previous Halvings is directly caused by the Halvings [18]. The graph below shows clear peaks and declines following such events in 2012 and 2016 respectively. The speculation in the online crypto community is the pattern seen where the price has a peak roughly a year after the Halving (a few orders of magnitude above the price at the time of Halving) will continue.

Figure 4 - Bitcoin Price Over Time with Halvings. Source: [19]

2.7.1 Halving 2012, 50 BTC to 25 BTC

The first Halving occurred on 28/Nov/2012, where the block reward dropped from 50 BTC (~$612USD then, ~$424,000 USD now) [20], to 25 BTC (~$306 USD then, ~$212,000 USD now)

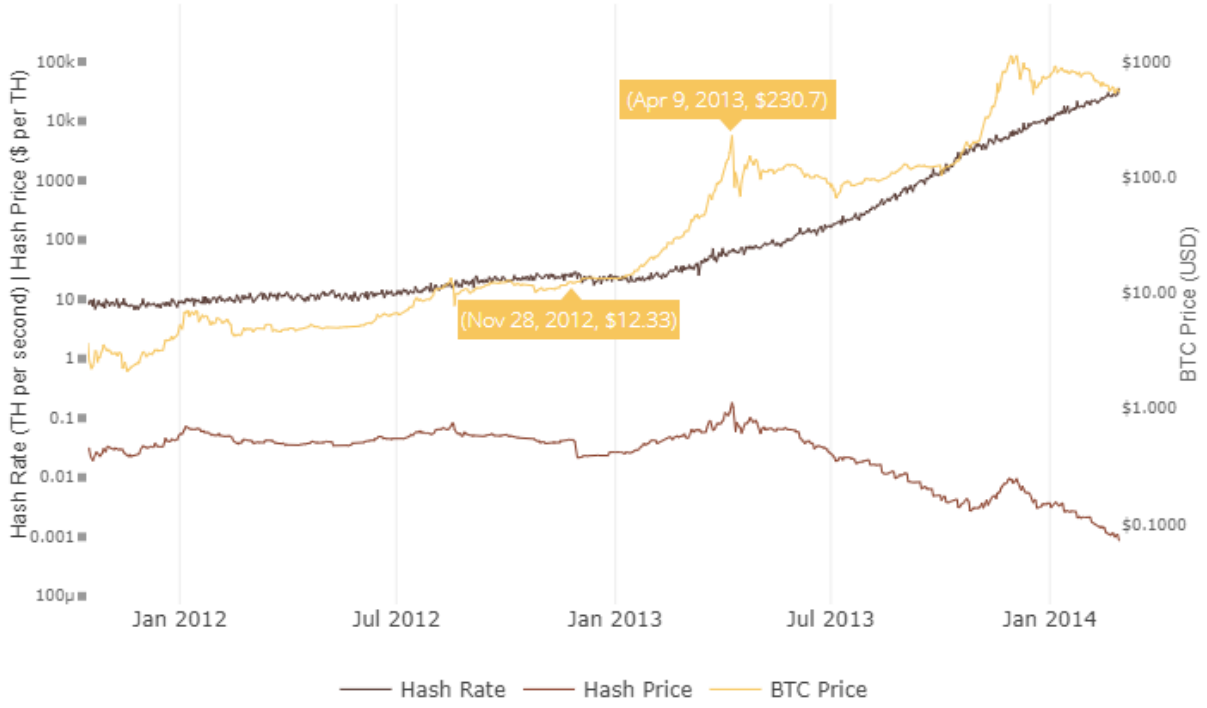

Figure 5 - Bitcoin Hashrate, Hash Price, and BTC Brice over 2012 Halving. Image Source: [15]

In the 12 months following the Halving, the industry observed a significant increase in the value of Bitcoin, on the order of ~20x, within 6 months. After a not insignificant correction, it retained about half of the value it had gained, holding somewhat steady for 12 months, then increasing again.

2.7.2 Halving 2016, 25 BTC to 12.5 BTC

The second Halving occurred on 9/Jul/2016, where the block reward dropped from 25 BTC (~$16,300 USD then, ~$212,000 USD now) to 12.5 BTC (~$8,150 USD then, $106,000 USD now).

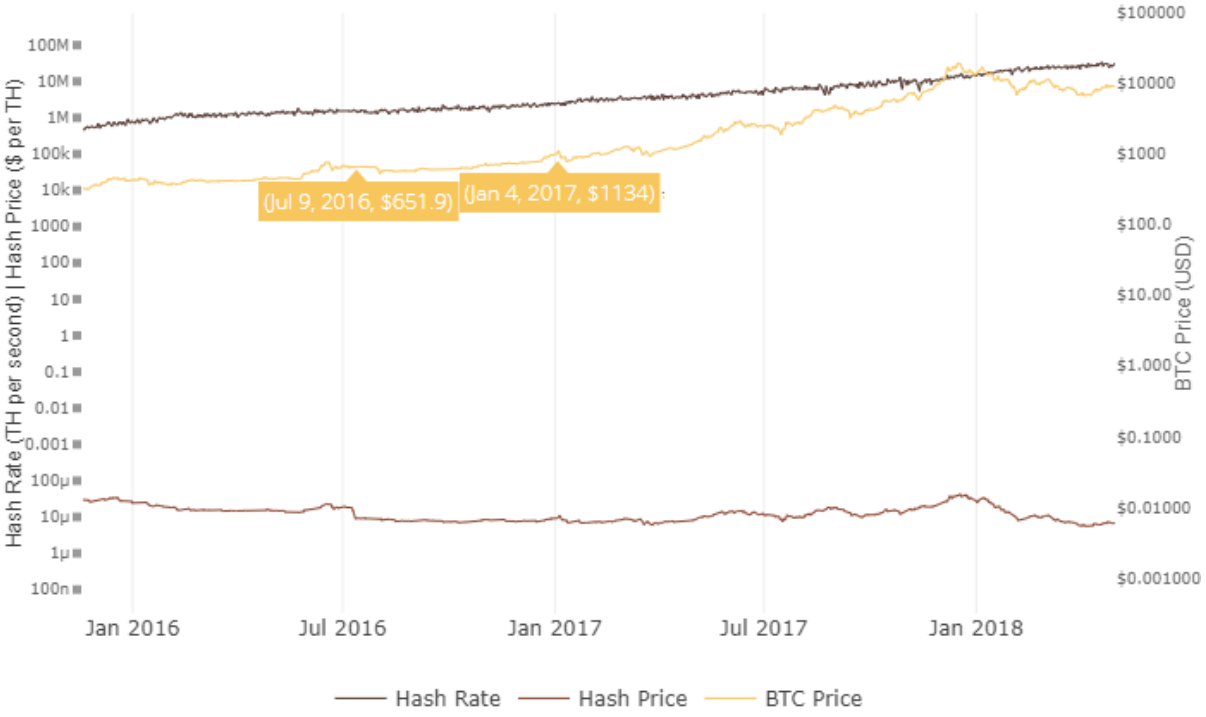

Figure 6- Bitcoin Hashrate, Hash Price, and BTC Brice over 2016 Halving. Image Source: [15]

The second Halving shows less of an impact on the price within the first six months, however it is still very significant compared to other assets in the finance industry.

It should be noted that approximately 12 months after the 2016 Halving Bitcoin saw its biggest surge in value, and 18 months after the Halving it's highest price to date. Spencer Wheatly et al in 2018 [21] argued that this spike was due to a short term feedback loop of speculation and enthusiasm, and not wholly caused by the Halving.

There has also been allegation that a single high-value actor intentionally manipulated the price of Bitcoin in 2017 following the halving, causing the surge [22]. This would imply the Halving itself is at most partially responsible for the unusual value inflation.

3.0 Market Speculation

The market has become significantly more aware of Bitcoin Halving leading up to the 2020 Halving when compared to the 2016 Halving. This can be evidenced through Google search trends leading up to the Halvings.

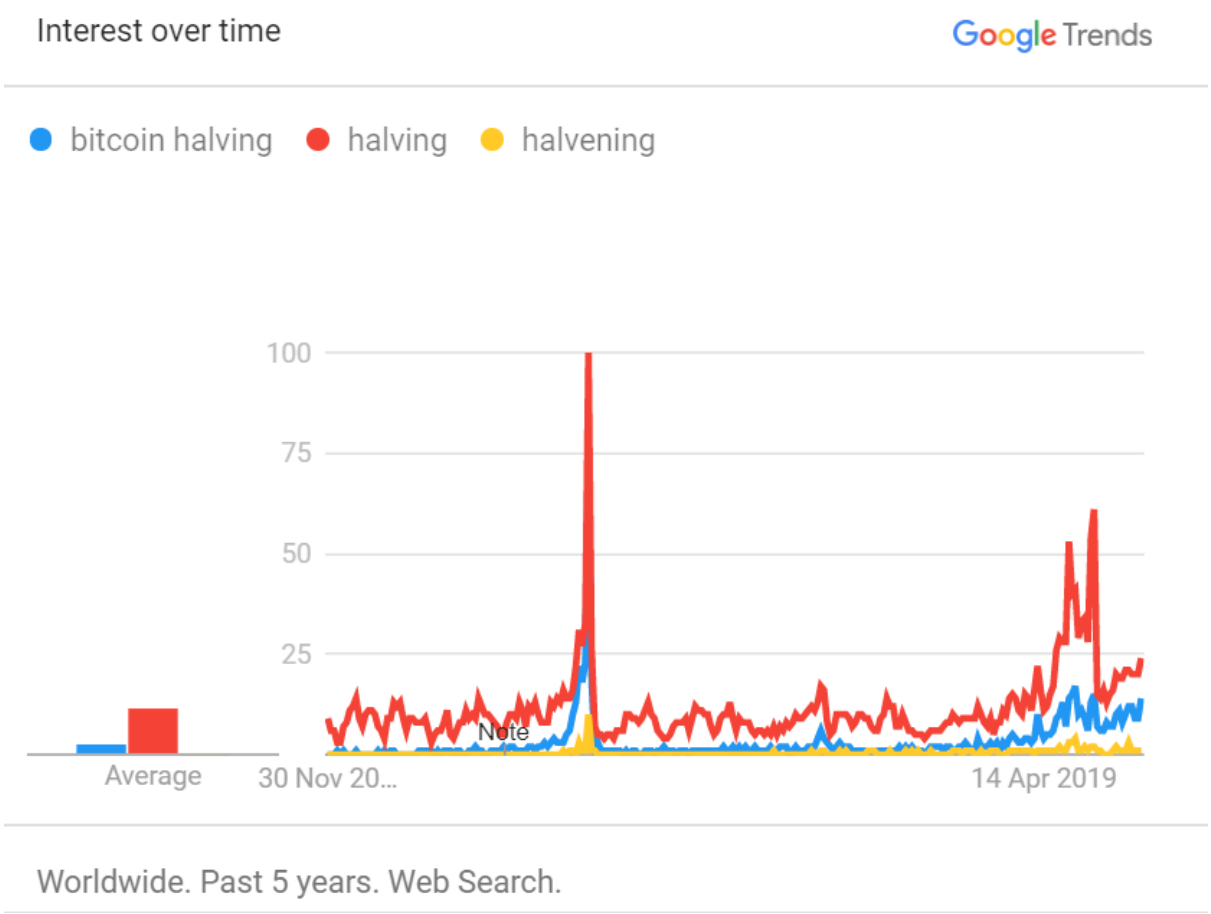

Figure 7 – Google Search Trends for Halving (and related key words). Data source: [23]

Here there is a significant spike of Google searches on the day of and week leading up to the 2016 Halving. There is also significant interest being generated from mid-2019, a full 11 months before the projected date of the Halving mid-May 2020.

This has not prevented the market from trading derivative products such as futures and options which cross the estimated date of the Halving. Below is an analysis of the BTC Options market, sourced from Deribit [24].

3.1 Call Options

A (European) **call** option is a financial contract which gives the buyer the right, but not obligation, to **buy** a tradable asset for an agreed upon price (strike price), on an agreed upon date (expiry date).

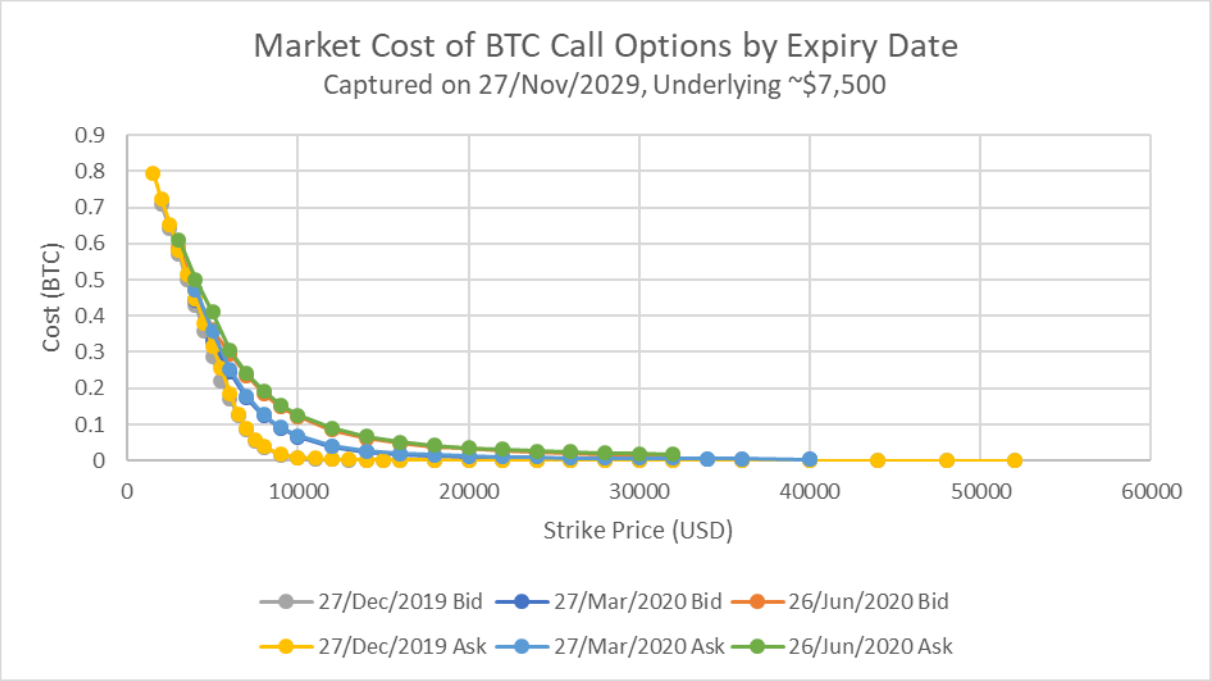

Figure 8 – Market Cost of Call Options by Expiry Date. Data Source: [24]

This graph shows the ask price of call options (the right to buy BTC at the strike price) for three different expiry dates, three months apart. As of writing, 26/June/2019 is the latest expiry available on the site, meaning the last two expiry dates shown (27/March/2020 and 26/June/2020) are either side of the Halving event.

These costs for the strike have an implied volatility, which can be calculated using the Black-Scholes pricing model. Assuming risk free rate of zero, the volatility of the above prices have been graphed below.

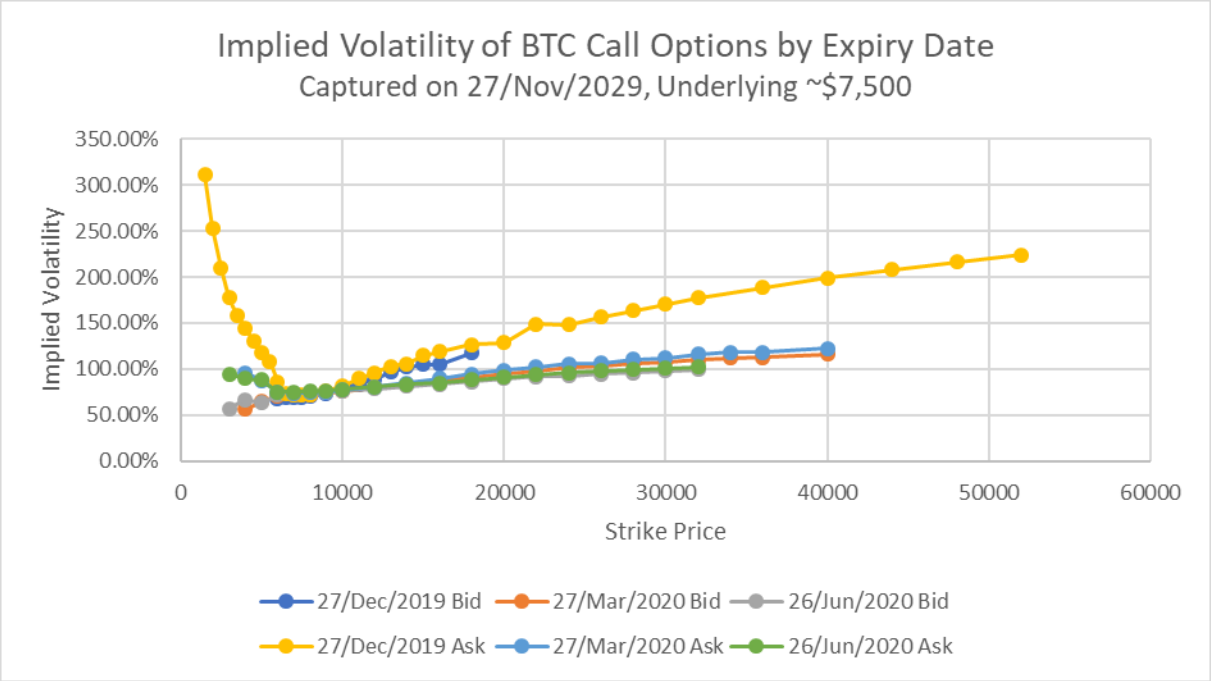

Figure 9 - Implied Volatility for Call Options by Expiry Date. Data Source: [24]

Here we see the implied volatility is quite high for options expiring in the near future. This is expected an expected equilibrium in options markets [25]. The general case here is the implied volatility for before and after the Halving is approximately the same at about 80%. This indicates traders believe the market will be able to smooth over any changes caused by the Halving resulting in the same volatility a month later.

For more information on these options, see:

- APPENDIX C - BTC Call Options [27-Dec-2019], p45
- APPENDIX E - BTC Call Options [27-Mar-2020], p47
- APPENDIX G - BTC Call Options [26-Jun-2020], p48

3.2 Put Options

A (European) **put** option is a financial contract which gives the buyer the right, but not obligation, to **sell** a tradable asset for an agreed upon price (strike price), on an agreed upon date (expiry date).

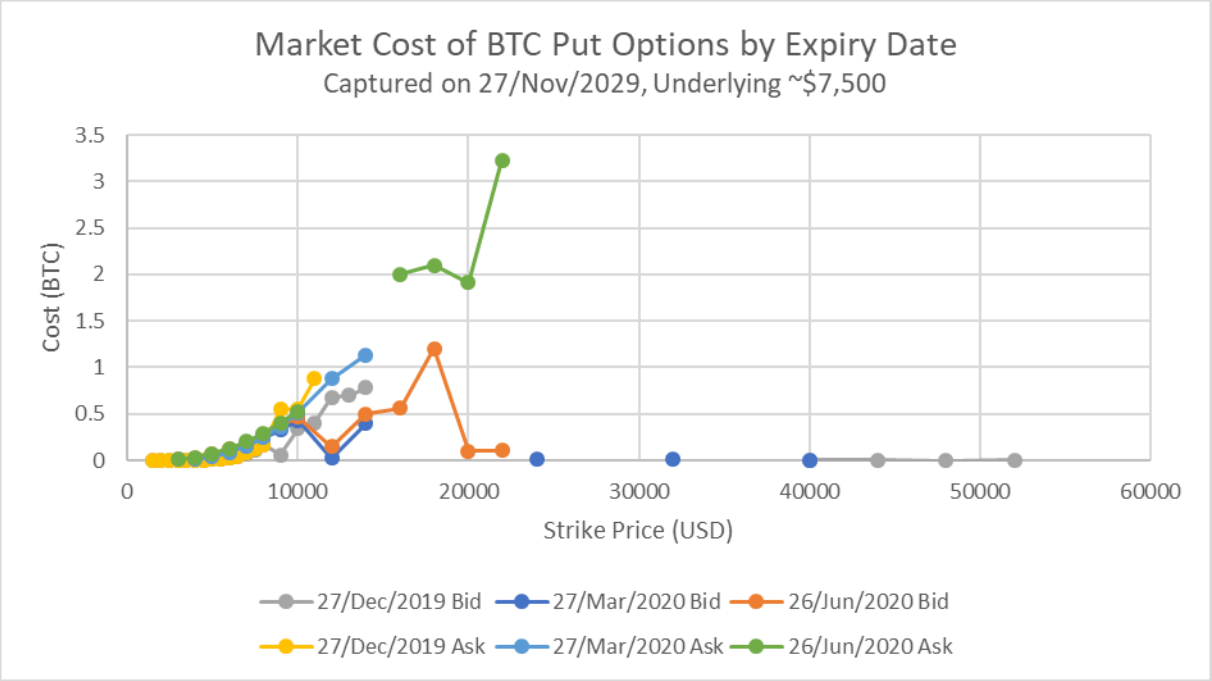

Figure 10 – Market Cost of Put Options by Expiry Date. Data Source: [24]

This graph shows the ask price of put options (the right to sell BTC at the strike price). Notably here the prices available only go up to $14,000 USD for before the Halving. This indicates that traders aren't willing to take the risk that Bitcoin value won't go above $14,000 for any reasonable price. However, after the Halving there are some speculative traders willing to take the chance that Bitcoin value will be $16,000 USD or above.

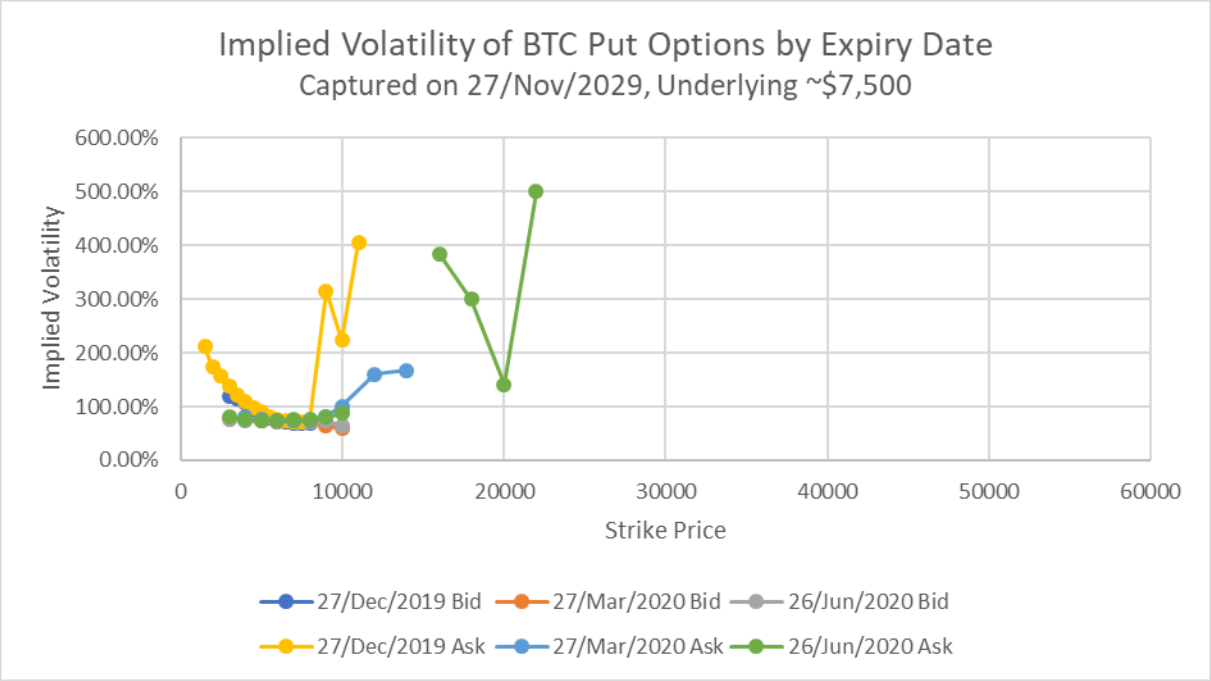

Figure 11 - Implied Volatility of Put Options by Expiry Date. Data Source: [24]

While the put options dataset is more sparse, it's still possible to observe a trend of the bid/ask after the Halving being inside the bid/ask before the Halving. These findings are significant as they stand somewhat in contrast to the popular predictions made by commenters.

For more information on these options see:

- APPENDIX D - BTC Put Options [27-Dec-2019], p46
- APPENDIX F - BTC Put Options [27-Mar-2020], p47
- APPENDIX H - BTC Put Options [26-Jun-2020], p48

4.0 Analysis of Previous Halvings

4.1 Block/Hash Reward and Difficulty

Small dips during the two previous Halving's are visible in the USD equivalent block yield, however the price of Bitcoin increases at a rate such that these step changes are recovered form and the yield as a whole increases.

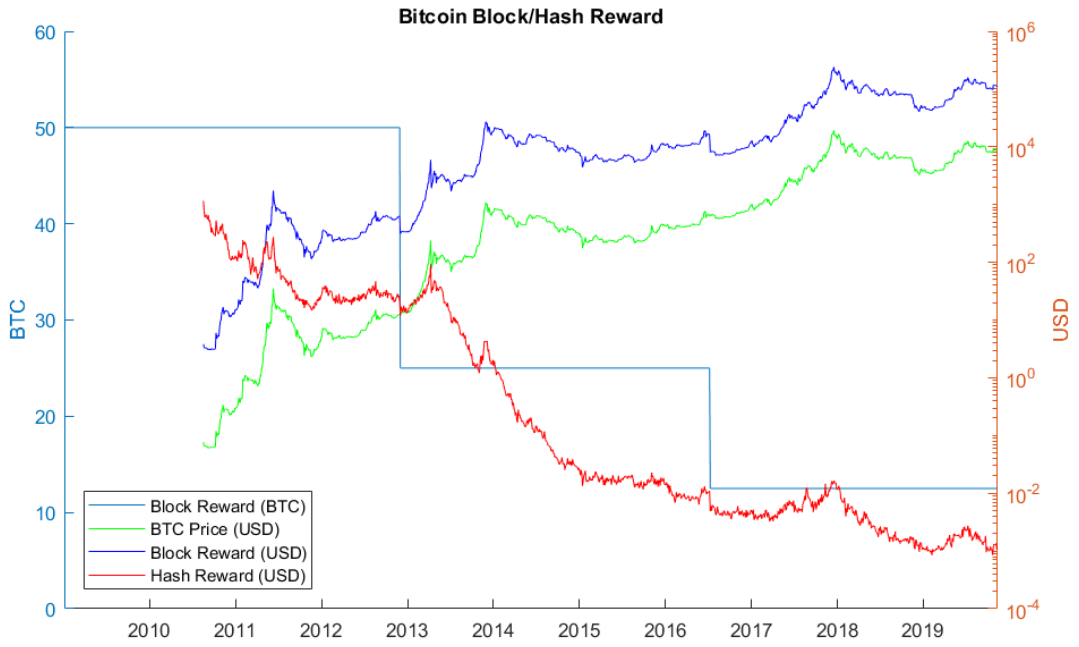

Figure 12 - Bitcoin Block/Hash Reward. Data source: [15] [20]

The hash reward here can be seen to be decreasing even as the USD block reward is increasing. This is due to a significant increase in global hashing power as the competitive landscape for Bitcoin mining grows alongside it's incentives. This can be observed in the graph below, as the hash rate increases, the mining difficulty is automatically adjusted by the Bitcoin protocol.

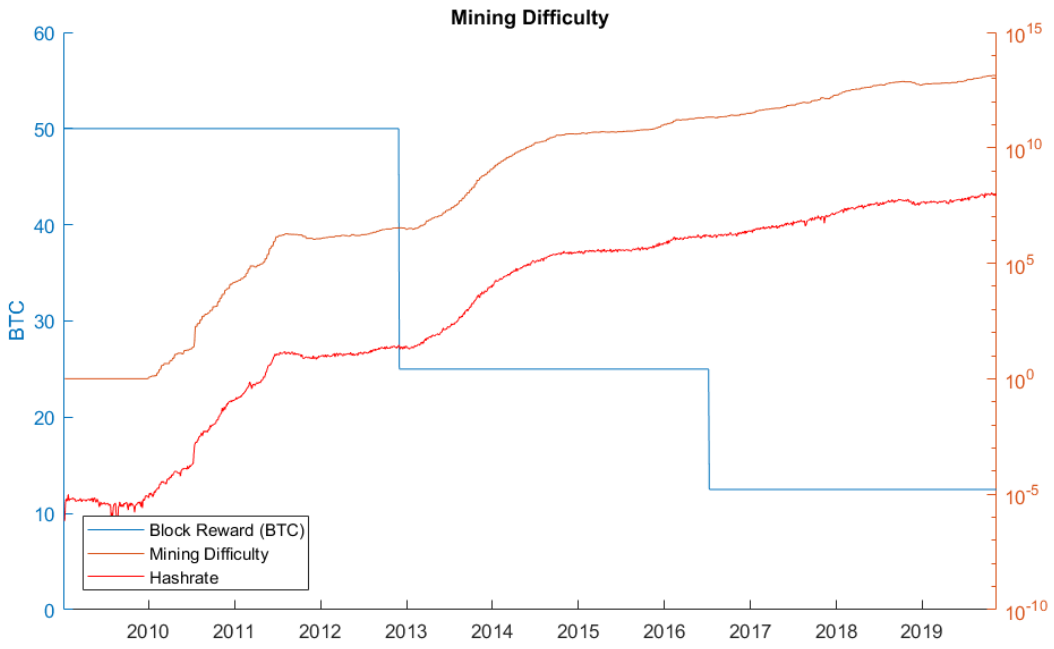

Figure 13 - Bitcoin Mining Difficulty. Data source: [15] [20]

4.2 Mining Power Consumption

Mining power consumption is an estimation based on available mining hardware and the publicly announced sales figures (where available) [26]. This has resulted in an estimated power per Terahash, best guess, upper bound and lower bound [12]. The available data only produces reliable estimates after late 2014, which only encapsulates the second Halving in 2016.

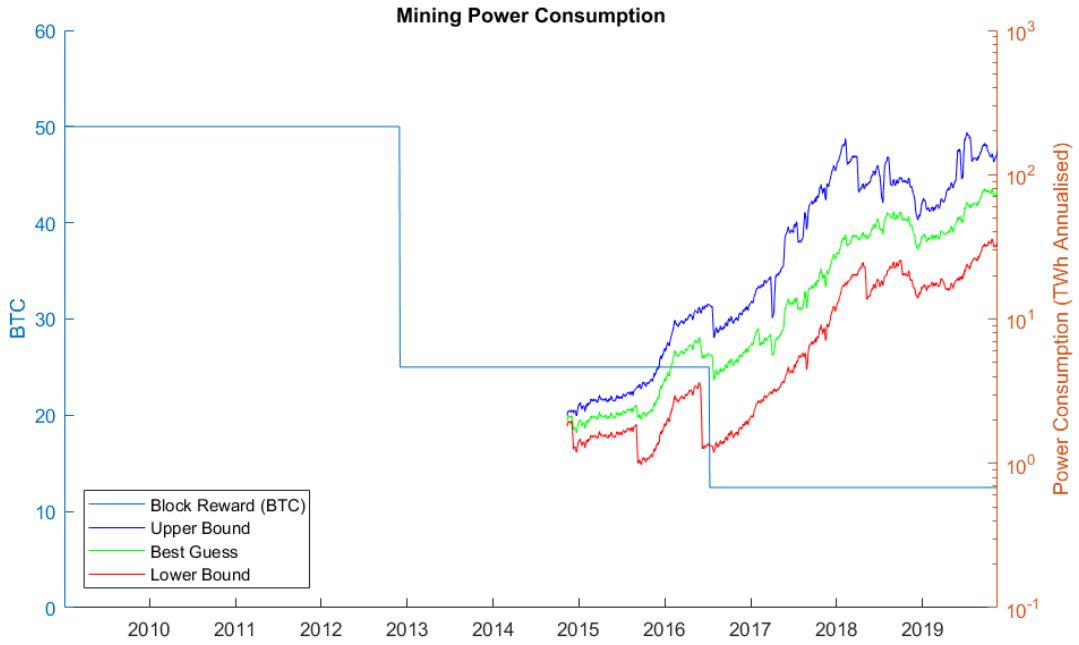

Figure 14 - Bitcoin Network Power Consumption. Data source: [12]

This data shows an upward trend in the power consumed by the Bitcoin network over time. Most notable is the sudden drop in consumption around the second Halving. When considering the actual miners the distribution is expected to be a bell curve with the peak at or near the best guess, and the tails extending to the upper and lower bounds. For the rest of this analysis, these datasets will be represented as three lines, as shown in the graph above.

4.3 Mining Estimated Global Cost/Revenue

Below is the estimated cost of mining based on the three estimation above (upper/lower/best guess). Power cost is simply the USD/KWh used in the calculation. The other factor considered is the **Power Utilization Efficiency** (PUE). This is a measure ratio of the amount power an entire mining operation uses, compared to the power applied only to the mining instruments (losses due to PSU and cooling). PUE is a value either equal to 1 (perfectly efficient) or greater.

The values used for these variables are different for the three levels used below:

	Power Cost (USD/KWh)	**PUE**
Upper Bound	0.02	1.01
Best Guess	0.05	1.03
Lower Bound	0.12	1.1

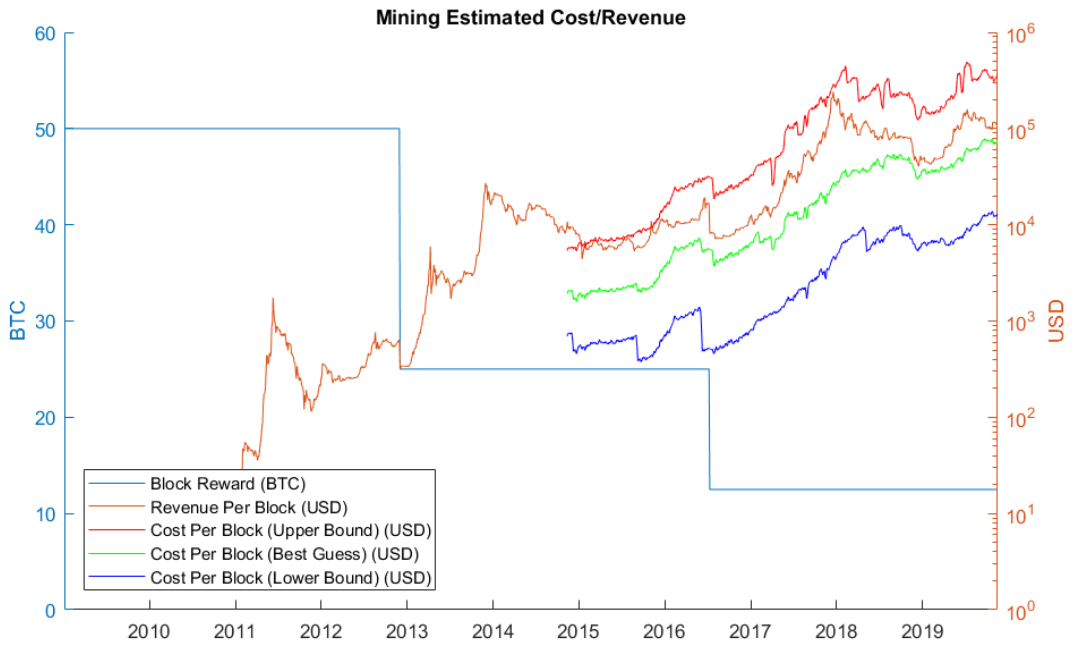

Figure 15 - Mining Estimated Cost/Revenue. Data source: [26] [20]

Here the data shows the most expensive estimated mining installations consistently returning negative profits, and the best guess and least expensive installations making a profit.

4.4 Mining Estimated Profitability

Profitability can be calculated by subtracting the estimated cost from the revenue.

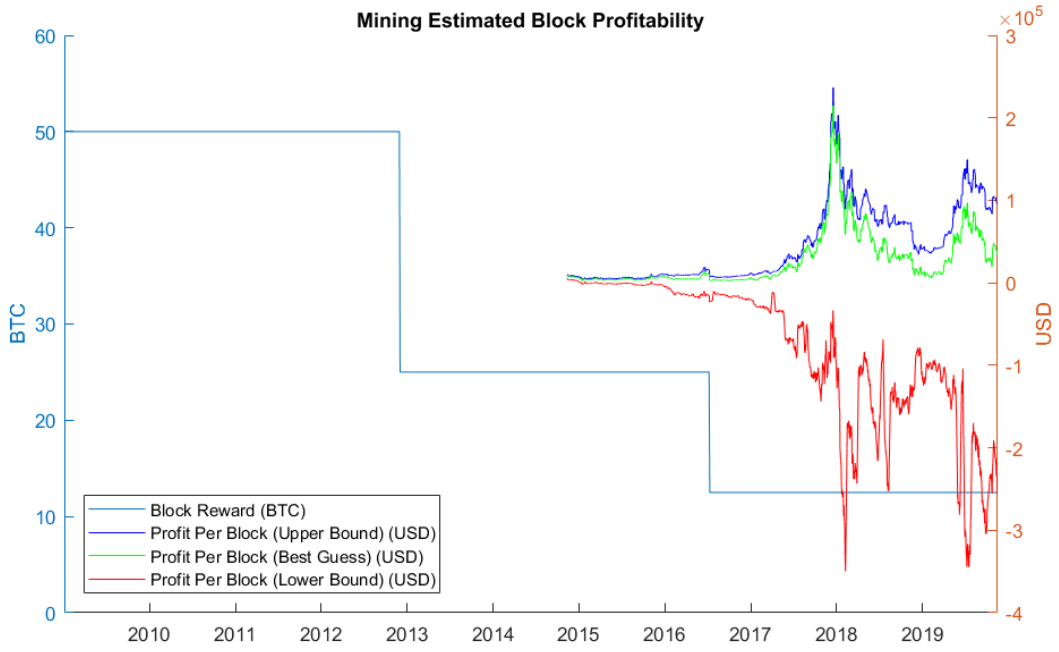

Figure 16 - Mining Estimated Block Profitability. Data source: [26] [20]

To account for the increasing work required to mine a single block the cost per Terahash is shown below.

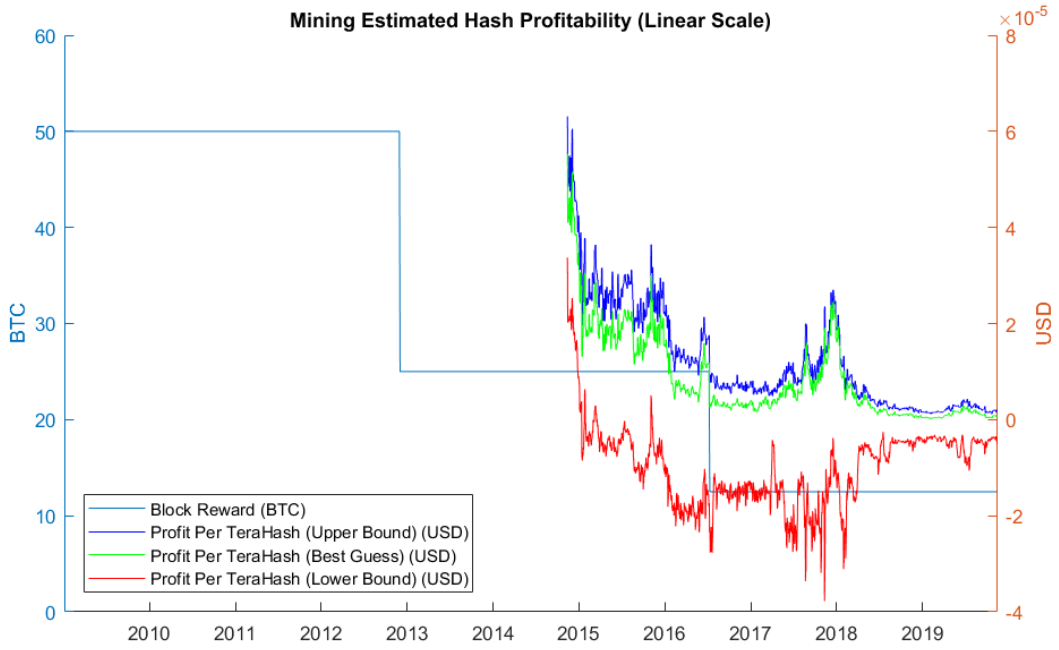

Figure 17 - Mining Estimated Hash Profitability (Linear Scale). Data source: [26] [20]

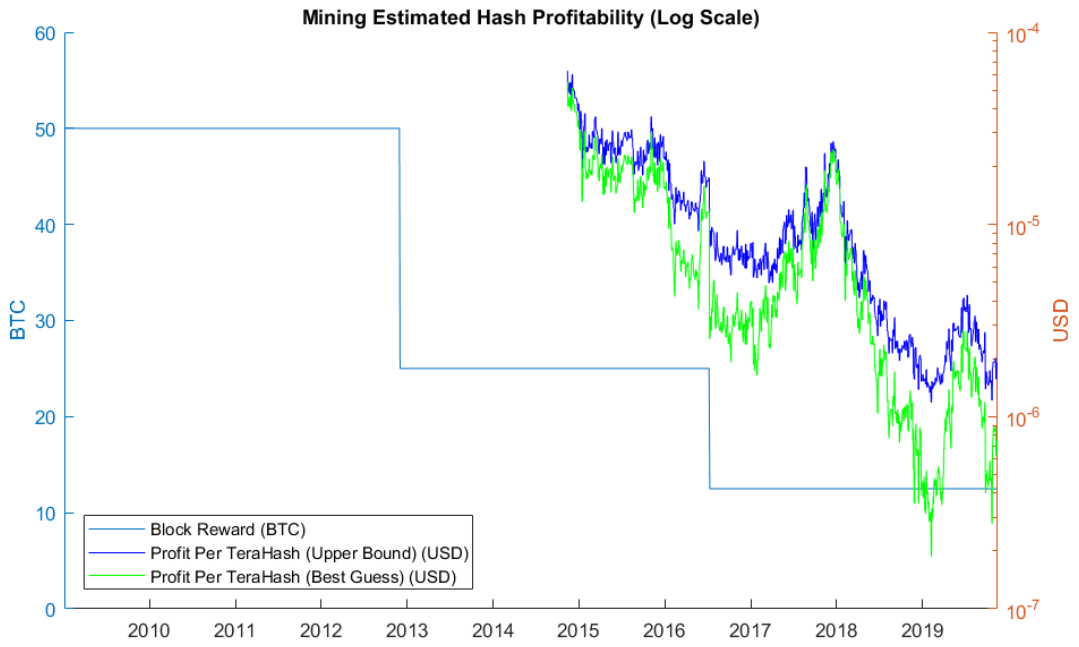

Figure 18 - Mining Estimated Hash Profitability (Log Scale). Data source: [26] [20]

Here the best guess and most optimistic estimation for cost of mining, combined with the mining profit have been trending downwards.

5.0 2020 Halving – First Order Consequences

5.1 Market and Mining Reaction (Current)

By taking the most recent values for cost per hash (best guess) and carrying it forward, it is possible to estimate the projected profit for different variations in global Hashrate and Bitcoin price [12] [9]. This assumes no significant mining technology breakthroughs are made before the Halving in May 2020. The effect of Hashrate is to influence the mining difficulty and can be used to model the profit as a competitive pressure (sharing the same reward amongst many miners) [27] [9]. Using these concepts, the profit per TH for a variable Hashrate and Bitcoin price have been modelled below for both before and after the 2020 Halving (assuming other factors such as price of electricity remain stable [28]).

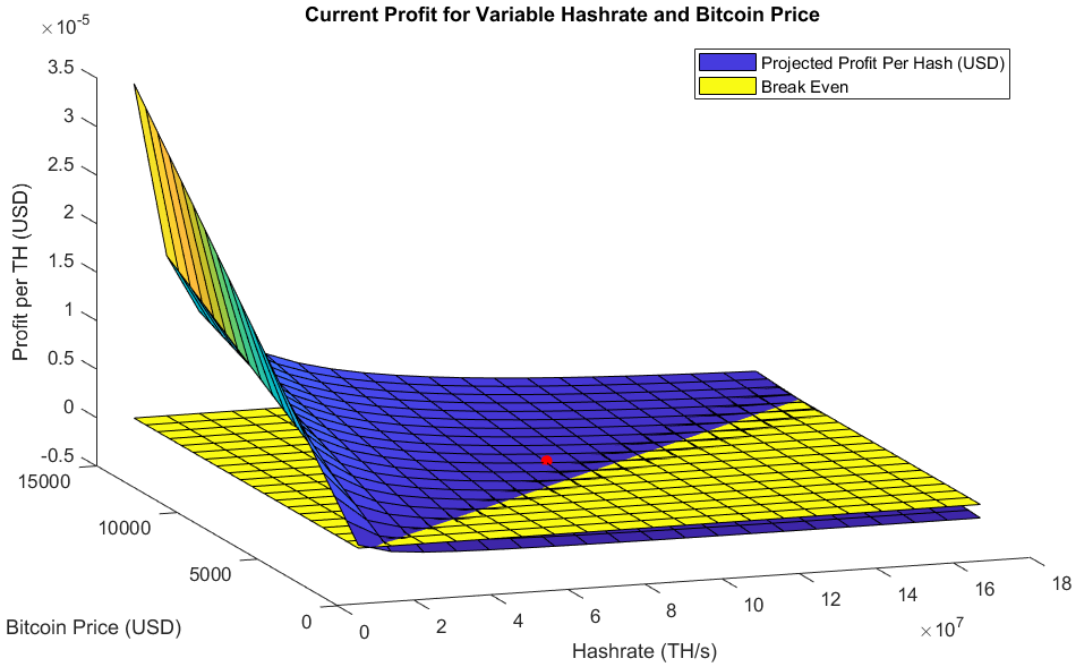

Figure 19 - Current Profitability of Bitcoin Mining for Variable Hashrate and Bitcoin price. Data source: [15] [20] [26]

This provides a surface of profitability, where returns below zero are making a loss and above zero are making a profit. To make this easier to interpret a second surface (in yellow) has been added on the z=0 plane. An increasing Hashrate can be seen to decrease the profitability as the same reward of Bitcoins is spread over more hashes performed.

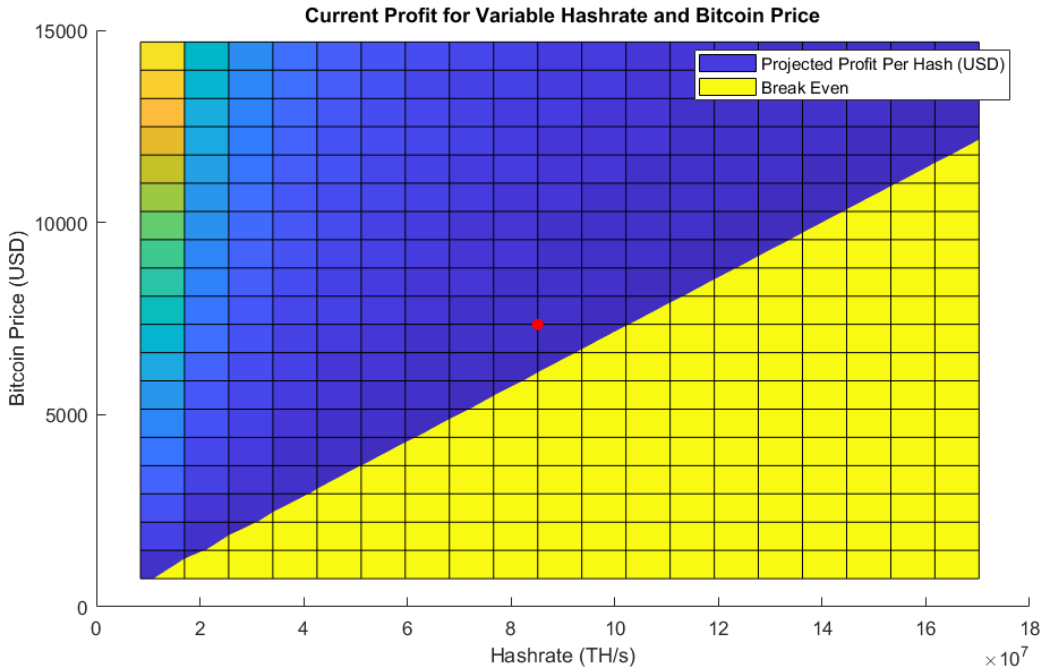

Figure 20 - Current Profitability with Current Variables Marked. Data source: [15] [20] [26]

This is the same surface as shown in Figure 20 above, with a top down view. The current values (as of 25/November/2019) [20] have been marked with a red dot. This mark lies in the profitable region of the graph, showing that current day mining is profitable.

5.2 Market and Mining Reaction (Projection)

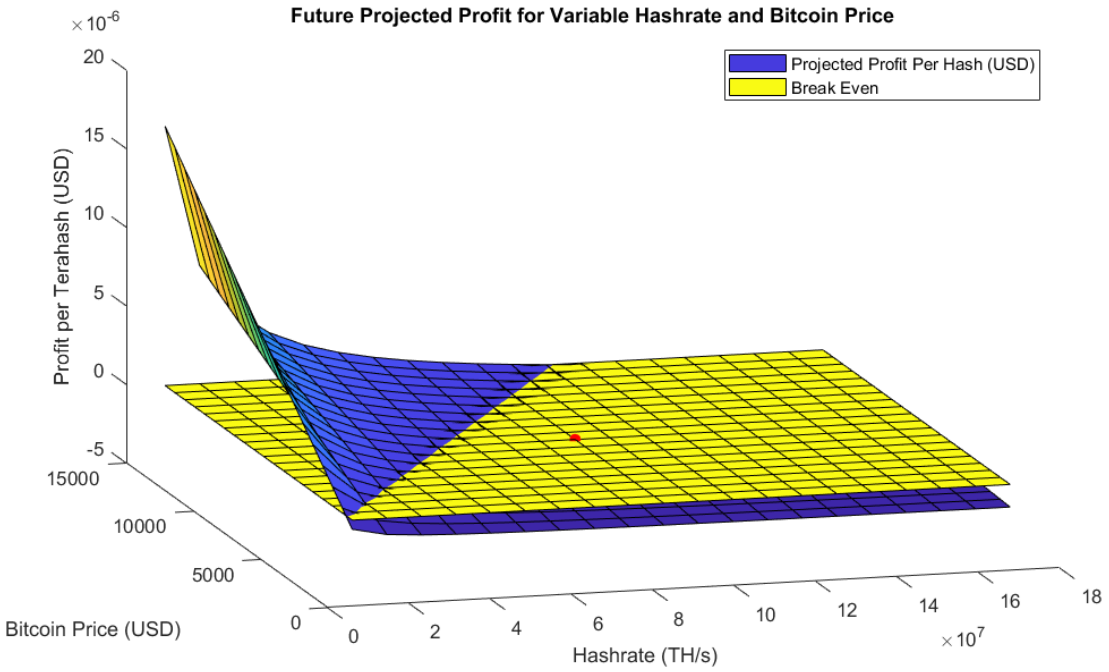

Figure 21 - Future Profit Projections for Variable Hashrate and Bitcoin Price. Data source: [15] [20] [26]

As expected, the profitability after Halving is significantly lower as shown in this chart above. Note: the size of the profitability region here should not be considered as the bounds of the graph have been arbitrarily chosen at double the current price and double the current Hashrate.

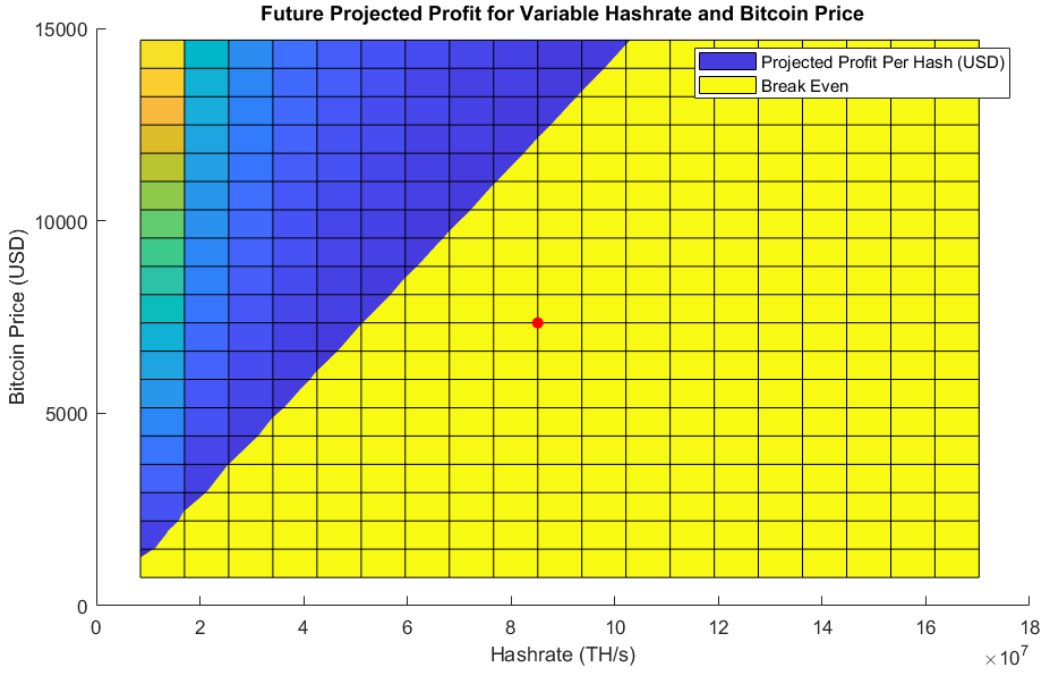

Figure 22 - Projected Profitability with Current Variables Marked. Data source: [15] [20] [26]

Here it can be seen that for mining to be break even after the Halving (for the best guess of cost of production [12]) either the price of Bitcoin will need to increase to ~$12,500 USD or the competitive landscape of mining decreases to ~$5x10^7$ TH/s (~50 EH/s) globally, a ~41% decrease. If both variables change to cover the shortest distance to profitability this would result in a price of approximately $11,000 USD or ~$6.8x10^7$ TH/s.

Not included in these diagrams are the transaction fees. These are a second order consequences and will be covered in the next section. Transaction fees do affect the estimation above, where the range of possibilities could possibly be made narrower by the increase in revenue from fees. If the transaction fees increase, then the value of Bitcoin would not need to increase to the same extent, or the global Hashrate would not need to reduce to the same extent.

5.3 Restricting Supply

Before the Halving, while all blocks yield a 12.5 BTC reward and a block is mined approximately every 10 minutes, the global production of Bitcoin is approximately 1,800 BTC per day. This figure will reduce to 6.25 BTC per block and approximately 900 BTC per day. The Halving of mining block rewards will result in a halving of the number of Bitcoins entering circulation on a daily basis.

6.0 2020 Halving – Second Order Consequences

6.1 Mempool Congestion

The Bitcoin mempool is where transactions appear before they are "confirmed" by being mined and committed to history. This is functionally a queue of transactions which are waiting to be processed. Miners will first mine the transactions with the highest transaction fees to maximise profits.

As analysed in 5.2 Market and Mining Reaction (Projection)(p26), if the price of Bitcoin does not change, the global Hashrate could drop by approximately 41%. If this happens the mining difficulty will take approximately 12 days to adjust, resulting in a period of significantly reduced block mining rate. At this reduced rate, each block will take an average of 24 minutes to mine, instead of the usual 10 minutes, delaying the confirmation of transactions on the network. This could result in a significant increase in mempool size as users of the network continue to submit transactions at the same frequency.

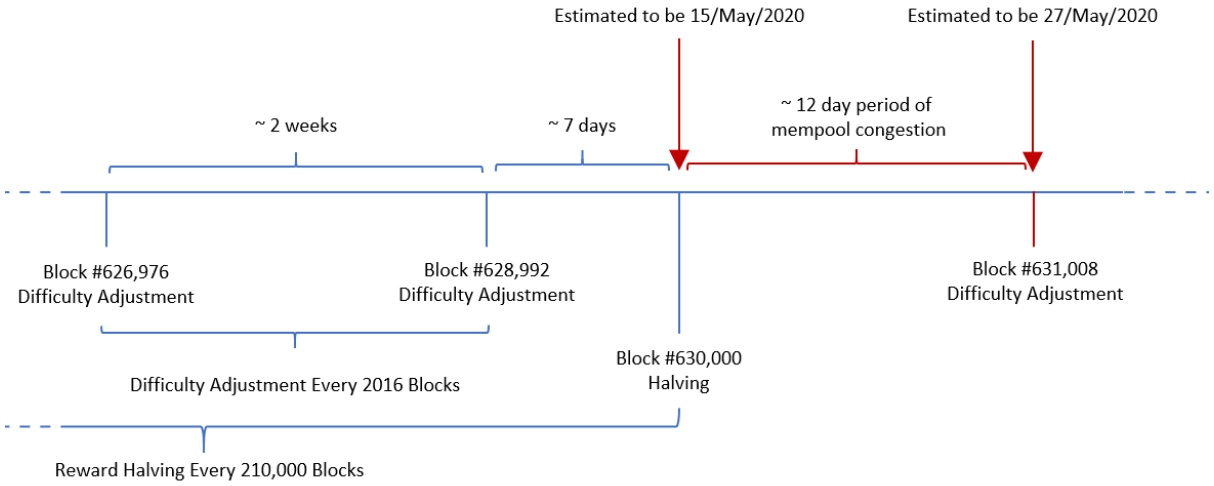

Figure 23 - Timeline of mining block events.

As shown above, the mining difficulty is usually adjusted every 2016 blocks, which is regularly adjusted such that is approximates to every two weeks. This means an adjustment will occur 1008 blocks, ~7 days, before the Halving. After the Halving another 1008 blocks will need to be mined before another difficulty adjustment takes place. The calculated extra time it will take to mine each block results in an extra 5 days to mine this quantity of blocks.

Unfortunately, historic mempool size is difficult to acquire for analysis here, as it is a "per miner" metric. Mempools are assembled by miners as they receive the broadcasted transactions, and most do not publish historic records. The available data shown below goes back to early 2016. Fortunately this in enough to show there was no sudden increase in mempool size at the point of the previous Halving.

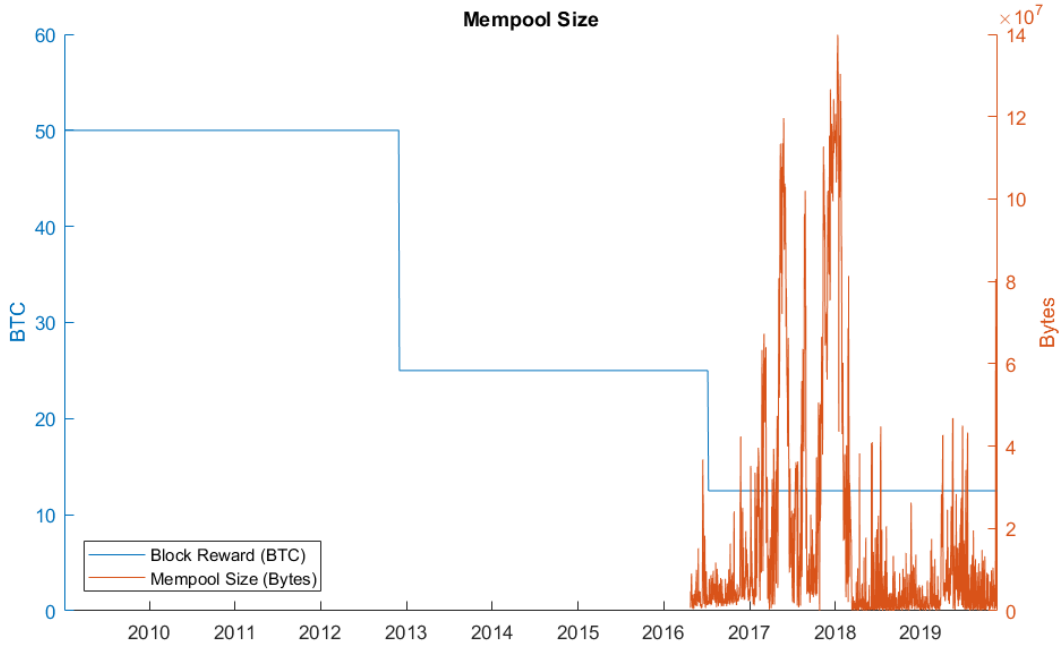

Figure 24 - Mempool Size. Data source [15]

This graph does show there was an increase during the media frenzy late 2017, early 2018. This spike in mempool size indicates transaction processing was delayed. Therefore, to ensure transactions are processed in a timely fashion (have their transaction mined ahead of the long queue) during this period, users needed to increase in the transaction fee they were offering to the miners, as shown below [29].

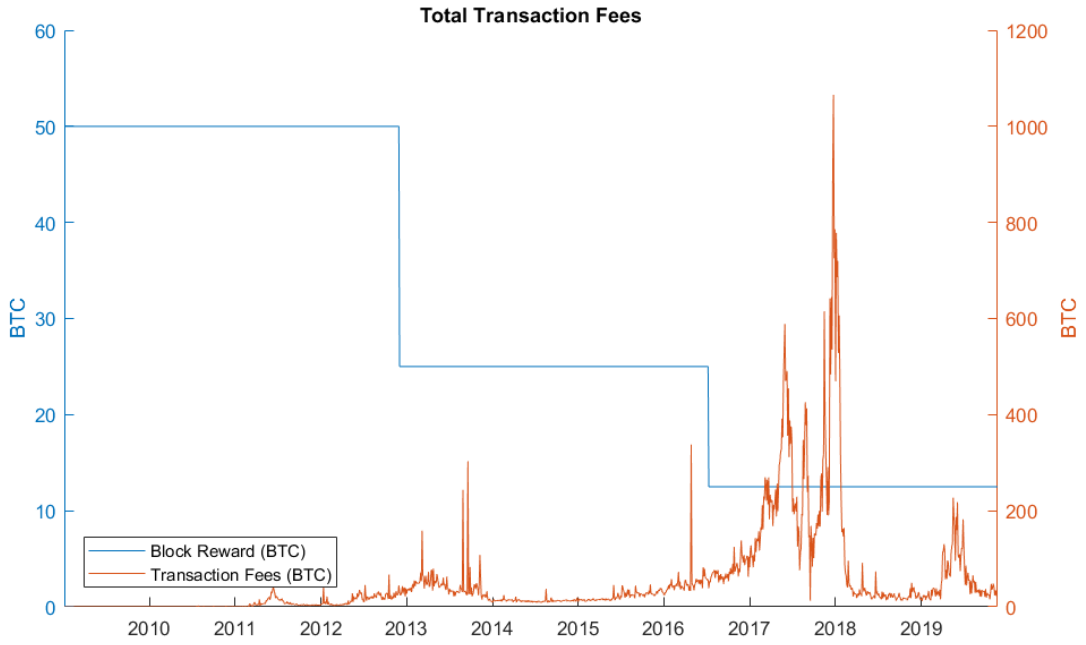

Figure 25 - Total Daily Transaction Fees. Data source [15]

6.2 Reducing Downward Price Pressure

As mentioned in 5.3 Restricting Supply, the daily quantity of mined Bitcoin will be reduced. This means the quantity of Bitcoin going into circulation and being liquidated by miners is going to go down.

Exchange	30 Day volume	Averaged 24 Hour Volume
Bitmex	9557202	318573
Binance	3862669	128756
FTX	951548	31718
Liquid	676619	22554
Coinbase Pro	616127	20538
Kraken	395280	13176
Bitstamp	314399	10480
Gate.io	155640	5188
Poloniex	103376	3446
Gemini	43392	1446
Bitso	14257	475
bitFlyer	3378	113
Binance DEX	2593	86
Binance Jersey	1169	39

Table 1 - Exchange Traded Volume (8/11/2019 – 7/12/2019). Data source: [30]

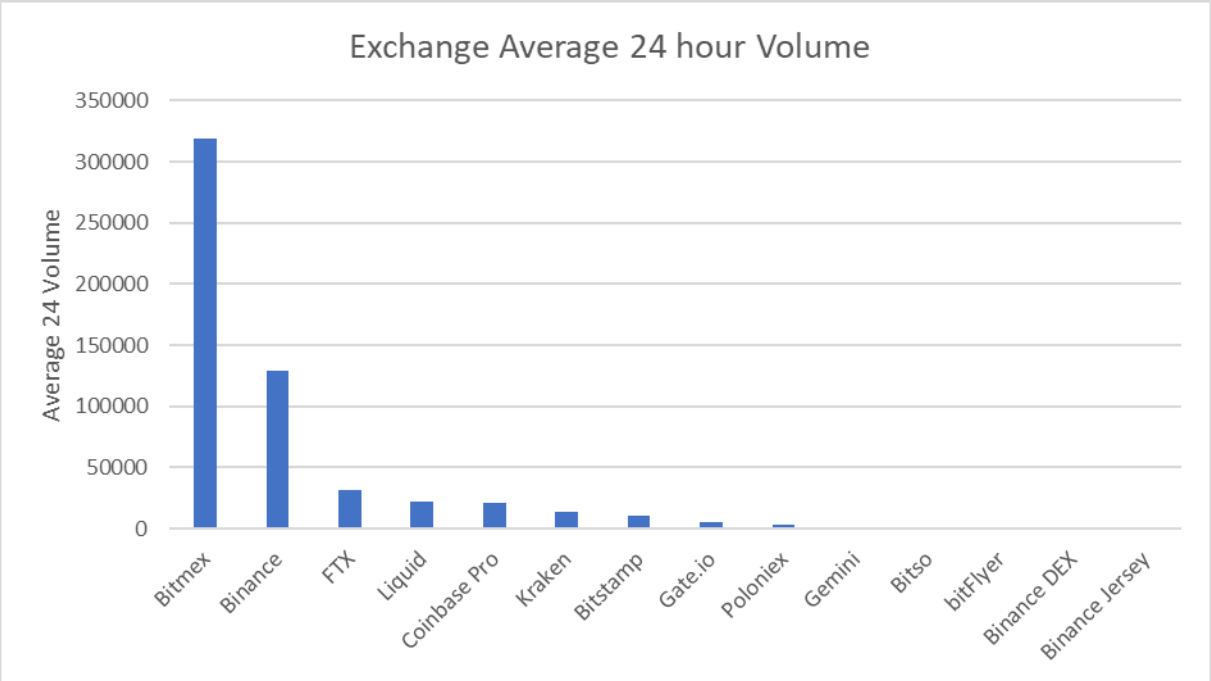

Figure 26 - Exchange Averaged Daily Volume. Data source: [30]

In total approximately 556K Bitcoin are traded, and 1.8K, mined every day. Assuming 100% of Bitcoin is sold as it is mined, liquidation of mined assets is responsible for 0.32% of global market activity. This creates small but constant downward pressure on the price of Bitcoin. This downward pressure will be cut in half after the Halving, which has the potential to cause the market price to increase.

It should also be noted that there are allegations many crypto exchanges engage in loss trading and some even fraudulently increase their reported volume. Two different analyses put the non-economic trade volumes at 95% [16] and 86% [17]. These estimates would place the corrected percentage of mining liquidation at 6.47% and 2.31% of daily traded volume respectively.

7.0 2020 Halving – Third Order Consequences

As this section discusses with third order consequences, it is increasingly more speculative than the previous section. Here we do not aim to make predictions about; only discuss the implications in the case the previous consequences are realised.

7.1 Bitcoin Utility

If transaction fees spike and confirmation times increase after the Halving as discussed in 6.1 Mempool Congestion (p28), the utility of Bitcoin as a means of transaction decreases [31]. This could potentially scare traders as long confirmation times paired with Bitcoin volatility could result the price of Bitcoin changing from the initiation of transaction to its confirmation [32]. Speculative investors may also perceive increased uncertainty, as concerns arise around whether Bitcoin can adequately be used to facilitate trade [33]. It should be noted that the acute effects related to mempool congestion would only last for approximately two weeks after the Halving.

7.2 Bitcoin Scarcity

As the supply of Bitcoin becomes restricted the scarcity increases. This restriction of supply could have positive effects on the value of Bitcoin and is an intended part of the Bitcoin protocol. Increasing scarcity is intended to be a means to prevent inflation of the currency [1] [9].

It's important to note however, that there are many large Bitcoin wallets which could affect the price of Bitcoin, seen in the graph below.

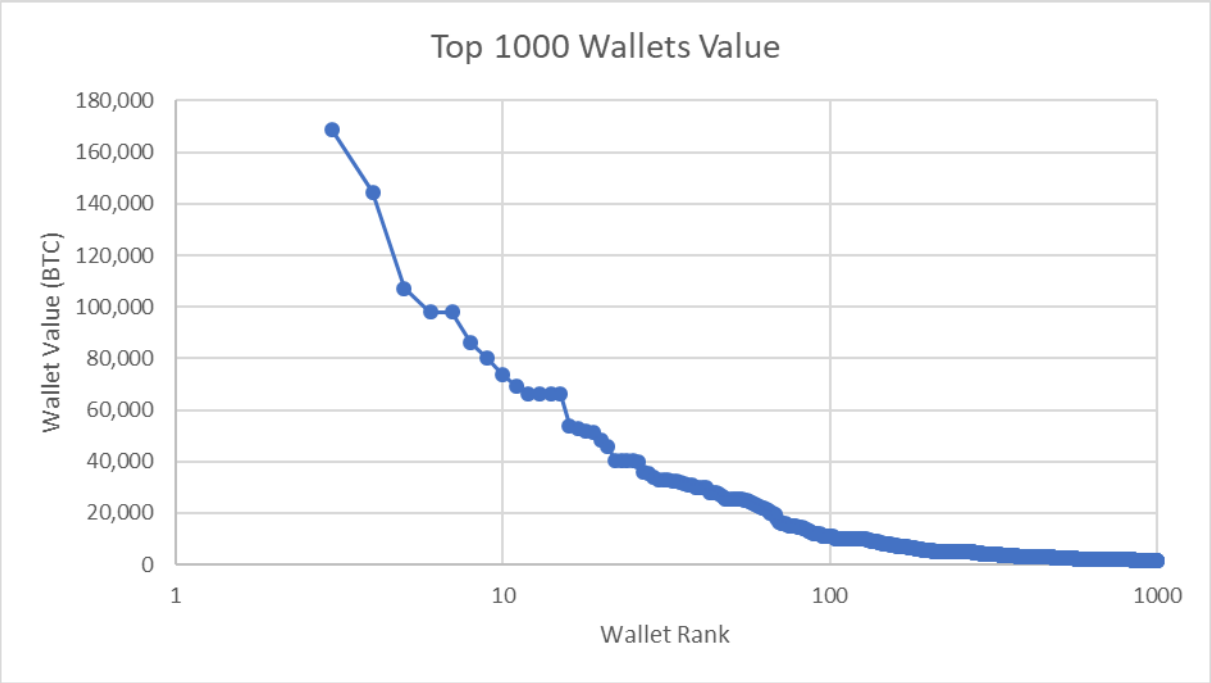

Figure 27 - Top 1000 BTC Wallets Value. Data Source: [34]

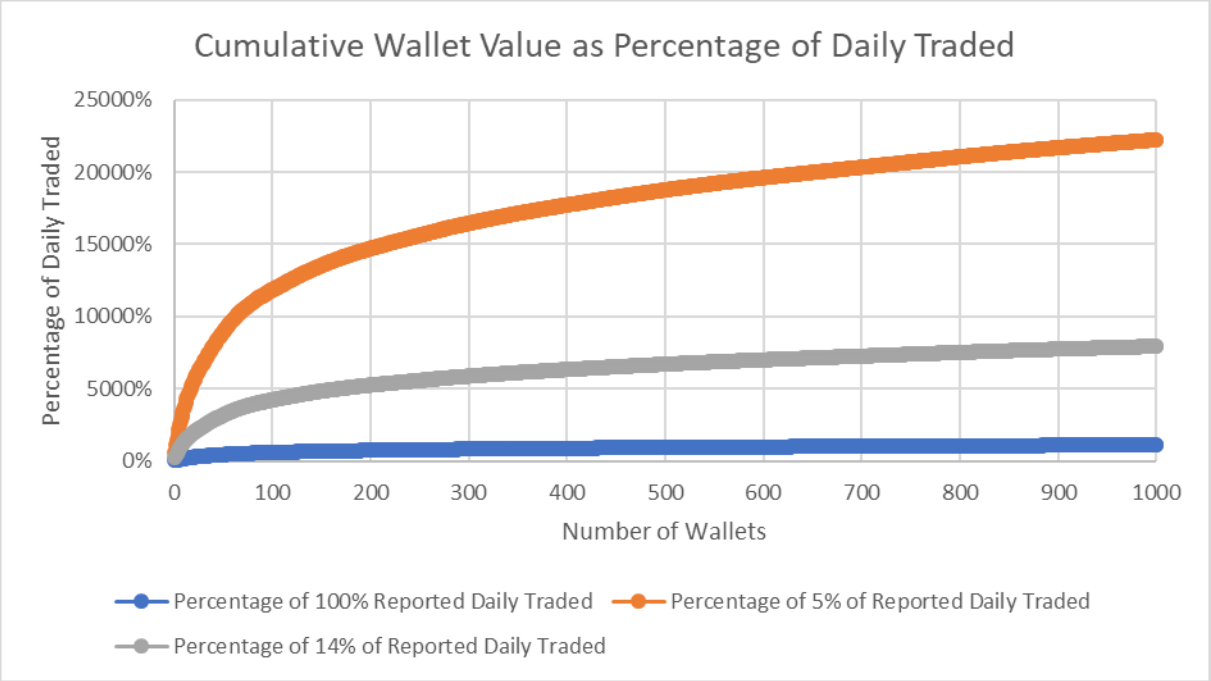

Figure 28 - Cumulative wallet value as percentage of daily traded volume

This graph shows the cumulative value of Bitcoin wallets as a percentage of daily traded (as at 26/November/2019). Three different lines are shown to account for the estimations of non-economic trade reported volume by exchanges. This information in interesting because the top 100 wallets have 5.9% of daily traded value, and potentially up to 4200% or 11800%. This means that if the top 100 wallets liquidated a tiny percentage of their Bitcoin on the same day, it could potentially disrupt the market [5] [6]. When considering Bitcoin scarcity, it is important to remember that there are private actors and individuals who can easily and dramatically increase the supply by shifting small percentages of their holdings.

8.0 Bitcoin Long-term

The response to the Halving event may be informative in understanding the long-term future of Bitcoin. The programmed future of Bitcoin is designed such that eventually there will be no programmed block reward at all, only transfer fees to reward miners. This section considers the implications of this and what it may mean for the industry.

8.1 Transaction Fees

The current reward for miners per block is on average 12.6875 BTC (~$92,000 USD). This includes the 12.5 BTC programmed reward, and ~0.1875 BTC in transaction fees. Currently transaction fees make up 1.5% of the reward. The programmed reward for miners will continue Halving every 210,000 blocks, roughly every 4 years, until approximately the year 2040 when the programmed reward goes to zero.

From the data presented in 4.3 Mining Estimated Global Cost/Revenue (p21), we can say the current cost per block mined is ~$75,600 USD. Therefore, mining companies are collecting on average 17.8% profit on each block.

Currently the average number of transactions per block is 2,700 [15], and the average fee is $0.70 USD equivalent. For miners to receive the same reward they currently are (~$92,000 USD) without programmed reward, the transaction fees would need to increase to ~$40 USD per transaction for at the current transaction/block rate.

Below is a breakdown of various values of transactions/block, and implied transaction fee for the miners to continue to receive the same USD equivalent reward.

Description	**Transactions/block**	**Implied cost**
Current average	2,700	~$28 USD
Estimated upper bound without restricting normal trading activity **[35]**.	4,200	~$18 USD
Mathematical upper bound for the Bitcoin protocol with full SegWit **[36]** optimisation **[35]**.	16,200	~$4.67 USD

Table 2 - Bitcoin Long-term Transaction Fees

These transaction fees are not viable for a currency intended to be used as an everyday transaction tool and therefore could have a significant impact on the long-term utility of Bitcoin. It should be noted that the last option is not possible without significantly reducing the functionality of Bitcoin (removing features like transaction batching) and is only included for completeness.

For Bitcoin to still be a functional currency the transaction fees will need to remain low. At Bitcoins' peak in 2017, transaction fees increased to $55 USD [37]. This was only sustained by the excitement surrounding the cryptocurrency at the time [21] and is not feasible as a long term outcome [31]. To

bring down the cost of mining to a reasonable level there will need to be a significant reduction in the competitive landscape of mining over the next 20 years. For most miners this will happen automatically. The hardware and software much of the industry has already installed is generalisable to other altcoin mining, and regularly checks to ensure it is mining the most profitable asset given its' configuration.

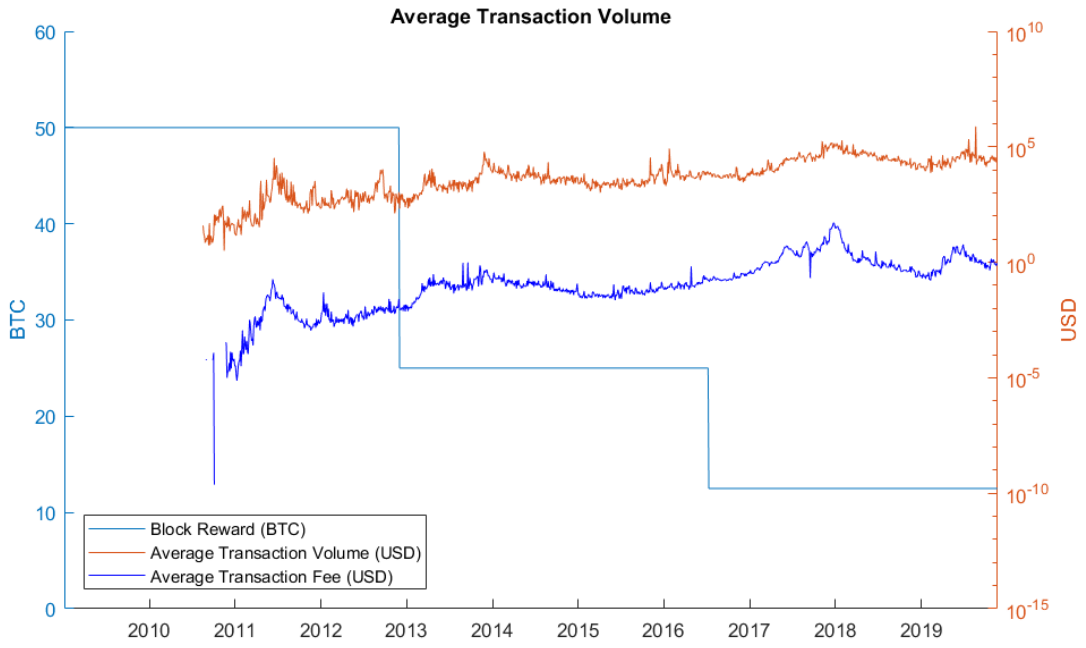

Figure 29 - Average Transaction Volume and Fee (USD)

The graph above shows the average transaction volume and fee. The average transaction volume for all time is $12,600 USD, and the all time average for transaction fee is $0.91 USD. Thus, as a percentage, the average transaction fee is 0.0073%. When considering the possibility of Bitcoin being an everyday transaction currency, it is useful to compare to the fees applied by Visa and Mastercard on international transactions, which is 0.3% [38]. This results in a "comparable" average transaction fee of $37.80 USD. The problem with this figure is Bitcoin transactions carry a flat fee (based on the size of the data in the transaction not correlated to the volume of the transaction). If fees increase to this value, it is possible the network will see a fewer transactions below $12,600 USD.

8.2 Security

Concerns around Bitcoin security arise from the potential decrease in global mining effort as programmed rewards go to zero [39]. Miners will need to rely entirely on transaction fees for income. This puts a strain on users of the network economic principals dictate they have an upper limit on the transaction fees they are willing to pay. The 2020 Halving could result in a drop in mining effort of 41%, indicating the total elimination of programmed reward may be even more severe. The Bitcoin network may become vulnerable to a type of attack known as a 51% attack [40]. In this attack a bad actor will attempt to amass a enough mining capacity so as to own 51% or greater of the global hashing power used in mining. With this ownership, the attacker could add fraudulent transactions of arbitrary size to the blockchain. The risk of this attack may result in uncertainty for traders and increased volatility.

In the near term, a drop in mining resources caused by the Halving will likely not be dramatic enough to cause any concern for a 51% attack. It may, however, cause speculators to briefly consider the possibility, impacting purchasing decisions.

There is a limit to the effect the threat of this attack will have. Economic theory dictates that no attacker will act unless there is enough potential profit to justify the risk [41]. To stage a 51% attack is expensive and comes with a risk that the network will coordinate to reverse the attack and blacklist the attacker before they have had enough time to liquidate the stolen Bitcoin. If the attacker is successful at this, traders may lose confidence in Bitcoin, and therefore its value, the value the attack was attempting to steal, will be destroyed. The attacker would have to liquidate the stolen Bitcoin at the same time as the price is crashing due to the attack, further reducing the potential reward of the attack. Global mining efforts would need to decrease to the point where an attack is cheap enough such that the potential profit from the already devalued Bitcoin justifies the risk.

9.0 Conclusion

Several factors affecting the value of Bitcoin, directly arising from the Halving have been discussed here, including scarcity, mining, downward price pressure, security and utility. Some of these have opposing influence on the value, and it is difficult to predict which will have a more significant influence, and what the long-term outcome will be.

The impact of the 2020 Halving will be significant for miners. The data indicates that, failing a sudden increase in price of Bitcoin, a significant percentage of miners will switch their mining efforts to other cryptocurrencies. If the value of Bitcoin spikes in the 12 – 18 months following the Halving, as in previous Halvings, then the effect on mining profitability will be minimal in the long term.

Following the Halving, in the short term it is possible the price of Bitcoin will drop as a result of the decreased utility and increased transaction price caused by mempool congestion. After which the reduced downward pressure on the price of Bitcoin could allow the price return to its pre-2020-Halving value. Data and previous similar events suggest that the 2020 Halving will not result in a price increase of a similar magnitude to that which followed the previous two Halvings given the market awareness of the Halving.

While opinions differ on whether Bitcoin has an inherent value, the strong correlation between mining expenditure and Bitcoin value does not prove a cause-effect relationship which would act to inflate the value of Bitcoin after the Halving. The significant price increase seen after previous halving events may not be directly or fully caused by the halvings themselves, and there may be other factors such as irrational speculation and market manipulation applying influence.

This Halving will be the first where a significant percentage of commercial Bitcoin miners may be priced out of the market. As a result, it may provide a good opportunity to assess the long-term utility and viability of Bitcoin mining and therefore whole Bitcoin experiment itself.

10.0 References

[1] S. Nakamoto, “Bitcoin: A Peer-to-Peer Electronic Cash System,” 2008. [Online]. Available: https://bitcoin.org/bitcoin.pdf.

[2] H. Son, H. Lewitt and B. Louis, “Jamie Dimon Slams Bitcoin as a ‘Fraud’,” Bloomberg, 13 September 2017. [Online]. Available: https://www.bloomberg.com/news/articles/2017-09-12/jpmorgan-s-ceo-says-he-d-fire-traders-who-bet-on-fraud-bitcoin.

[3] “Tulipomania - when the bulb bubble burst,” Investment Moot, 2010.

[4] E.-T. Cheah and J. Fry, “Speculative bubbles in Bitcoin markets? An empirical investigation into the fundamental value of Bitcoin,” *Economic Letters,* vol. 130, pp. 32-36, 2015.

[5] A. Johansen, O. Ledoit and D. Sornette, “Crashes as Critical Points,” 19 Oct 1998. [Online]. Available: https://pdfs.semanticscholar.org/e68c/24ac35b02d3694326ee8aa130f728dfd4a0b.pdf.

[6] R. J. Shiller, Irrational Exuberance, New Jersey: Princeton University Press, 2000.

[7] A. Hayes, “Bitcoin price and its marginal cost of production: support for a fundamental value,” *Applied Economics Letters,* vol. 26, no. 7, pp. 1-7, June 2018.

[8] F. Kjærland, A. Khazal, E. A. Krogstad and F. B. G. Nordstrøm, “An Analysis of Bitcoin’s Price Dynamics,” *Risk and Financial Management,* October 2018.

[9] A. S. Hayes, “Cryptocurrency value formation: An empirical study leading to a cost of production model for valuing bitcoin,” *Telematics and Informatics,* vol. 34, no. 7, pp. 1308-1321, 2015.

[10] M. Cerliani, “WARNING!!!,” 25 Jun 2018. [Online]. Available: https://www.researchgate.net/publication/317601872_Bitcoin_price_and_its_marginal_cost_of_production_supporting_evidence/comments.

[11] S. Bhambhwani, S. Delikouras and G. Korniotis, “The fundamental drivers of cryptocurrency prices,” 24 August 2019. [Online]. Available: https://voxeu.org/article/fundamental-drivers-cryptocurrency-prices.

[12] Cambridge Centre for Alternative Finance, “The Cambridge Bitcoin Electricity Consumption Index (CBECI),” University of Cambridge, 2019. [Online]. Available: https://www.cbeci.org/. [Accessed 17 Nov 2019].

[13] J. J. Roberts, “Texas Bitcoin Mining Startup Gets $50 Million From Peter Thiel to Steal China’s Crypto Crown,” Fortune.com, 15 October 2019. [Online]. Available: https://fortune.com/2019/10/15/what-is-bitcoin-mining-layer1-peter-thiel-crypto-investment/.

[14] M. Thum, “The Economic Cost of Bitcoin Mining,” *CESifo Forum*, vol. 19, pp. 43-45, 2018.

[15] Blockchain.com, “Bitcoin Hash Price,” Woobull, 16 Nov 2019. [Online]. Available: https://charts.woobull.com/bitcoin-hash-price/. [Accessed 16 Nov 2019].

[16] T. Fusaro and M. Hougan, “Bitwise Asset Management,” 20 March 2019. [Online]. Available: https://www.sec.gov/comments/sr-nysearca-2019-01/srnysearca201901-5164833-183434.pdf.

[17] Alameda Research, “Investigation into the Legitimacy of Reported Cryptocurrency Exchange Volume,” 3 July 2019. [Online]. Available: https://ftx.com/volume-report-paper.pdf.

[18] Bitstocks, “Bitcoin Halvenings — The Rub of Halvening 2020,” Medium, 16 Oct 2019. [Online]. Available: https://medium.com/@bitstocks/bitcoin-halvenings-the-rub-of-halvening-2020-72bd02c243f5.

[19] V. Tahiri, “Bitcoin Price Movement Before and After Halving Predicted by Analyst,” Beincrypto.com, 19 November 2019. [Online]. Available: https://beincrypto.com/bitcoin-price-movement-before-and-after-halving-predicted-by-analyst/.

[20] O. Beigel, “100% Complete Bitcoin Price History Graph,” 99bitcoins, 12 Nov 2019. [Online]. Available: https://coinmarketcap.com/currencies/bitcoin/historical-data/. [Accessed 16 Nov 2019].

[21] S. Wheatley, D. Sornette, H. A. Tobias, M. Reppen and R. N. Gantner, “Are Bitcoin Bubbles Predictable? Combining a Generalized Metcalfe's Law and the LPPLS Model,” *SSRN Electronic Journal*, March 2018.

[22] Y. Khatri, “A single whale on Bitfinex likely manipulated bitcoin’s historic surge in 2017, academics say,” 4 November 2019. [Online]. Available: https://www.theblockcrypto.com/linked/45658/a-single-whale-on-bitfinex-likely-manipulated-bitcoins-historic-surge-in-2017-say-academics.

[23] Alphabet, “Google Trends,” Google, [Online]. Available: https://trends.google.com/trends/explore?date=today%205-y&q=bitcoin%20halving,halving,halvening. [Accessed 26 November 2019].

[24] Deribit, “Deribit Bitcoin Futures and Options Exchange,” Deribit, [Online]. Available: https://www.deribit.com/main#/options?tab=BTC-26JUN20. [Accessed 26 November 2019].

[25] T. G. Andersen, N. Fusari and V. Todorov, “Short-Term Market Risks Implied by Weekly Options,” 14 June 2016. [Online]. Available: https://www.kellogg.northwestern.edu/faculty/todorov/htm/papers/wo.pdf.

[26] University of Cambridge, “CBECI SHA-256 Mining Equipment List,” [Online]. Available: https://docs.google.com/spreadsheets/d/1ciqka_-t0zDSOVyB4yhVZBfLFGKwJMlQ2EwA0CB1ljM/edit#gid=0.

[27] A. D. Dwivedi, G. Srivastava and R. Singh, “Bitcoin Mining: A Game Theoretic Analysis,” Sept 2018.

[28] A. Tiwari, M. Shahbaz and D. Macedo, “Bitcoin returns and risk: A general GARCH and GAS analysis,” Sept 2018.

[29] A. Hertig, “The average fees required to send a bitcoin transaction are up again.,” Coindesk, 18 April 2019. [Online]. Available: https://www.coindesk.com/bitcoin-fees-jump-to-nearly-1-year-highs-but-why.

[30] data.bitcoinity.org, “Bitcoin Trading Volume,” 19 November 2019. [Online]. Available: https://data.bitcoinity.org/markets/volume/6m?c=e&t=b. [Accessed 19 November 2019].

[31] W. Wu, “Why Bitcoin Is Not a Viable Currency Option,” Wharton, August 2018. [Online]. Available: https://kw.wharton.upenn.edu/kwfellows/files/2018/06/2018-08-30-Bitcoin-Student-Series.pdf. [Accessed 26 Novemmber 2019].

[32] I. Aru, “Bitcoin Rising Fees, Confirmation Queues See Users, Investors Switching to Altcoins,” Coin Telegraph, 18 May 017. [Online]. Available: https://cointelegraph.com/news/bitcoin-rising-fees-confirmation-queues-see-users-investors-switching-to-altcoins. [Accessed 26 Novebmer 2019].

[33] E. Ganne, “Can Blockchain revolutionize international trade?,” World Trade Organisation, 2018. [Online]. Available:

https://www.wto.org/english/res_e/booksp_e/blockchainrev18_e.pdf. [Accessed 26 November 2019].

[34] 99Bitcoins, “Top 1000 Richest Bitcoin Addresses,” 99Bitcoins, 27 November 2019. [Online]. Available: https://99bitcoins.com/bitcoin-rich-list-top1000/. [Accessed 27 November 2019].

[35] E. Georgiadis, “How many transactions per second can bitcoin really handle ?,” 1 April 2019. [Online]. Available: https://eprint.iacr.org/2019/416.pdf.

[36] P. Wuille, J. Lau and E. Lombrozo, “bip-0141.mediawiki,” 19 December 2015. [Online]. Available: https://github.com/bitcoin/bips/blob/master/bip-0141.mediawiki.

[37] “Bitcoin Avg. Transaction Fee historical chart,” [Online]. Available: https://bitinfocharts.com/comparison/bitcoin-transactionfees.html. [Accessed 1 December 2019].

[38] BBC, “Mastercard and Visa agree to cut overseas card fees,” 29 April 2019. [Online]. Available: https://www.bbc.com/news/business-48098100. [Accessed 1 December 2019].

[39] A. Barone, “What Happens to Bitcoin After All 21 Million Are Mined?,” Investopedia, 22 October 2019. [Online]. Available: https://www.investopedia.com/tech/what-happens-bitcoin-after-21-million-mined/. [Accessed 26 November 2019].

[40] FXCM, “What Happens When All 21 Million Bitcoin Are Mined?,” FXCM, 14 September 2018. [Online]. Available: https://www.fxcm.com/uk/insights/what-happens-when-all-bitcoin-are-mined/. [Accessed 26 November 2019].

[41] R. Singh, A. D. Dwivedi and G. Srivastava, “Bitcoin Mining: A Game Theoretic Analysis,” 2018.

[42] J. Bouoiyour and R. Selmi, “Bitcoin: A beginning of a new phase?,” *Economics Bulletin,* vol. 36, no. 3, August 2016.

[43] E. Bouri, G. Azzi and A. Haubo Dyhrberg, “On the return-volatility relationship in the Bitcoin market around the price crash of 2013,” 2016. [Online]. Available: https://www.econstor.eu/bitstream/10419/146870/1/869536516.pdf. [Accessed 16 Nov 2019].

[44] Cryptonite, “Will Bitcoin’s price rise following the halving in 2020?,” Hackernoon, 13 May 2019. [Online]. Available: https://hackernoon.com/will-bitcoins-price-rise-following-the-halving-in-2020-4885f9dcffb0. [Accessed 16 Nov 2019].

APPENDIX A - Block References

First block at 50 BTC

Source 1:

https://btc.com/000000000019d6689c085ae165831e934ff763ae46a2a6c172b3f1b60a8ce26f

Source 2:

https://www.blockchain.com/btc/block/000000000019d6689c085ae165831e934ff763ae46a2a6c172b3f1b60a8ce26f

Last block at 50 BTC

Source 1:

https://btc.com/00000000000000f3819164645360294b5dee7f2e846001ac9f41a70b7a9a3de1

Source 2:

https://www.blockchain.com/btc/block/00000000000000f3819164645360294b5dee7f2e846001ac9f41a70b7a9a3de1

First block at 25 BTC

Source 1:

https://btc.com/000000000000048b95347e83192f69cf0366076336c639f9b7228e9ba171342e

Source 2:

https://www.blockchain.com/btc/block/000000000000048b95347e83192f69cf0366076336c639f9b7228e9ba171342e

Last block at 25 BTC:

Source 1:

https://btc.com/00000000000000003035bc31911d3eea46c8a23b36d6d558141d1d09cc960cf

Source 2:

https://www.blockchain.com/btc/block/00000000000000003035bc31911d3eea46c8a23b36d6d558141d1d09cc960cf

First bock at 12.5 BTC

Source 1:

https://btc.com/00000000000000002cce816c0ab2c5c269cb081896b7dcb34b8422d6b74ffa1

Source 2:

https://www.blockchain.com/btc/block/00000000000000002cce816c0ab2c5c269cb081896b7dcb34b8422d6b74ffa1

APPENDIX B - Mining Hardware Efficiency

Source: [26]

Miner name	Date of release		UNIX date of release	Hashing power (Th/s)		Power (W)	Efficiency (J/Gh)
Bitmain Antminer S3	07.2014	0.478Th/s	1404172800	0.478	366W	366	0.77
Bitmain Antminer S5	12.2014	1.155Th/s	1417392000	1.155	590W	590	0.51
Bitmain Antminer S7	09.2015	4.73Th/s	1441065600	4.73	1293W	1293	0.27
Bitmain Antminer S9 (11.5Th)	06.2016	11.5Th/s	1464739200	11.5	1127W	1127	0.10
Bitmain Antminer S7-LN	06.2016	2.7Th/s	1464739200	2.7	697W	697	0.26
Bitmain Antminer R4	02.2017	8.7Th/s	1485907200	8.7	845W	845	0.10
Bitmain Antminer S9 (12.5Th)	02.2017	12.5Th/s	1485907200	12.5	1225W	1225	0.10
Bitmain Antminer T9 (11.5Th)	04.2017	11.5Th/s	1491004800	11.5	1450W	1450	0.13
Canaan AvalonMiner 741	04.2017	7.3Th/s	1491004800	7.3	1150W	1150	0.16
Bitmain Antminer S9 (13Th)	07.2017	13Th/s	1498867200	13	1300W	1300	0.10
Bitmain Antminer T9 (12.5Th)	08.2017	12.5Th/s	1501545600	12.5	1576W	1576	0.13
Bitmain Antminer S9 (13.5Th)	09.2017	13.5Th/s	1504224000	13.5	1323W	1323	0.10
Pantech SX6	09.2017	8.5Th/s	1504224000	8.5	1000W	1000	0.12
Bitmain Antminer S9 (14Th)	11.2017	14Th/s	1509494400	14	1372W	1372	0.10
Bitfury B8	12.2017	49Th/s	1512086400	49	6400W	6400	0.13
Ebang Ebit E9+	01.2018	9Th/s	1514764800	9	1300W	1300	0.14
Bitmain Antminer T9+ (10.5Th)	01.2018	10.5Th/s	1514764800	10.5	1432W	1432	0.14
MicroBT Whatsminer M3	01.2018	12Th/s	1514764800	12	2000W	2000	0.17
Bitfily Snow Panther A1	01.2018	49Th/s	1514764800	49	5400W	5400	0.11
Pantech WX6	01.2018	34Th/s	1514764800	34	5000W	5000	0.15
Ebang Ebit E10	02.2018	18Th/s	1517443200	18	1650W	1650	0.09
Canaan AvalonMiner 821	02.2018	11.5Th/s	1517443200	11.5	1200W	1200	0.10
Bitmain Antminer V9 (4Th)	03.2018	4Th/s	1519862400	4	1027W	1027	0.26
MicroBT Whatsminer M3X	03.2018	12.5Th/s	1519862400	12.5	2050W	2050	0.16
Halong Mining DragonMint T1	04.2018	16Th/s	1522540800	16	1480W	1480	0.09
Canaan AvalonMiner 841	04.2018	13.6Th/s	1522540800	13.6	1290W	1290	0.09
ASICminer 8 Nano Pro	05.2018	76Th/s	1525132800	76	4000W	4000	0.05
Innosilicon T2 Terminator	05.2018	17.2Th/s	1525132800	17.2	1570W	1570	0.09
Bitmain Antminer S9i (14Th)	05.2018	14Th/s	1525132800	14	1320W	1320	0.09
Bitmain Antminer S9i (13.5Th)	05.2018	13.5Th/s	1525132800	13.5	1310W	1310	0.10
Bitmain Antminer S9i (13Th)	05.2018	13Th/s	1525132800	13	1280W	1280	0.10
Ebang Ebit E9.2	05.2018	12Th/s	1525132800	12	1320W	1320	0.11
Ebang Ebit E9.3	05.2018	16Th/s	1525132800	16	1760W	1760	0.11
Bitfily Snow Panther B1	07.2018	16Th/s	1530403200	16	1380W	1380	0.09
Aladdin Miner 16Th/s Bitcoin	07.2018	16Th/s	1530403200	16	1400W	1400	0.09
Ebang Ebit E9i	07.2018	13.5Th/s	1530403200	13.5	1420W	1420	0.11
Innosilicon T2 Turbo	08.2018	24Th/s	1533081600	24	1980W	1980	0.08
Bitfily Snow Panther B1+	08.2018	24.5Th/s	1533081600	24.5	2100W	2100	0.09
Bitmain Antminer S9j (14.5Th)	08.2018	14.5Th/s	1533081600	14.5	1350W	1350	0.09
Bitmain Antminer S9 Hydro (18Th)	08.2018	18Th/s	1533081600	18	1728W	1728	0.10
MicroBT Whatsminer M10S	09.2018	55Th/s	1535760000	55	3500W	3500	0.06
MicroBT Whatsminer M10	09.2018	33Th/s	1535760000	33	2145W	2145	0.07
Innosilicon T2 Turbo+ 32T	09.2018	32Th/s	1535760000	32	2200W	2200	0.07
Canaan AvalonMiner 921	09.2018	20Th/s	1535760000	20	1700W	1700	0.09

Ebang Ebit E11++	10.2018	44Th/s	1538352000	44	1980W	1980	0.05
ASICminer 8 Nano 44Th	10.2018	44Th/s	1538352000	44	2100W	2100	0.05
Ebang Ebit E11+	10.2018	37Th/s	1538352000	37	2035W	2035	0.06
Ebang Ebit E11	10.2018	30Th/s	1538352000	30	1950W	1950	0.07
GMO miner B2	10.2018	24Th/s	1538352000	24	1950W	1950	0.08
Bitfury Tardis	11.2018	80Th/s	1541030400	80	6300W	6300	0.08
Bitmain Antminer S11 (20.5Th)	11.2018	20.5Th/s	1541030400	20.5	1530W	1530	0.07
GMO miner B3	11.2018	33Th/s	1541030400	33	3417W	3417	0.10
Holic H22	12.2018	22Th/s	1543622400	22	1700W	1700	0.08
Holic H28	12.2018	28Th/s	1543622400	28	2100W	2100	0.08
Innosilicon T3 43T	01.2019	43Th/s	1546300800	43	2100W	2100	0.05
Innosilicon T3 39T	03.2019	39Th/s	1551398400	39	2150W	2150	0.06
Bitmain Antminer S17 Pro (53Th)	04.2019	53Th/s	1554076800	53	2094W	2094	0.04
Bitmain Antminer S17 Pro (50Th)	04.2019	50Th/s	1554076800	50	1975W	1975	0.04
Bitmain Antminer S17 (56Th)	04.2019	56Th/s	1554076800	56	2520W	2520	0.05
Bitmain Antminer S17 (53Th)	04.2019	53Th/s	1554076800	53	2385W	2385	0.05
Innosilicon T3+ 52T	05.2019	52Th/s	1556668800	52	2200W	2200	0.04
Bitmain Antminer T17 (40Th)	05.2019	40Th/s	1556668800	40	2200W	2200	0.06
StrongU STU-U8	07.2019	46Th/s	1561939200	46	2100W	2100	0.05
MicroBT Whatsminer M20S	08.2019	70Th/s	1564617600	70	3360W	3360	0.05
MicroBT Whatsminer M21	08.2019	31Th/s	1564617600	31	1860W	1860	0.06

APPENDIX C - BTC Call Options [27-Dec-2019]

Source: [24]. Captured on 27/November/2019

Last	Size	IV	Bid	Ask	IV	Size	Vol	Δ|Delta	Strike
0.8415	16	0.00%		0.7945	311.10%	16	-	1	**1500**
-	14	0.00%	0.7105	0.7235	253.20%	14	-	1	**2000**
-	13	0.00%	0.6405	0.6525	209.50%	13	-	1	**2500**
0.5835	11	0.00%	0.571	0.582	177.30%	11	-	1	**3000**
0.5625	10	0.00%	0.4995	0.5135	158.60%	10	-	0.99	**3500**
0.4255	10	0.00%	0.4285	0.4465	144.50%	10	-	0.98	**4000**
0.5285	13.2	0.00%	0.3575	0.38	129.90%	17.4	-	0.96	**4500**
0.4645	15	0.00%	0.2875	0.316	118.40%	15	-	0.93	**5000**
0.25	14	0.00%	0.22	0.255	108.40%	14	-	0.88	**5500**
0.19	25	67.80%	0.1715	0.1865	86.30%	25	-	0.8	**6000**
0.1345	19.9	69.70%	0.1245	0.1275	72.70%	15	16.5	0.7	**6500**
0.0865	26.9	68.90%	0.0845	0.0875	71.50%	20.6	8.5	0.56	**7000**
0.056	29.5	69.00%	0.0555	0.0585	71.70%	27.3	39.3	0.43	**7500**
0.039	14	70.30%	0.0365	0.0385	72.30%	32.9	52.5	0.31	**8000**
0.0175	37.3	73.40%	0.0155	0.0175	76.20%	49.7	55	0.16	**9000**
0.0085	62	78.30%	0.0075	0.009	81.60%	20	22.8	0.09	**10000**
0.006	167	83.20%	0.004	0.006	89.80%	81.1	8.2	0.05	**11000**
0.003	112.4	88.90%	0.0025	0.004	95.90%	38	1.7	0.03	**12000**
0.002	14	96.80%	0.002	0.003	102.80%	37.2	0.2	0.02	**13000**
0.001	14	102.00%	0.0015	0.002	106.00%	5	-	0.02	**14000**
0.001	14	105.30%	0.001	0.002	114.80%	65	4.2	0.01	**15000**
0.001	88.5	104.80%	0.0005	0.0015	118.60%	14	0.1	0.01	**16000**
0.0005	38.3	117.50%	0.0005	0.001	126.40%	13	0.2	0.01	**18000**
0.0005	-	-	-	0.0005	128.90%	8.7	6.5	0	**20000**
0.0005	-	-	-	0.001	148.80%	34	-	0	**22000**
0.0005	-	-	-	0.0005	148.00%	14	-	0	**24000**
0.0005	-	-	-	0.0005	156.20%	14	-	0	**26000**
0.0005	-	-	-	0.0005	163.70%	14	-	0	**28000**
0.001	-	-	-	0.0005	170.70%	14.9	-	0	**30000**
0.0005	-	-	-	0.0005	177.10%	14.9	-	0	**32000**
0.0005	-	-	-	0.0005	188.70%	14	-	0	**36000**
0.0005	-	-	-	0.0005	199.00%	19.8	-	0	**40000**
0.0005	-	-	-	0.0005	208.20%	15	-	0	**44000**
0.0005	-	-	-	0.0005	216.50%	14	-	0	**48000**
0.0005	-	-	-	0.0005	224.10%	46	-	0	**52000**

APPENDIX D - BTC Put Options [27-Dec-2019]

Source: [24]. Captured on 27/November/2019

Strike	Last	Size	IV	Bid	Ask	IV	Size	Vol	Δ|Delta
1500	0.001	-	-	-	0.0005	211.50%	91.9	-	0
2000	0.0005	-	-	-	0.0005	173.20%	11.1	-	0
2500	0.001	-	-	-	0.001	156.80%	125.6	-	0
3000	0.001	42	120.10%	0.0005	0.0015	138.50%	91	-	0
3500	0.0015	24	115.30%	0.0015	0.002	120.40%	1	1.1	-0.01
4000	0.004	25	106.80%	0.003	0.0035	109.80%	1	0.1	-0.03
4500	0.0055	75	94.80%	0.0045	0.0055	98.80%	4.2	2.8	-0.04
5000	0.0095	37.6	86.60%	0.008	0.0095	90.50%	68	6	-0.07
5500	0.014	33	79.50%	0.014	0.0155	82.10%	14	46.5	-0.12
6000	0.026	48.8	73.90%	0.025	0.027	76.50%	53.2	38.1	-0.19
6500	0.044	42	70.60%	0.044	0.047	73.60%	29	101.3	-0.3
7000	0.0765	36.9	69.30%	0.0745	0.0775	72.00%	38.9	60.3	-0.44
7500	0.114	24.2	68.90%	0.1155	0.1185	71.50%	20	1.3	-0.57
8000	0.1685	16.7	69.70%	0.1665	0.1715	74.60%	8.1	28	-0.69
9000	0.2545	1	0.00%	0.06	0.55	315.10%	1	0.8	-0.84
10000	0.39	1	0.00%	0.3435	0.555	223.30%	0.5	1	-0.92
11000	0.651	0.3	0.00%	0.405	0.88	405.90%	1	-	-0.95
12000	0.725	0.1	0.00%	0.678	-	-	-	-	-0.97
13000	0.638	0.2	0.00%	0.7	-	-	-	-	-0.98
14000	0.7205	0.2	0.00%	0.78	-	-	-	-	-0.98
15000	0.959	-	-	-	-	-	-	-	-
16000	1.261	-	-	-	-	-	-	-	-
18000	1.1125	-	-	-	-	-	-	-	-
20000	1.729	-	-	-	-	-	-	-	-
22000	2.217	-	-	-	-	-	-	-	-
24000	-	-	-	-	-	-	-	-	-
26000	-	-	-	-	-	-	-	-	-
28000	2.2765	-	-	-	-	-	-	-	-
30000	2.51	-	-	-	-	-	-	-	-
32000	2.744	-	-	-	-	-	-	-	-
36000	3.212	-	-	-	-	-	-	-	-
40000	2.58	1	0.00%	0.001	-	-	-	-	-1
44000	3.46	1	0.00%	0.001	-	-	-	-	-1
48000	-	1	0.00%	0.0005	-	-	-	-	-1
52000	3.59	1	0.00%	0.001	-	-	-	-	-1

APPENDIX E - BTC Call Options [27-Mar-2020]

Source: [24]. Captured on 27/November/2019

Last	Size	IV	Bid	Ask	IV	Size	Vol	Δ|Delta	Strike
0.464	9	56.60%	0.445	0.472	96.10%	9	-	0.93	**4000**
0.4535	23	64.30%	0.3285	0.3595	87.50%	23	-	0.85	**5000**
0.2315	33.3	70.80%	0.244	0.252	75.10%	23.8	-	0.74	**6000**
0.1565	27.5	71.60%	0.174	0.178	73.40%	12.5	-	0.61	**7000**
0.1345	19.3	72.50%	0.1235	0.1275	74.20%	54.9	2.6	0.48	**8000**
0.0975	15	74.20%	0.0895	0.0915	75.10%	0.2	50.1	0.38	**9000**
0.068	14	75.90%	0.066	0.069	77.40%	28.7	78.2	0.3	**10000**
0.04	14	79.60%	0.0385	0.0405	80.80%	29.6	7.8	0.19	**12000**
0.026	31	83.20%	0.0245	0.0265	84.80%	15	2	0.13	**14000**
0.0195	29.6	87.40%	0.0175	0.0195	89.40%	15	0.2	0.09	**16000**
0.015	50.3	90.90%	0.013	0.016	94.60%	49.4	0.1	0.07	**18000**
0.0105	35	94.80%	0.0105	0.013	98.40%	35.1	-	0.06	**20000**
0.0105	64	97.80%	0.0085	0.011	102.10%	45.3	5	0.05	**22000**
0.0065	15	101.60%	0.0075	0.0095	105.40%	44.5	-	0.04	**24000**
0.0075	53	103.30%	0.006	0.0075	106.70%	1	-	0.03	**26000**
0.0065	25.8	106.60%	0.0055	0.007	110.30%	15	-	0.03	**28000**
0.005	48	107.80%	0.0045	0.006	112.10%	19	-	0.03	**30000**
0.004	36.5	110.00%	0.004	0.006	116.00%	48	-	0.02	**32000**
0.004	37	111.60%	0.0035	0.0055	118.20%	48	1	0.02	**34000**
0.0035	47	112.80%	0.003	0.0045	118.50%	19	-	0.02	**36000**
0.0035	35	116.20%	0.0025	0.004	122.70%	33	10	0.02	**40000**

APPENDIX F - BTC Put Options [27-Mar-2020]

Source: [24]. Captured on 27/November/2019

Strike	Last	Size	IV	Bid	Ask	IV	Size	Vol	Δ|Delta
4000	0.0155	32	76.30%	0.014	0.017	80.40%	57	1.2	-0.06
5000	0.0405	15	73.20%	0.038	0.041	75.40%	19.2	6.1	-0.15
6000	0.0835	29.8	71.40%	0.082	0.0855	73.30%	1.6	3.1	-0.26
7000	0.1495	18.1	71.80%	0.1505	0.1545	73.60%	18.8	20.3	-0.39
8000	0.304	8.2	71.30%	0.236	0.244	74.70%	8.4	-	-0.52
9000	0.44	19	65.20%	0.325	0.362	82.10%	10.8	-	-0.62
10000	0.44	9	59.00%	0.429	0.5115	100.10%	17.1	3	-0.7
12000	0.77	1	0.00%	0.022	0.88	160.10%	1	-	-0.81
14000	1.1385	0.5	0.00%	0.4	1.135	167.00%	0.5	-	-0.87
16000	1.08	-	-	-	-	-	-	-	-
18000	1.23	-	-	-	-	-	-	-	-
20000	1.108	-	-	-	-	-	-	-	-
22000	1.545	-	-	-	-	-	-	-	-
24000	-	6	0.00%	0.01	-	-	-	-	-0.96
26000	-	-	-	-	-	-	-	-	-
28000	-	-	-	-	-	-	-	-	-
30000	-	-	-	-	-	-	-	-	-
32000	-	2	0.00%	0.01	-	-	-	-	-0.97
34000	-	-	-	-	-	-	-	-	-
36000	-	-	-	-	-	-	-	-	-
40000	4.54	2	0.00%	0.0005	-	-	-	-	-0.98

APPENDIX G - BTC Call Options [26-Jun-2020]

Source: [24]. Captured on 27/November/2019

Last	Size	IV	Bid	Ask	IV	Size	Vol	Δ|Delta	Strike
0.6035	8	56.70%	0.5885	0.61	94.40%	8	-	0.96	**3000**
0.589	7	66.60%	0.4705	0.5005	89.60%	7	-	0.91	**4000**
-	7	63.50%	0.361	0.41	88.50%	7	-	0.83	**5000**
0.2835	13.4	71.90%	0.296	0.3045	75.30%	10.6	-	0.73	**6000**
0.22	10.7	73.30%	0.235	0.24	75.10%	11.1	-	0.64	**7000**
0.1895	12.7	73.90%	0.186	0.192	75.90%	18.3	0.9	0.55	**8000**
0.156	30.8	74.60%	0.1485	0.154	76.40%	12.3	10.7	0.47	**9000**
0.1245	15	76.30%	0.1225	0.126	77.50%	12.9	14.9	0.4	**10000**
0.09	20	78.80%	0.085	0.0895	80.50%	22.8	5.6	0.3	**12000**
0.067	15	81.10%	0.062	0.067	83.30%	23.8	7.5	0.23	**14000**
0.0525	30	83.60%	0.0475	0.0505	85.10%	1	0.1	0.18	**16000**
0.039	22	86.00%	0.038	0.0425	88.50%	25	-	0.15	**18000**
0.0335	13.8	89.70%	0.0335	0.036	91.20%	40	-	0.13	**20000**
0.041	9	91.60%	0.028	0.031	93.60%	40	-	0.11	**22000**
0.027	28	92.70%	0.023	0.027	95.70%	40	-	0.1	**24000**
0.02	19	94.80%	0.0205	0.024	97.80%	40	-	0.09	**26000**
0.023	34.7	95.90%	0.0175	0.0215	99.60%	25	-	0.08	**28000**
0.017	29	97.90%	0.016	0.019	100.90%	10.8	-	0.07	**30000**
0.0175	34	99.50%	0.0145	0.017	102.20%	10.9	-	0.06	**32000**

APPENDIX H - BTC Put Options [26-Jun-2020]

Source: [24]. Captured on 27/November/2019

Strike	Last	Size	IV	Bid	Ask	IV	Size	Vol	Δ|Delta
3000	0.012	20.2	76.80%	0.0105	0.0135	81.50%	39	3	-0.04
4000	0.0305	11.1	73.60%	0.03	0.034	76.70%	12	1	-0.09
5000	0.0675	12.8	72.60%	0.067	0.0705	74.40%	0.1	0.1	-0.17
6000	0.1165	12.7	72.30%	0.123	0.1295	74.90%	16.9	0.6	-0.27
7000	0.2035	12.4	72.80%	0.197	0.204	75.20%	18.3	1.5	-0.36
8000	0.35	18.3	72.30%	0.2825	0.293	75.70%	7	-	-0.45
9000	0.363	10.1	72.60%	0.3815	0.4035	79.90%	9.6	4	-0.53
10000	0.48	6.4	64.90%	0.4665	0.531	86.90%	6.4	1.1	-0.6
12000	0.783	0.2	0.00%	0.15	-	-	-	-	-0.7
14000	0.99	1	0.00%	0.5	-	-	-	-	-0.77
16000	1.22	1	0.00%	0.56	2	384.80%	0.1	-	-0.82
18000	1.5	1	0.00%	1.2	2.1	299.30%	0.1	-	-0.85
20000	1.765	1	0.00%	0.1	1.91	141.30%	0.1	-	-0.87
22000	-	1	0.00%	0.11	3.225	500.00%	0.7	-	-0.89
24000	-	-	-	-	-	-	-	-	-
26000	-	-	-	-	-	-	-	-	-
28000	-	-	-	-	-	-	-	-	-
30000	-	-	-	-	-	-	-	-	-
32000	-	-	-	-	-	-	-	-	-