Modeling the Trajectory of Bitcoin using System Dynamics

by

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B.Eng in Electrical and Electronic Engineering, Nanyang Technological University (2013)

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Abstract

Cryptocurrencies today have a cumulative market cap in the trillions of dollars, consume more energy annually than many countries, and show explosive volatility in their prices. Despite the extensive literature studying their rise, few attempts have been made to use a structural or mechanistic modeling approach to describe the dynamics of the ecosystem. In this study, a model has been built using System Dynamics to formulate and describe the mechanisms and decisions affecting the production side, which consists of the mining of blocks into the blockchain, and the market side, which involves actors using cryptocurrency units to serve different ends.

Bitcoin (BTC), the first cryptocurrency, is now over a decade old, and is still the most popular. It has a market cap larger than all the others. It serves well as a template or point of comparison to build models that seek to understand the dynamics of this system, and is hence used as the basis of this study.

The supply or production side of the system focuses on the mechanisms and interactions that determine the mining of blocks awarding BTC. The demand or market side of the system looks to explain the decision-making mechanism for the different users in the system – classified as 'chartists', 'fundamentalists', and 'transacters' in addition to the miners. The model developed looks to capture the feedbacks generated by the process of mining in the network, the inherent design of the BTC protocol, supply-demand balancing to cause changes in BTC price, exogenous data factors such as the price of mining hardware, transaction volume and fee, and cost of energy, and connect it to the decisions made by the different actors in the system based on an analysis of their costs and benefits.

The model is then calibrated to historic data. Results from this calibration process are discussed. Further refinements and scenarios to be analyzed are suggested.

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Chapter 1
Motivation

For over a decade, cryptocurrencies have seen a meteoric rise in value and public attention. Perspectives about their impact range from being a revolutionary financial instrument to a threat to monetary policy.

Several institutions now support BTC and other cryptocurrencies in some form and are calling for broader adoption. This adoption can be either an investment, store of value, or legal tender. Today, the BTC in circulation is worth nearly a trillion dollars and can be considered the inspiration for several other cryptocurrencies that have sprouted since its inception. Considering the amount of computational power required for the generation of a new currency unit, there are concerns surrounding its environmental impact, with its network's estimated annualized energy consumption over 200 TWh, comparable to the power consumption of Thailand with a carbon footprint similar to Czech Republic. A single transaction is estimated to require roughly 2200 kWh [12]. To put it into context, 2200 kWh is the average energy consumed by an average US household in ten weeks [28].

Additional risks such as illegal transactions capitalizing on its anonymized nature and its inherent lack of value in the traditional sense also add to the discussion surrounding it. Hence, regulators have to craft policies that can solve the difficult task of balancing ensuring that the public is protected sufficiently from difficult situations such as fraud, theft, etc., while also allowing innovation and disruption. There are many things about the dynamics of the BTC ecosystem that are still unclear, such as the concentration and cost-benefit comparison of mining, the motivations of the market participants, the impact of regulation, and so on. A better understanding of the working of this entire system will provide more clarity to help inform policy, revisit blockchain protocol design choices, give insight into its place in the broader financial system, and estimate its potential trajectory.

Chapter 2
Background

This section covers some background material essential to understanding the ideas and formulations explained later. It starts with a general overview of cryptocurrencies and their different types before describing key concepts that form the core of BTC. These include the underlying blockchain technology, the hashing process that generates the blocks in the blockchain, and the proof-of-work concept it uses as its consensus mechanism. Following that, the process of mining, transactions, and a step-by-step overview of the BTC protocol is provided. Finally, the economics of BTC is commented on.

Cryptocurrency

The critical feature of a cryptocurrency, one that formed the backbone of the original argument presented for it in the Bitcoin whitepaper by Satoshi Nakamoto, is that it is a decentralized system of payments or value storage outside the traditional scrutiny of the government. It does not require a financial institution to serve as a middleman or trusted third party. The blockchain technology that forms the basis for any currently existing cryptocurrency replaces reliance on a few centralized record keepers, such as banks or credit card networks, instead of relying on a large number of anonymous agents that are part of the network contributing to verifying blocks that form part of the blockchain. This removal of centralized accountability and the anonymity afforded to its users are often touted as significant advantages by believers. Still, the downside is that it presents difficulties in diagnosis and resolution of issues in the system, gives regulators many new challenges and headaches, and creates new sources of risk that have not been encountered before [1].

Supplementary, alternative or digital currencies are not new concepts, but cryptocurrencies are designed without a central point of trust. They are designed to be digital assets working as a medium of exchange, with cryptographic methods securing transactions, controlling the creation of additional currency units, and verifying transfers of assets between different entities in the system. Several different types of cryptocurrencies exist today and were classified by Hardle et al. [2] into seven broad classes. These are:

1) Cryptocurrencies that were designed as transaction mechanisms, like BTC and Litecoin. They can be thought of as Gold 2.0.
2) Distributed computation token cryptocurrencies, such as Ethereum and Tezos, where small programs are executed when called upon on every available node.
3) Utility token cryptocurrencies that use programmable blockchain assets, such as golem and storj. These allow users to buy or rent out assets they have or need, such as computation power and disk space. Other examples include Sia and FileCoin.
4) Security tokens represent stocks, bonds, or other financial assets. New offerings of these are called STOs (Security Token Offerings). They hold the promise of efficiency gains in clearing and settlement.
5) Like the ERC-20 issued on the Ethereum blockchain, Fungible tokens are interchangeable and represent something more valuable. They can be considered special tokens on such blockchains.
6) Non-fungible tokens are non-interchangeable, and examples include Cryptokitties and Decentraland. These are like fungible tokens, but also have the added property of being unique. The ERC-721 token on the Ethereum blockchain is another example.
7) Stablecoins are collateralized with some kind of asset. This asset can be a traditional fiat currency, such as tether. It can also be collateralized with real assets such as gold such as Digix Gold, or petroleum such as Venezuela's petro. And finally some, such as MakerDAO, are cryptocurrency collateralized.

There are yet more cryptocurrencies, such as Facebook's Libra, are not easy to categorize, but this gives a sense of the different uses for cryptocurrencies beyond the large and well-known ones such as BTC and Ethereum.

A central idea among cryptocurrencies is a network of peers with equal standing. Each peer has a copy of the ledger and offers up compute power to provide algorithmic consent on the correct ledger, thereby deciding new additions to the blockchain via consensus. Peers do not need to know or trust each other in the network.

It is also possible to restrict the peers in a blockchain and create private permissioned versions of it. Central banks such as the MAS, Bundesbank, and SARB have reported interest in such applications. In this case, trust is necessary to the permissioned blockchain because the central bank owns these coins. Since they govern the coins, they have the right to change the supply of coins or enact policy relating to them should they desire. [30]

Any transaction type can be added to a blockchain. Because of its immutability, a blockchain serves as an official, indisputable record of the transaction's financial contract. Examples of these transactions can include asset transfers, property sales, exchanges of goods and services, or others that are less legal such as those on the darknet.

<u>Blockchain</u>

Haber and Stornetta [3] proposed a blockchain in 1991. They used it to solve the problem of certifying when a digital document was created or changed by hashing the document and timestamping the hash output. This concept forms the backbone of present-day cryptocurrencies.

A blockchain is divided into more miniature datasheets, called a block. The block contains information about its position in the chain and a summary of its contents. Information is repeated between a block, the previous, and the next block in the chain, such that inconsistencies (or corruption) in the block information will cause the network to throw it out and correct it. Such information is called a digest [2]. This forms a significant component of the information security on the blockchain. These digests, placed at the end of a block (to point to the next) and the beginning of the next block (to point to the previous), are generated via cryptographic hashing functions.

Hashing Process

A hash function is simply a mathematical transformation. It takes an input and transforms it into an output form known as a hash. In the context of the blockchain, it creates the digests connecting blocks. Hashing differs from encryption because encryption secures a piece of data with a lock that can be decrypted with a key, whereas a hash has no decryption step. A good hashing algorithm will make it infeasible to find two different input values that result in the same output hash.

A commonly used cryptographic hashing algorithm, the SHA-256 (Secure Hash Algorithm), has a maximum input size of 2^64-1 or over two thousand petabytes and an output of 256 bits. This algorithm is used in the BTC blockchain.

The hashing function ensures the integrity of the blocks in the blockchain. If the same input is passed through the process, the recalculated hash output must be consistent with the stored hash output. If it is not, this means that the information has been corrupted. Small input changes, such as an extra character, will completely change the hash output.

Proof-of-work consensus mechanism

The danger of using a simple SHA-256 blockchain is that a corrupt actor can potentially change a historical block and all subsequent blocks to match the hashes, essentially rewriting the ledger.

The BTC blockchain is built based on a proof-of-work consensus to render this event unlikely. This is based on the initial proposal by Satoshi Nakamoto in the Bitcoin Whitepaper [4], where instead of providing any SHA-256 output to add a block in a blockchain, a special output requiring many leading zeroes is needed. The SHA-256 hash value of the proposed block has to be lower than or equal to the current target for it to be accepted by the network. This target determines the 'difficulty' of the hashing problem, which is set so that a new block is added every specific period, known as the target block generation time (10 minutes according to current policy), on average. This difficulty is updated or re-targeted every 2016 blocks at present. This works out to an average difficulty adjustment period of 2 weeks.

Several miners apply computing power to solve this hashing problem, commonly measured in terms of a hash rate. This is done via a brute-force search. The first miner to find the hash output that satisfies the difficulty target presents the block with its group of transactions and digest to the network. Once each node in the network verifies the block, it is added to the blockchain. This is the proof-of-work consensus mechanism. The miner of the freshly mined block is rewarded with a set BTC reward and the fees for all transactions that have been ratified in the block.

Proof-of-work makes it unlikely that a historical block can be rewritten and all subsequent blocks altered after the fact since it will require a tremendous amount of computing power that is not currently available. However, if over 51% of the computing power is controlled by one entity, there is a possibility that this occurs. This is the infamous '51% attack' condition. This is not the only approach to consensus – Ethereum started with a proof-of-work mechanism but switched to a proof-of-stake, where blocks are allocated proportionally to the current holding. Today, others are in action, such as

STEEM's 'proof-of-brain' and Slimcoin's 'proof-of-burn' mechanisms.

Mining

The entire process of adding a block to the blockchain via the proof-of-work consensus mechanism is somewhat analogous to gold mining, where it is expensive to do, and a reward is provided only if the requisite material is found. Hence, the term 'mining' came to be applied to solving these hashing problems on a cryptocurrency network.

BTC Protocol

The basic working of the BTC protocol is described in the Whitepaper [4] and is summarized below:

1) New transactions are broadcast to all nodes.
2) Each node collects new transactions into a block.
3) Each node works on finding a difficult proof-of-work for its block.
4) When a node finds a proof-of-work, it broadcasts the block to all nodes.
5) Nodes accept the block only if all transactions are valid and not already spent.
6) Nodes express their acceptance of the block by working on creating the next block in the chain, using the hash of the accepted block as the previous hash.
7) The incentive is paid to the node that found the proof-of-work.
8) Ties: Nodes always consider the longest chain the correct one and will keep working on extending it. If two nodes broadcast different versions of the next block simultaneously, some nodes may receive one or the other first. In that case, they work on the first one they received but save the other branch if it becomes longer. The tie will be broken when the next proof-of-work is found, and one branch becomes longer; the nodes working on the other branch will then

switch to the longer one, and the system continues as usual.

By convention, the first transaction in a block is a unique transaction that starts a new coin owned by the creator of the block.

The incentive can also be funded with transaction fees. If the output value of a transaction is less than its input value, the difference is a transaction fee added to the incentive value of the block containing the transaction. Once a predetermined number of coins have entered circulation, the incentive can transition entirely to transaction fees and be completely inflation-free.

While network nodes can verify transactions for themselves, the simplified method can be fooled by an attacker's fabricated transactions for as long as the attacker can continue to overpower the network. This is the pitfall described commonly as the '51% attack' case.

Transactions

A notional estimate of the transaction capacity of BTC can be calculated as follows:

- A block is mined every 10 minutes, which works out to 144 blocks per day
- The space allocated for transaction data per block is 1MB, and an average transaction requires 480 bytes [17] of capacity. This works out to roughly 2100 transactions per block at peak volume.
- Taking the block generation time and transaction throughput, we arrive at a figure of 3.5 transactions per second. In practice, the actual throughput is in the 3 to 7 transactions per second range.

In comparison, Visa is estimated to process nearly 1700 transactions per second, while PayPal is estimated to process about 200 transactions per second. [5]

This transaction rate limitation is the essence of BTC's scalability problem. It is recognized to be one of the bars to more widespread adoption and has resulted in a large body of research suggesting possible solutions to this rate limitation, surveyed in some depth by Zhou et al. [7]

Nevertheless, simplistic and short-sighted policy actions such as increasing the block size to allow more transactions to be supported per block will have ramifications in terms of storage capacity requirement, while modifications to target block generation time will either result in lowered security (because of easier hashing problems) or higher compute power requirement in the network (because of an increase in attractiveness of mining stemming from an increase in mining incentive per unit time), and lead to new problems. This is where modeling the system can provide insight and elevate system understanding.

Economics of BTC

BTC has no intrinsic value. It can only function if market acceptance is sufficient, and there is the belief that some value can be attributed to it. The currency has value in a traditional fiat currency system because of the trust placed in central banks issuing it. In the case of a cryptocurrency, additions to the ledger are approved by a network of participants. There does not need to be trust between the players in the system. There only needs to be trust in the hashing algorithm and the network working on the blockchain. Transactions are validated only if the output and input match. If the transaction does not have the assets requested for transfer, it will not go through. Further, new cryptocurrency issues are algorithmically predetermined; in BTC's case, it is issued by the act of mining blocks.

Chapter 3

Problem Definition

One of the key drivers of interest in BTC is the valuation seen for it over the decade or so since its inception. Figure 1 shows a chart of its explosive price growth.

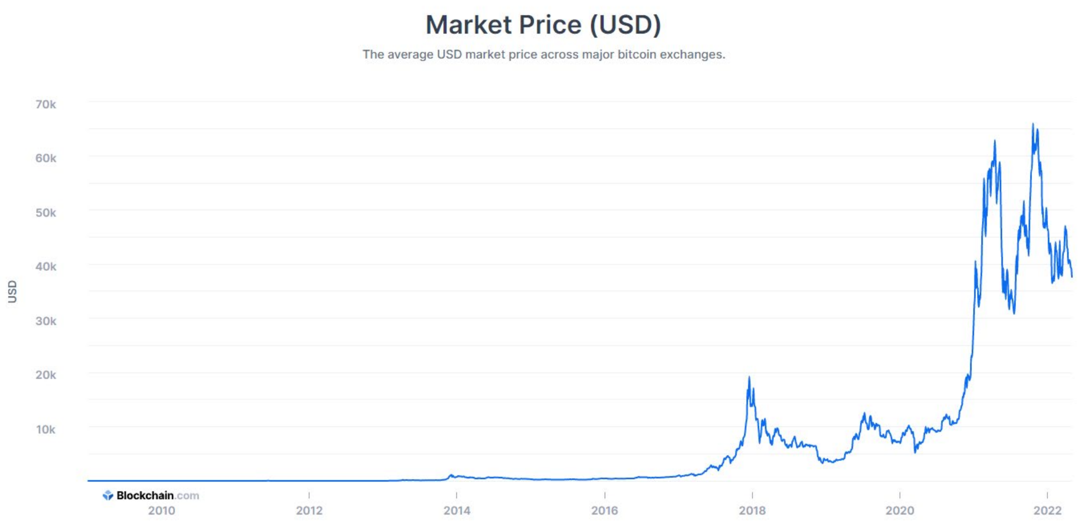

Figure 1: BTC's price history. The y-axis shows the price, while the x-axis shows the timeline. Image from blockchain.com [13]

The trajectory of BTC's price can be told as a story of three parts:

1. Almost zero value for the first eight years of its life – the system was sustained mainly by dedicated actors who believed in its value but did not receive enough attention to warrant a second glance by most people.
2. An exponential price spike in 2017 followed by a collapse in value – a sudden influx of interest led to a meteoric rise in price, but it was not sustained. The fall was as steep as the rise and hence was classed as a 'bubble,' but it did result in an overall long-term increase in perceived value, with price levels stabilizing around the $6000 mark.

3. A less severe collapse followed another exponential price spike in late 2020 in value – at this point, BTC was widely-known. Institutional investors started offering products and services based on it, such as coin funds. Several cryptocurrencies with different protocols existed at this point, based on the original idea of BTC. Some countries started accepting it as legal tender. All these factors resulted in a giant price spike.

Another aspect of BTC that is key to understanding it is the nature and volume of transactions in its blockchain. Makarov et al. [1] analyzed the blockchain in 2021 using the open-source software of Bitcoin Cor, with the BlockSci program to parse the raw data into individual transactions. As of June 28, 2021, there have been 689,000 blocks of 652 million Bitcoin transactions and 896 million addresses organized in a more than 379 GB blockchain database. Their analysis provides several vital pieces of information about transactions in the BTC network:

- 90% of transaction volume on the blockchain is not economically meaningful, a by-product of protocol design.
  - Since all payment flows between addresses are perfectly observable, many bitcoin users adopt strategies designed to impede the tracing of bitcoin by moving their funds over long chains of multiple addresses and splitting payments among them, resulting in a large amount of spurious volume.
- 75% of BTC trading volume is done via exchanges – including online wallets, OTC desks, and institutional investment platforms.
- 3% of transactions are considered 'illegal,' including black market exchanges, scams, gambling, etc.
- Transaction volume explained by miners is more minor than these other avenues.
- Exchanges are the most connected nodes on the network.
- Non-integrated, independent exchanges mean that price arbitrage

opportunities exist. This occurs because regulation with 'Know Your Customer' (KYC) norms is burdensome because of the varying nature of exchanges and their countries. Tracing is difficult as a result.

- This has taxation impacts since capital gains can be hidden.
- Restrictions on transacting in BTC, such as a blockchain 'monitoring entity', can make it traceable, but it is contrary to the spirit of BTC itself. The requirement for a trusted third party or monitoring entity is exactly what the currency saw as an issue it wanted to overcome.

The amount of computation power devoted to solving hashing problems in the BTC network has grown as explosively as its price. Figure 2 shows the network's total compute power trend in terms of its hash rate measured in TH/s (terahash per second).

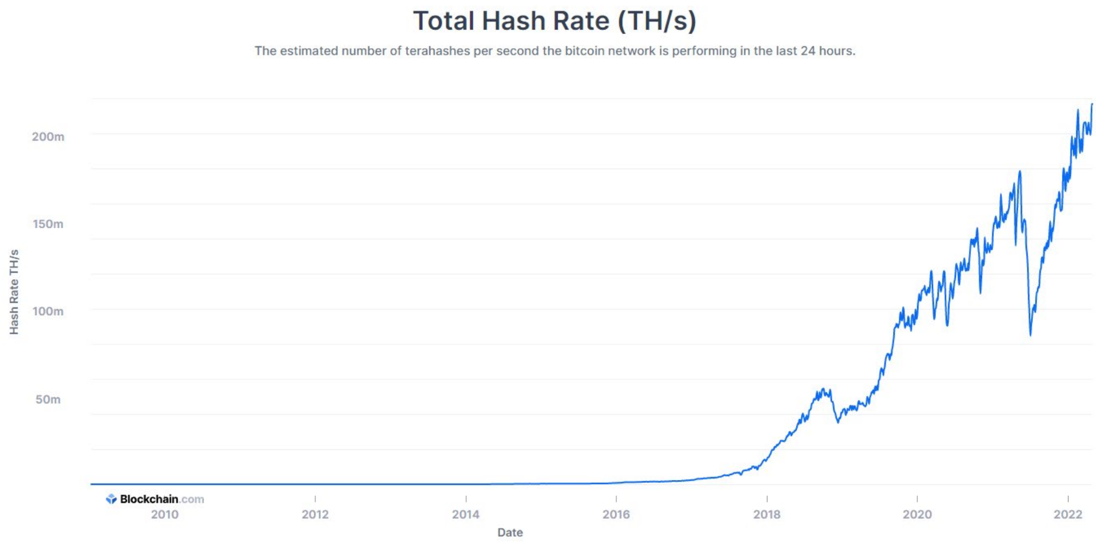

Figure 2: BTC network's total hash rate over time. The y-axis shows the hash rate in TH/s, while the x-axis shows the timeline. Image from blockchain.com [14]

Understanding this growth is another crucial piece to explaining the dynamics of this system. The Makarov paper discusses several key findings of the distribution of miners and BTC holdings in the network.

- Mining capacity is highly concentrated.
    - The top 10% of miners control 90% of the network's computing power or hash rate.
    - Roughly 0.1% (about 50 miners) control close to 50% of mining capacity.
    - This counter-cyclical concentration varies drastically with the BTC price, especially around halving events.
    - As expected, the concentration decreases following sharp increases in the BTC price since it increases the incentive to mine and, therefore, its attractiveness. In contrast, it grows in periods when the price drops.
    - Geographical clustering analysis showed that between 2015 and early 2020, around 60-80% of the mining capacity was located in China.
- The infamous Xinjiang incident showed how high the impact of this concentration of miners is. There was access to a cheap supply of coal-powered electricity in the Xinjiang province that supported a large compute power capacity. An accident caused a power shutdown, taking a sizable proportion of miners off the network, and causing the network to drastically slow down block generation until the next difficulty adjustment checkpoint was reached.
- Around the end of 2020 - intermediaries were estimated to own 5.5 million BTC or roughly one-third of the total circulation. Individual wallets controlled approximately 8.5 million BTC, with the top thousand individuals holding about 3 million.

All this shows that most of the wealth and activity attributed to the BTC ecosystem is limited to a small subset of individuals in the world. In its present state, at the current proportion of adoption, it cannot rationally be countenanced as a viable currency. However, it is difficult to estimate how many individual miners are currently on the network. An estimate provided for it is 1 million [16], but this would mean each miner controlled 200 TH/s of computing power on average, which is difficult to maintain without sizable capital investment. Thus, it is more helpful to think of them at an aggregate level. The model described later uses the concept of 'mining units,' contributing an average level of computation power that changes over time as more powerful compute hardware is available.

The market capitalization (outstanding currency multiplied by its traded value) of BTC has exceeded USD 1 trillion at some points in its life and now sits at about USD 800 billion. A chart showing the trend of its market capitalization is shown in Figure 3.

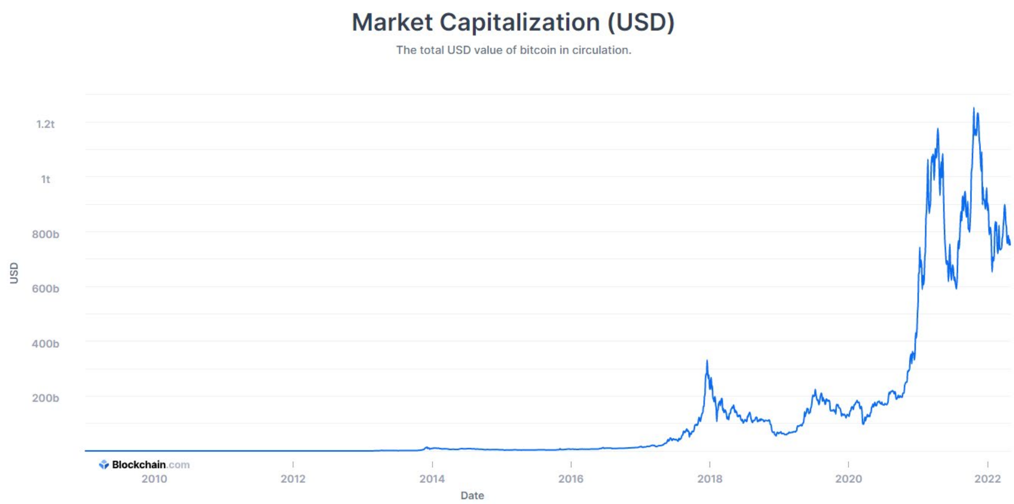

Figure 3: BTC's market capitalization trajectory to date, image from blockchain.com [14]

Projections for its future vary, with views as extreme as total collapse and enough belief that it will rise to replace today's currency system. Other aspects of its design, such as its limited supply (roughly 21 million, of which over 18 million have already been mined), its block generation target time (currently set to 10 minutes), and its difficulty retargeting time (currently set to 2016 blocks, which works out to roughly two weeks at the block generation time target) also intimately affects its dynamics.

Modeling to study and explain the behavior seen so far by identifying key drivers and structures within the system and using this to predict its future trajectory is a valuable endeavor.

Several prior attempts have been made to understand BTC dynamics, with papers focusing on a subset of the outcomes and behaviors but not aimed at capturing multiple interacting pieces.

A BIS working paper by Auer [8] connects mining transaction fees to transaction speed. It looked at the wait time for the transactions under different conditions of fee-setting. In this case, the notional supply is limited (by the block throughput), and this causes exponentially lower speeds at low incentives. Essentially, transaction fees scale higher due to the transactor's impatience – that is, the higher the payment, the more likely it is that the transaction is serviced quicker.

Prat et al. [9] proposed an agent-based model that attempted to forecast how competitive mining can be for new entrants, formulating the cost of mining in terms of hardware requirement and energy consumption. Mining rigs have also improved roughly following Moore’s law regarding compute power per unit energy consumed and cost per unit hash rate. This causes new entrants to come in with a higher share of computing power than the average incumbent.

Cong et al. [10] suggest a dynamic equilibrium model of token pricing and platform adoption. Platforms provide value by supporting economic activities, and tokens on those platforms enable transactions between peers. Tokens derive value from this process, reflecting users’ participation in the network.

Dai et al [29] propose a framework to specifically study the supply side, such as transaction fees, miner's liquidation policies, and inventory holdings, as block rewards decline and transaction demand is uncertain.

Another working paper by Cong et al. [11] explores the dynamics of mining pools and the cost-benefit analysis for miners, both new and existing, to enter pools. The general idea is that pooling resources increase the probability of the entire pooled unit mining a block. The reward is distributed among all participants based on the proportion of computing power they provided in the pool. The tradeoff is a 'pooling fee' charged by the pool managers for participants to be a part of the pool. This is generally seen to be 1-3% of the payoff.

These models all provide valuable insights and ideas but do not provide a clear overall view of the mechanisms and structural aspects of the system driving this behavior in totality. This is where modeling using a System Dynamics approach can provide new insight.

System dynamics is a control theory-inspired modeling approach to understanding the non-linear behavior of systems using stocks, flows, feedback loop structures, and time delays. It falls into the structural or mechanistic models class and considers things on an aggregated level. Many of the principles and template modeling structures used in this report are borrowed from John Sterman's excellent 'Business Dynamics' textbook. [6]

Chapter 4
Modelling Approach

Based on the discussions and ideas presented in the previous chapters, a big-picture view of the overall system can be developed. This consists of two distinct sides:

1. The Production Side – or supply side, as this report uses the two somewhat interchangeably. This includes the addition of blocks into the BTC blockchain via the mining process, with more BTC released into the system as a result of the addition of these blocks.
2. The Market Side – or demand side, sets the price of units of BTC via the interactions of different users in the system and a market-clearing process based on classical economic supply and demand dynamics. This side of the system has actors that buy or sell BTC as an investment or use it for transactions as a replacement for currency.

From this big-picture view of the system, several essential mechanisms were identified for further conceptualization. They were:

1. Mining Difficulty Balancing – The difficulty of the hash problem and compute power on the network balance each other by design to maintain the block generation time close to the target of 10 minutes. This target value is set by design in the BTC protocol. Additionally, the difficulty is adjusted every 2016 block. During this adjustment process, the hashing problem is made more difficult if the block generation time for the preceding 2016 blocks was too low (because of an increase in computing power since the previous adjustment). It is made easier if block generation time is too high (because of a drop in computing power since the last adjustment). There is an upper

and lower limit to successive values of difficulty. It cannot be more than four times or less than 1/4th of the previous target difficulty. This is represented in Figure 4 as the 'Mining Difficulty' Balancing loop.

2. Cost-Benefit Tradeoff of Mining – The decision to be a miner in the network is a function of a cost-expected benefit tradeoff analysis. The expected benefit is the sum of the BTC reward (or seigniorage) and transaction fees associated with a block multiplied by the probability of mining a block. This probability of mining a block is the applied compute power divided by the total compute power in the network. The cost associated with mining has two components – a fixed hardware cost and a variable energy consumption cost. The cash flow of expected benefit minus variable cost over the entire active period of mining discounted at an applicable reference rate has to be greater than the fixed cost for a net profit. This profit also needs to be compared against the expected profit from simply investing the fixed cost amount in a reference financial instrument. The higher the expected benefit, the more attractive mining is, increasing miners and computing power in the network. Since an increase in compute power causes a spike in difficulty, it becomes harder to mine a block and therefore increases costs reducing the expected benefit, resulting in an overall balancing effect. This is represented in Figure 4 as the 'Cost-Benefit Tradeoff of Mining' Balancing loop.
3. Liquidity – As more blocks get mined, the more the outstanding BTC in circulation, the better the access to it, and the greater the transaction volume. This makes the network larger, with more miners entering due to higher expected benefits, ensuring that the blockchain remains operational with blocks mined and more BTC added into circulation as time goes on. It may also be pertinent to note an artificial cap on the number of BTC that can be created, set

to 21 million by design. This is represented in Figure 4 as the 'Liquidity' Reinforcing loop.

4. Fundamentals Investment – People who believe in the long-term potential of BTC as a store of value, investment, or currency, will look to acquire units of the coin and tend to hold it for a long duration. This category of trader or investor is classified as 'fundamentalists.' Additional signals from the price trends over their characteristic time horizon will dictate whether it becomes more attractive, thereby attracting more fundamentalists. This is represented in Figure 4 as the 'Fundamentals Invstment' Reinforcing loop.
5. Speculative Investment – Short-term or speculative interest in BTC will rise (or fall) depending on its short-run price trends. People falling in this category of short-term or speculative investors are classified as 'chartists,' and short-run price trends will give them signals to either increase their holding because the price is going up or decrease it if it goes down. This is represented in Figure 4 as the 'Speculative Investment' Reinforcing loop.
6. Impact of Halving Events – Halving events affect the release of BTC with the mining of blocks. When such an event occurs, there is a reduction in the BTC awarded per new block mined to half the previous level. If the BTC reward per block before the halving event was 50 (as it was at the inception of the cryptocurrency), it reduces to 25 after the halving event. It is set by the current policy to occur every 210,000 blocks. This works out to roughly four years between each halving event. This is represented in Figure 4 as the 'Impact of Halving Events' Balancing loop.
7. Block Generation and BTC Creation – Blocks are added to the blockchain as close to the set target time by 10 minutes. According to current policy, each block may contain up to 1MB (recent averages have been around 0.9MB) of transaction data. Considering

the average transaction size on the BTC blockchain is roughly 480 bytes [17], the throughput seen is approximately 2000 transactions per block or 3.3 transactions per second. As the blockchain gets built up, it is subject to the various other mechanisms outlined above, and it can be thought of as a stock. Each block rewards BTC to the winning miner and effectively adds BTC into circulation. This is expected to continue to roughly 2140 when all the notionally available BTC units are mined. Beyond that, new blocks added will not award BTC for successful mining, and the system is expected to be sustained solely by transaction fee incentives for miners. The mechanics of this forms the basis of the formulation described in Figure 5.

Considering all these mechanisms, a Causal Loop Diagram (CLD) was built to represent the conceptual framework for the model. It is shown in Figure 4.

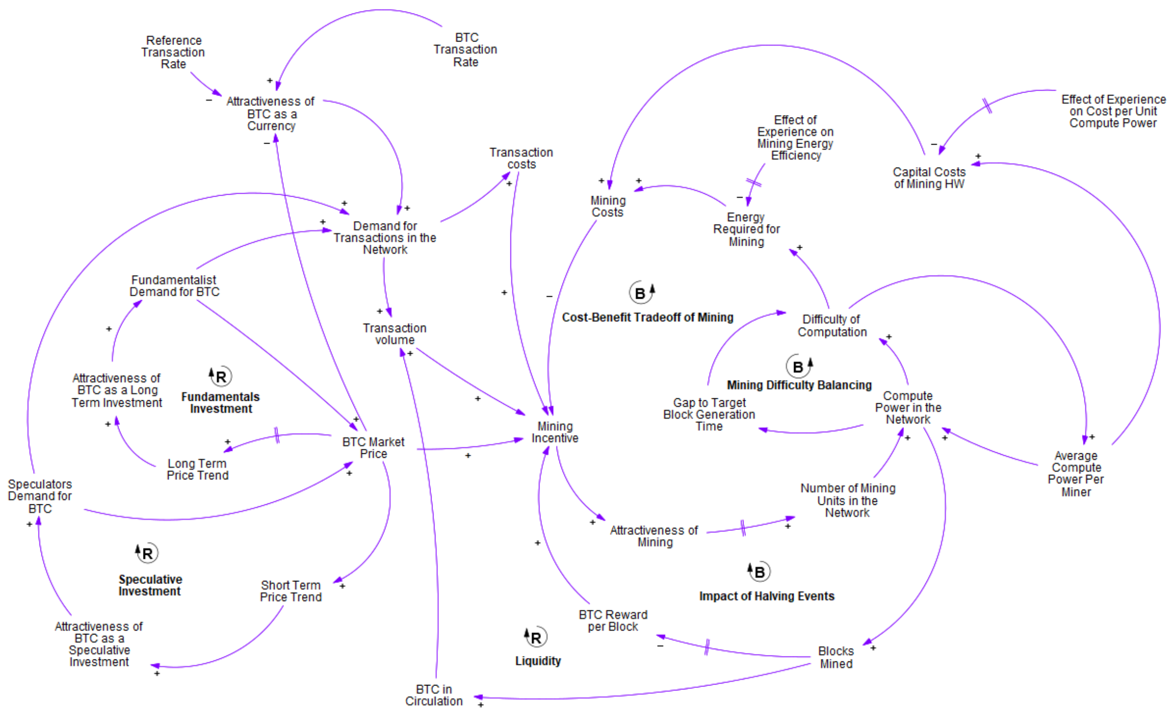

Figure 4: CLD of proposed BTC Ecosystem model

This CLD provides a qualitative description of the system and informs the thought process behind the quantitative formulations. All modeling is done on Ventana System's Vensim DSS software.

Production Side

The critical mechanisms captured on the production side are covered in this section. These include block generation, difficulty adjustment, and the processes guiding miner behavior.

Block Generation and BTC Creation

The processes of block generation and BTC creation take place in parallel, i.e., as more blocks are added to the blockchain, more BTC is created to reward the mining of those blocks. Hence, they can be thought of as a co-flow structure. With that in mind, the fundamental skeleton and formulation for the block generation and BTC creation mechanism are shown in Figure 5.

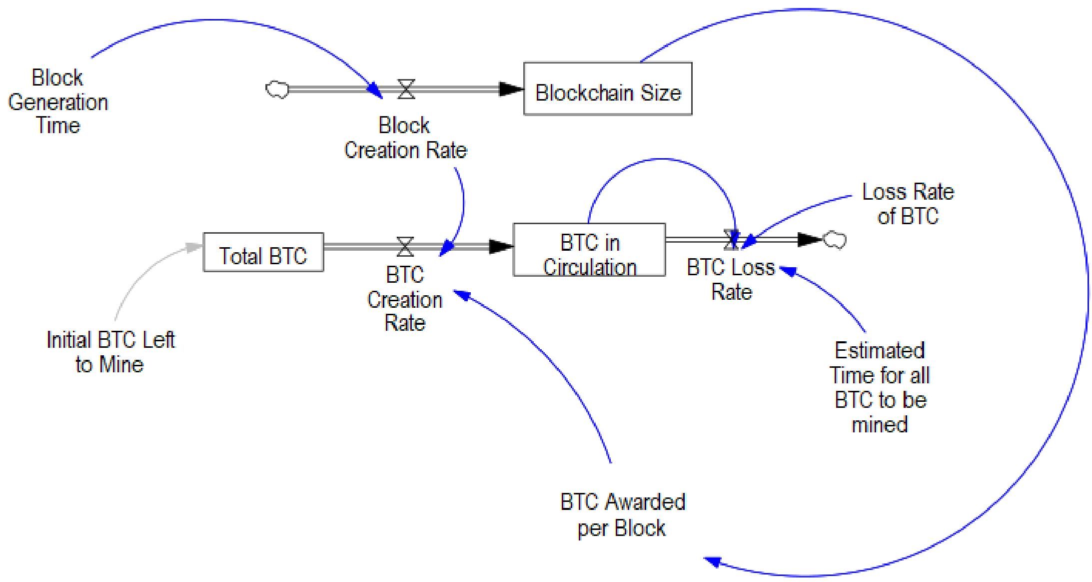

Figure 5: Block Generation and BTC Creation Co-Flow Structure

The outflow from the BTC in Circulation stock is a loss rate formulated to be constant based on data published in reports by Chainalysis, a blockchain forensics firm [18]. Based on the reported figure of roughly 2.8-3.7 million BTC lost (17-23% at that point in 2017), a conservative estimate of 20% is assumed in the model. Additionally, the BTC awarded per block is a function of the Blockchain Size and the halving interval, which is later covered in detail.

Difficulty Adjustment

As described before, difficulty adjustment is a balancing process that seeks to balance the difficulty of the hash problem. The block generation time stays as close to the target (10 minutes) as possible, given the network hash rate at any given point in time. The difficulty itself is formulated as a dimensionless quantity that scales the problem to be solved by the network to generate a block in the blockchain so it takes this specific time interval.

The structural formulation for this process is shown in Figure 6.

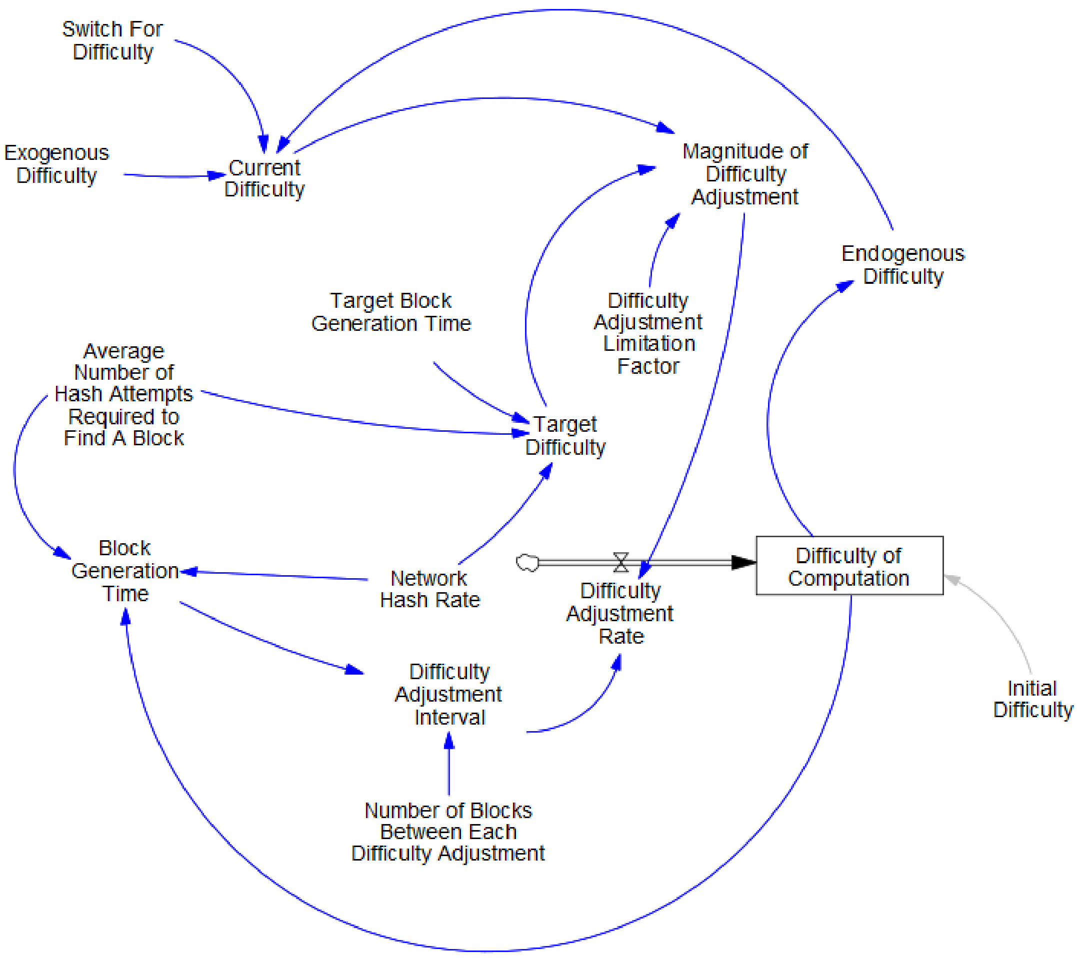

Figure 6: Difficulty Adjustment Model Structure

The current Difficulty, Block Generation time, and Network Hash Rate are related as follows:

Block Generation Time = Difficulty of Computation * 2^32 / Cumulative Network Hash Rate

The 2^32 term that translates to a number a little over 4 billion is derived from the hashing algorithm currently used in the Bitcoin blockchain, the SHA-256, and is represented in the model by 'Average Number of Hash Attempts Required to Find a Block.' This can be changed by policy – for example, if the BTC blockchain decides to switch from the SHA-256 algorithm.

The 'Target Block Generation Time' is a constant set by policy and is currently 10 minutes. Substituting this in the relationship will provide the Target Difficulty setting that needs to propagate when the next difficulty adjustment occurs. The 'Number of Blocks between each Difficulty Adjustment' term essentially represents that by policy, a difficulty adjustment only happens once every 2016 blocks. The actual interval of time taken depends on the actual block generation time in that period. Additionally, the 'Difficulty Adjustment Limitation Factor' accounts for the corner-case conditions, which dictate that the new adjusted difficulty of computation cannot be more than four times or less than $1/4^{th}$ the previous difficulty setting.

Finally, the 'Switch for difficulty' connected to the Difficulty of Computation set endogenously by the model and the exogenous difficulty sourced from data is an essential construct for calibration purposes. The idea is to drive the model with data sources to calibrate all the constants affecting the system so that when the data source is taken away and replaced by the model-generated value, the model can run endogenously, replicating the behavior seen in the data and be used to possibly forecast into the future, or change levers of interest to gain a better understanding of how the system behaves.

Miner's Cost-Benefit Tradeoff

There are two important structures of note in this section.

The first concerns the Miners or Mining Units in the system, which apply computational power to solve the current blockchain hashing problem. The sum of all the computing power in the network used to mine the next block in the blockchain is the Network Hash Rate. It must be noted that this is not necessarily the sum of all the hash rates available to each miner since a miner can decide, based on their cost-benefit analysis, not to use the full hash power to attempt mining blocks for the BTC blockchain.

The number of miners in the network is simply the total of all active miners competing to solve the hashing problem to mine a block in the network at a given point in time. We consider an aggregated average compute power associated with each miner, or mining unit, with miners entering bringing in roughly twice the compute power of the average on the network and miners leaving taking out around half the average. The formulation of this structure is shown in Figure 7.

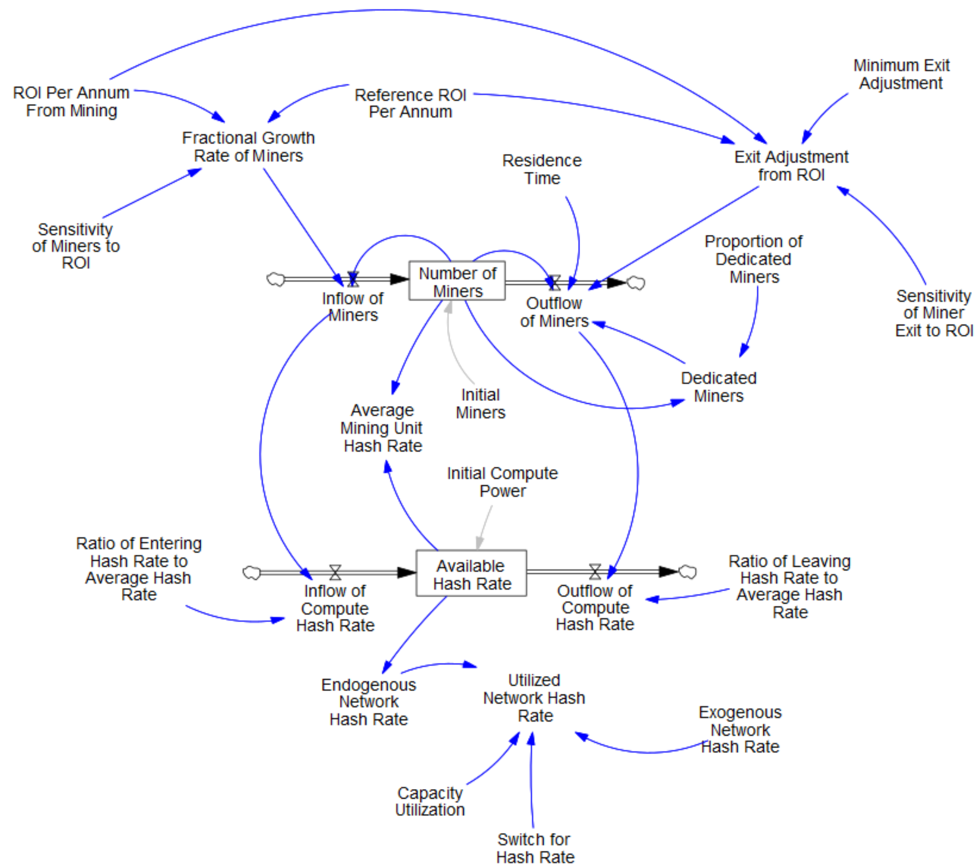

Figure 7: Network Compute Power – Number of Miners Co-flow Structure

A co-flow structure is again used to relate the stocks of the number of miners and the cumulative available network hash rate. An additional refinement of the formulation could be distinguishing between mining pools and individual miners. Adding this can provide a more granular view of the system. It may be of interest to some as an extension to the current formulation that considers an 'average compute power' per 'mining unit.' For the current model, where the focus is on the system at an aggregate level, that distinction does not add new insights and adds unnecessary additional complexity.

As alluded to earlier, a mining unit need not commit the entire hash rate at their disposal to solve the hashing problem on the BTC network. This is characterized by the 'Capacity Utilization' variable, formulated as a function of the miner's cost-benefit decision, which is later covered. A 'Dedicated Miner' construct is also added to indicate the miners that stay on the network no matter what happens. These miners will apply their compute power to mine on the network irrespective of the benefit level. The inflow to and outflow from the 'Number of Miners' stock is affected by fractional rates that depend on the return on investment from mining and a reference rate of return. Essentially, the higher the ratio of these two factors, the more attractive the proposition of mining is, and the higher the inflow into the stock.

Conversely, suppose the return from mining is lower than a reference return (which can be thought of in terms of a reference investment such as an index fund or treasury bond). In that case, the attractiveness of mining reduces, and this causes miners to leave the network, increasing the outflow. It may also be noted that there is a steady outflow of miners due to the oldest mining hardware on the network not being competitive and becoming obsolete. The minimum formulation for exit adjustment captures that.

Residence time represents the average amount of time a miner is expected to spend on the network, contributing their computing power to hashing blocks on the blockchain. It is scaled up or down from its base value by the exit adjustment variable. Finally, a switch for network hash rate is inserted into the model for calibration purposes. The idea is to have the model endogenously generate the behavior indicated by exogenous input after calibrating all constants to cause behavior as close as possible.

The second structure of note relates to individual miners' decisions. This formulation is shown in Figure 8.

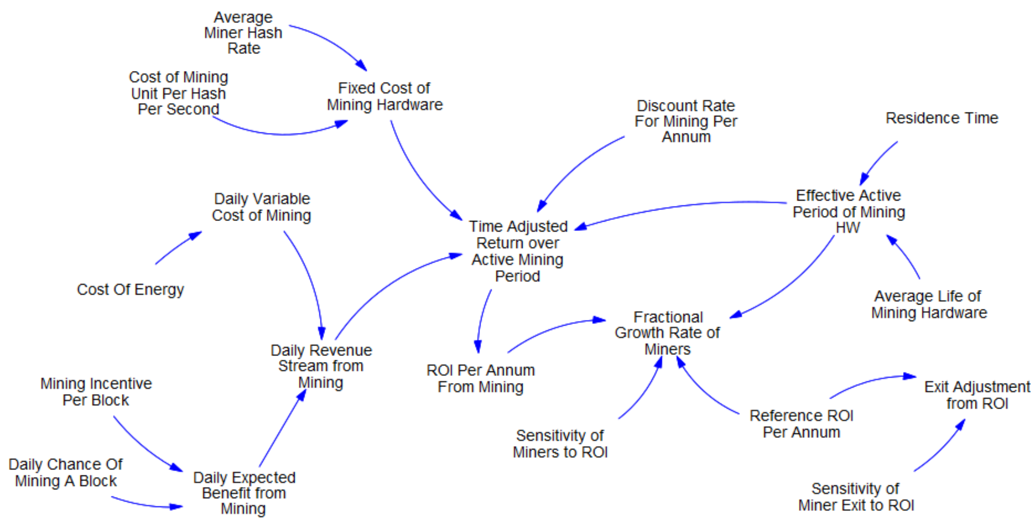

Figure 8: Miner decision structure

Every time a mining unit mines a block, its reward has two components, a cumulative transaction fee, equal to the individual transaction fees of all transactions included in the block mined, and a seigniorage fee of a specified amount of BTC units, set by policy and the current length of the blockchain.

The seigniorage fee from mining a block is set to the current BTC reward level guaranteed by the blockchain. There is a limited supply of BTC by design (currently set to 21 million), and the number of BTC generated and rewarded per block is halved at a pre-defined interval of blocks (presently set to 210000). Considering the target block generation time of 10 minutes, halving intervals are roughly four years. At the start, each block was awarded 50 BTC. Subsequently, three halving events have occurred, and the current block mining reward is set to 6.25 BTC. Therefore, this incentive portion is the BTC reward multiplied by its market price.

The probability of a mining unit (individual or pool) mining a block is directly proportional to the hash rate put into the network by the mining unit. Over a sufficiently large time interval, the number of blocks mined by a mining unit equals the hash rate contributed by it divided by the network's total hash rate.

The total cost of mining can be broken down into a fixed hardware cost with a specified expected lifetime and the cost of energy from running a mining unit with a specified hash rate output per unit time. Technological advancements in the past decade have successfully reduced both hardware cost per unit hash rate and energy costs significantly. However, the explosive rise of bitcoin has meant that the hash rate requirements to stay competitive in the network have also risen explosively. Overall, it has made it more expensive to mine bitcoin. Energy and hardware costs can also differ in different regions, presenting arbitrage opportunities for miners. Instead, this has not been considered, opting for an aggregate average approach to calculating these costs.

A miner's behavior results from a cost-benefit analysis comparing the costs versus the incentives. Three sensitivity values characterize it: Sensitivity of ROI to exit (which reduces the residence time of the miner), Sensitivity of ROI to entry (which dictates whether a new miner enters the network), and the Sensitivity of Costs to capacity utilization (which determines how much of their compute power the miner uses to continue mining in the network, subject to a minimum utilization). The capacity utilization decision structure is shown in Figure 9. These sensitivity values and other constants are calibrated to generate the seen behavior from the endogenous structures in the model.

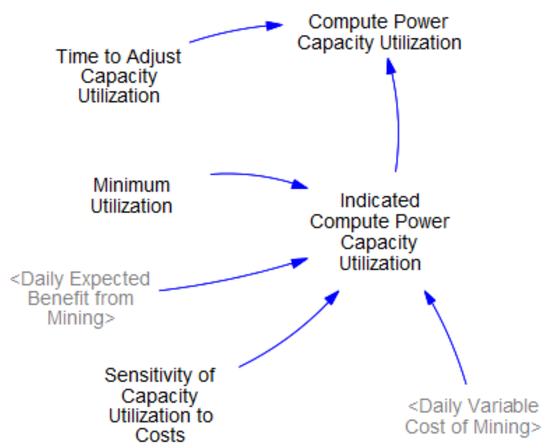

Figure 9: Capacity Utilization Structure

Capacity utilization changes are considered to happen over time, not instantaneously. It moves towards the indicated value over this period. Additionally, investing in mining hardware is a significant outlay and is expected to see some minimum level of utilization irrespective of the cost-benefit analysis over its useful life.

The incentive formulation for miners is expressed in terms of a fixed cost (for HW) compared against a time-discounted daily benefit (probability of mining a block multiplied by the total reward from mining a block minus the cost of energy for running the HW to mine) over the minimum of the period of the miner's residence time and the lifetime of the HW.

From these diagrams, the relationships between all these different mechanisms on the production or supply side of the BTC blockchain can be seen and understood.

A further note is that halving events tie into these dynamics since they are dependent on the size of the blockchain. Therefore, it links directly to the block generation process and directly affects the cost-benefit tradeoff to miners, affecting the number of miners in the system and the network hash rate-difficulty balancing process.

<u>Market Side</u>

This section describes the essential formulations and structures that guide the market or demand side. On this side of the system, price trends inform demand for BTC from different user categories. The model considers three such types – fundamentalists, chartists, and transacters. A simplifying assumption is that miners are assumed to be suppliers of BTC, essentially making them price-takers simply. The interactions between these different user types and their behavior affect the price of BTC through a market-clearing mechanism.

All user types are affected by price signals, which are classified into long-term (greater than six months) and short-term (less than three months) signals. They are further characterized by a few sensitivity values: Sensitivity to long-term and short-term price trends affecting entry and exit and sensitivity to pressure to expand holding from momentum or fundamentals.

The users of BTC are classified into three types:

1. Fundamentalists – These users are investors who believe in BTC as a long-term investment. They are characterized by higher sensitivity to long-term trends, lower sensitivity or indifference to short-term movements, and a longer residence time.
2. Chartists - These users are speculators akin to the colloquially termed 'day traders' who are driven only by technical indicators in their buying and selling decisions. They are characterized by higher sensitivity to short-term trends, lower sensitivity or indifference to long-term trends, and a shorter residence time. They will also tend to hold less BTC than the other user classes since they are simply looking to capitalize on short-term price volatility in the market.
3. Transacters – These users look at BTC as means of exchange for goods and services, similar to currency. This can include roughly 3% of transactions considered 'illegal' or not above-board. They exhibit low sensitivity or indifference to price trends, either long- or short-term. They have residence times similar to or possibly more significant than the fundamentalists since they look at BTC differently.

The entry and exit of users in the system and their holding levels can be modeled as parallel flows. The structure for the user entry and exit piece is shown in Figure 10.

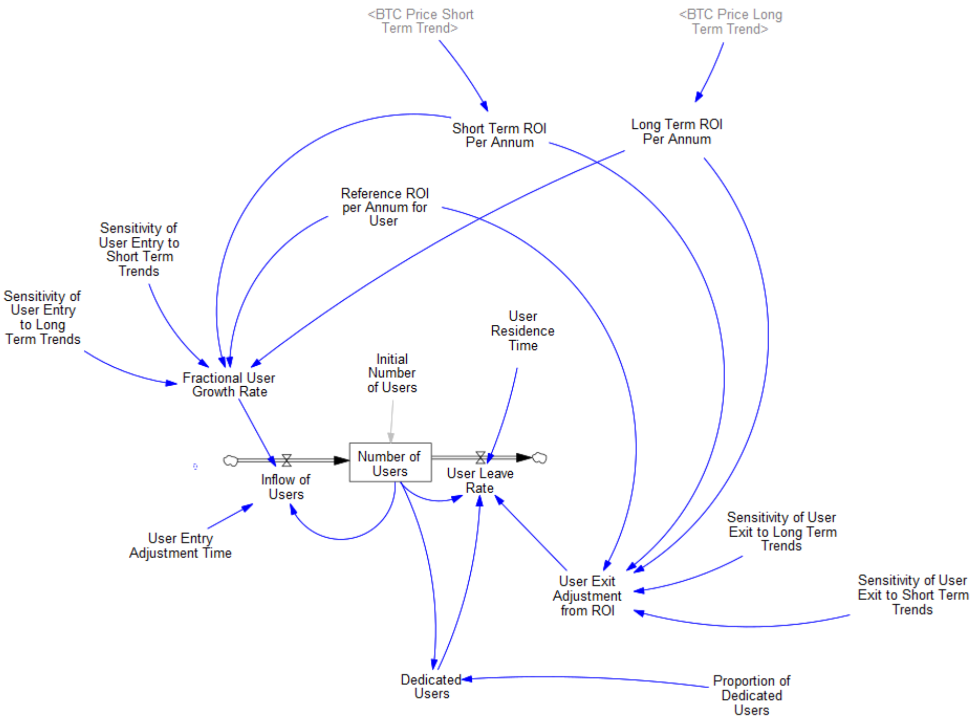

Figure 10: User Entry and Exit Stock and Flow Structure

It may be noticed that there are parallels between this structure and the structure formulated for the miner's decisions. Both these decisions are the function of cost-benefit analysis comparing the actual (or expected, in this case, since the trend is considered and forecast forward for a time horizon) return against a notional reference return. It may also be noted that the word 'User' is used instead of the different categories. All the user types can be modeled with essentially the same structure. Hence, Vensim's subscript feature was used with 'User' as the base and the three distinct user types 'Chartist,' 'Fundamentalist,' and 'Transacter' as the subscripts, with each one being modeled using the same structure but different effective behavior due to differences in the variables that drive it.

The following structure of interest is the market-clearing structure. This essentially describes the mechanics of increasing or reducing holding in BTC between the different groups based on price signals received from the market.

Figure 11 shows how this market-clearing mechanism is formulated.

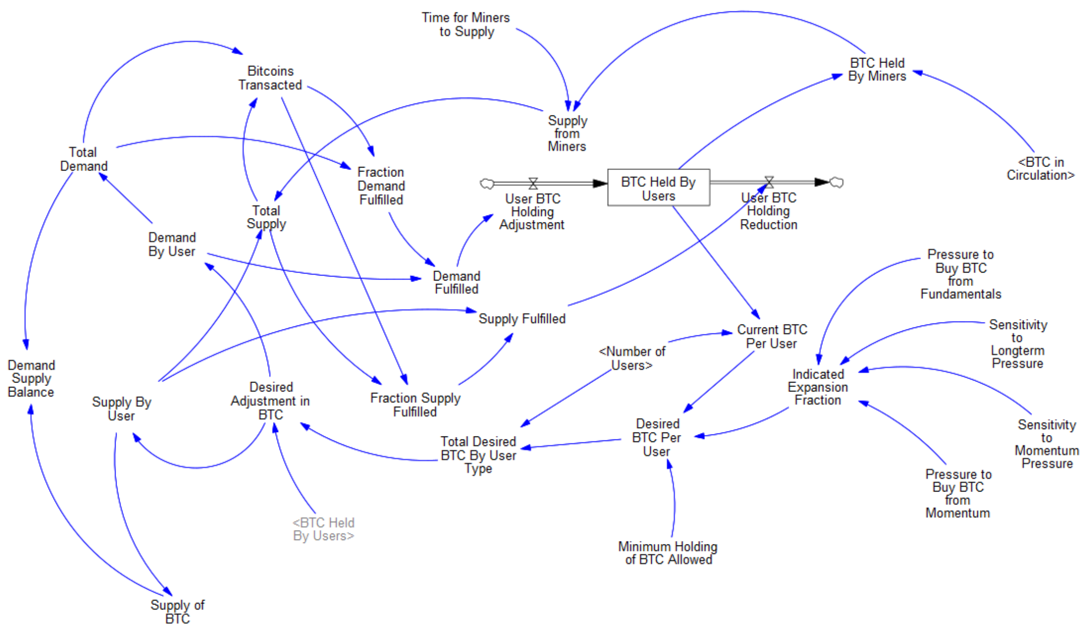

Figure 11: BTC Market-Clearing Structure

Long-term (fundamentals) and short-term (momentum) price signals influence how much holding of BTC each user type seeks to hold. This is represented by the expansion fraction, which increases or decreases the desired level of BTC holding. This is implemented as a multiplicative factor on the current BTC holding. Its formulation is covered in the price-setting mechanism discussion section. The desired BTC holding is subject to a maximum and minimum value. The desired and current values of holdings are compared. If the desired holding is greater than the existing holding, the user wants to buy BTC and adds to the demand. If the desired holding is less than the current holding, the user wants to sell BTC and adds to the supply.

The BTC in Circulation may be recognized from the production-side formulations. At any point in time, the total of all holdings of the three user types and miners in the system is equal to this value. As discussed earlier, miners are essentially assumed to be price-takers (since their cost-benefit analysis is based on the current price of BTC) and only add to the supply. The users' total demand and supply of BTC (excluding the miners) contribute to the demand supply balance, which affects the indicated price in the price formulation mechanism covered later.

The fraction of demand or supply served is the number of BTC transacted, equal to the minimum of total demand and supply. It causes holding levels to adjust accordingly per user type. Demand Fulfilled affects the inflow of the BTC holding stock, adding to it, while Supply Fulfilled affects the outflow of the BTC holding stock, subtracting from it. An important point to note in all this is that demand and supply are always considered per unit time, and hence are effective rates affecting the stock of BTC holding per user type.

The final formulation on the market side involves the generation of price signals from trends and the demand-supply balance adjusting the price to its new level based on the market-clearing mechanisms.

The essential idea here is price trends, occurring either over the short-term (momentum-based) or long-term (fundamentals-based), triggering pressure to either expand or contract BTC holdings, these requests getting cleared in the market, and affecting the new price based on its sensitivity to the demand-supply balance.

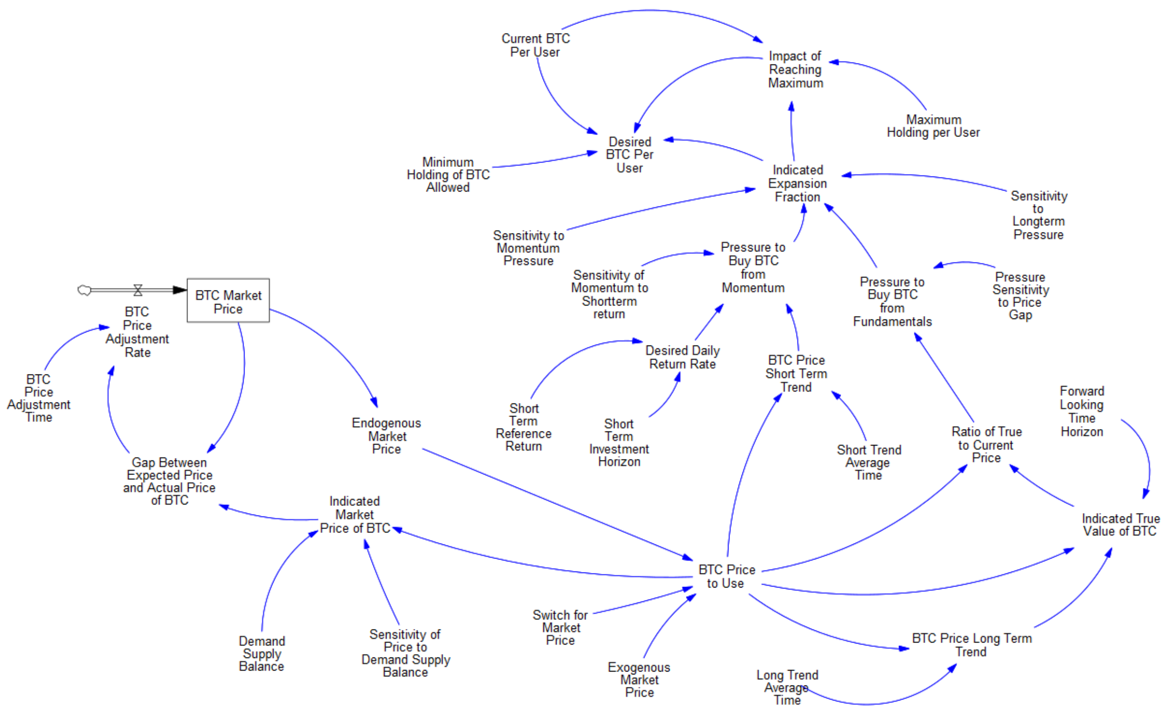

Figure 11: BTC Price-Setting Structure

The adjustment of BTC Market Price to expected changes may be familiar from the structure used to adjust difficulty on the production side. The price goes towards its indicated level from the market-clearing and price-setting process. The trend functions use the simple trend function in Vensim, while the horizons to decide the pressure terms from momentum or fundamentals are calibrated to data. The indicated expansion fraction features sensitivity terms for each user type and scales the desired BTC holding depending on the pressure terms. Additionally, a minimum and maximum holding level is considered, which clips the scaling within a range of reasonable values.

The switch for the market price is used in the calibration process to allow the model to endogenously generate the behavior seen once the exogenous inputs are removed.

Some aspects of the model have not been fully elaborated on on the demand side, and these will constitute future work and be elaborated upon in the next chapter.

Bringing all these pieces together, it is now possible to fill in the equations for all the variables (numbering over a hundred) in the model, perform a sanity check to ensure that their units are dimensionally consistent, and calibrate the critical state variables against data sources. Hence, the following pertinent topic in the modeling approach is to talk about the data sources.

Data Sources

Data about the past trajectory of BTC and other inputs, such as the evolution of compute hardware for mining, both in terms of cost and energy consumption per unit hash rate, were primarily sourced from APIs hosted on blockchain.com [19]. Some of the critical data pulled from this site include BTC Price, Transaction Volume, Transaction Fees, Network Hash Rate, and Difficulty. Code for the data pulls was written in python and included in the appendix with the rest of the model details.

Additionally, data about the energy consumption and price trajectory of hardware in terms of hash rate were synthesized from the Bitcoin wiki [20], the IEA[21], the Hashrate Index[22], bitooda [23], minerdaily [24], and the digiconomist[12] blog. Simple linear-fit models were used to formulate these factors (energy consumption per unit hash rate and cost per unit hash rate). However, they could arguably be better characterized by exponential models a la Moore's curve. All relevant data files were pulled into files in the CSV format, combined, and then imported into Vensim, which converted them into the vdfx format native to it.

Chapter 5
Calibration and Discussion

The fully formulated model was then put through partial calibration to identify the best-fit values of the constants that would allow it to mimic the exogenous data sources as closely as possible. [31]

The general approach to this is to use data to drive the model, estimate parameters in one sector, then let the model generate that sector to estimate parameters in the next sector, and so on. The eventual goal is to use the estimated/calibrated model to simulate and analyze different scenarios for the future. Vensim has calibration functions built into it, and these were utilized to great effect in identifying the best-fit parametric values.

The critical state variables calibrated against the production or supply-side data were difficulty and network hash rate. On the market or demand side, it was the BTC market price.

<u>Production-Side Calibration</u>

As covered in previous chapters, the difficulty of computation and network hash rate are intimately linked state variables. Since difficulty is balanced as a result of network hash-rate, the production side was calibrated by modifying parametric values and then comparing the endogenous model-generated network hash rate to the exogenous data input using a simple least-squares fit. Additionally, data values were used to drive the model for mining incentive-related variables – cost of energy, hardware, transaction fees and number per block, and price of BTC.
A table of the final calibrated parametric values with the ranges considered

for them is provided in Table 1.

Table 1: Production-Side Calibrated Parametric Values

Parameter Name	Calibrated Value	Lower Limit	Upper Limit
Maximum Mining Unit Cost ($)	245569	100,000	1,000,000
Cost Of Energy ($/Watt-Day)	0.001714	0.0015	0.0048
Minimum Utilization (fraction)	0.05	0.05	0.50
Sensitivity of Capacity Utilization to Costs (dmnl)	16.264	2.000	32.000
Sensitivity of Miner Exit to ROI (dmnl)	0.250	0.013	2.000
Sensitivity of Miners to ROI (dmnl)	0.226	0.013	2.000
Residence Time (Day)	2545	700	3650
Discount Rate For Mining Per Annum (%/Year)	0.1250	0.0000	0.1250
Reference ROI Per Annum (%/Year)	0.1307	0.0300	0.1500
Time To Adjust Number of Miners (Day)	10	7	30
Time To Adjust ROI Perception (Day)	44	15	90
Time to Adjust Capacity Utilization (Day)	17	1	45
Average Life of Mining Hardware (Day)	1566	700	1825

It may be observed that some of these values hit their lower or upper limit. There is possibly a case to relax some of these limits further to see if a better fit is obtainable.

The result of the calibration for network hash rate is shown in Figure 12. Here, the x-axis starts around the time of BTC's inception, and extends as close as possible to the present day. The y-axis shows the network hash-rate in TH/s. As we can see in the graphs, the network hash rates are in excess of 200 million TH/s in the present day.

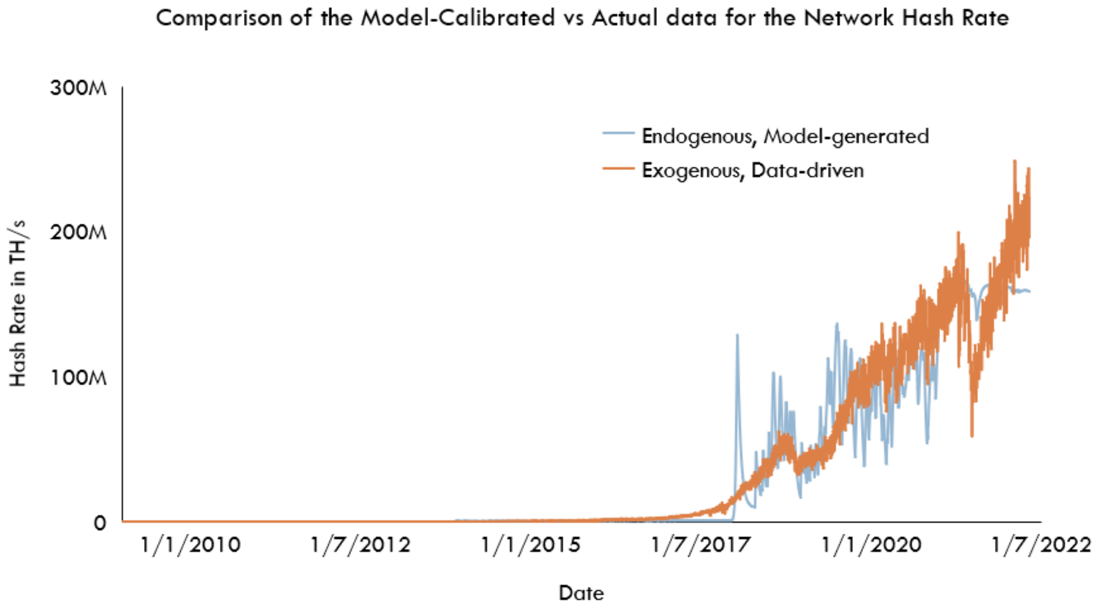

Figure 12: Results of Network Hash Rate Calibration. X-Axis shows dates, Y-Axis shows Network Hash Rate in TH/s

The goodness-of-fit was measured with the R-Squared metric for the two curves. This came to 0.902. Hence, the fit can be considered sufficient to capture its behavior.

Difficulty was also measured endogenously using the parametric values of the network hash rate calibration. It was then compared to the exogenous data source to estimate how well they matched. This is shown in Figure 13.

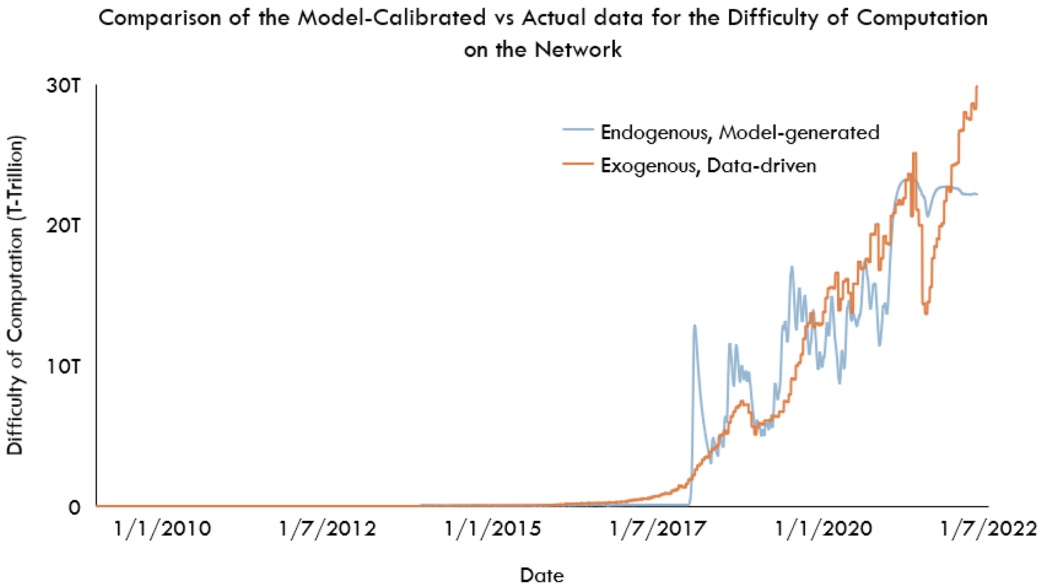

Figure 13: Comparison of endogenous and exogenous difficulty using calibrated values. X-Axis shows dates, Y-Axis shows difficulty scaling of the hash problem. T stands for Trillion.

Recall from the previous chapter that difficulty is a dimensionless quantity that scales how hard the hashing problem on the network is. Hence, a difficulty of 10 trillion essentially means that 4.3e22 hash attempts are expected to be required to solve the problem. At a hash rate of roughly 70 million TH/s, this problem should take around 600s or 10 minutes to solve. This provides a notion of why the numbers are so large on both these graphs. Additionally, also recall that difficulty only updates every 2016 blocks. This explains why it shows less volatile behavior than network hash rate.

Some of the key calibrated parametric values seen for the production side were:

1. Cost of Energy ~7.1 cents per unit. This value is around the lower end of commercial values estimated by the EIA for the US [25] and hence connects well with reality.
2. Minimum utilization ~0.05. This means that miners spend at least 5% of their compute power once they've bought a mining unit. The capacity utilization curve from calibration is shown in Figure 14. It varies mainly with the mining incentive, with utilization going up

roughly when prices go up, especially after BTC had some value attached to it. A note here is that the lion's share of mining incentive comes from the seigniorage fee (transaction fees tend to make up ~1-2% on average). This makes sense from a cost-benefit perspective since you'd want to be at minimum power if the benefit did not exceed the cost and increase it as benefit levels increased.

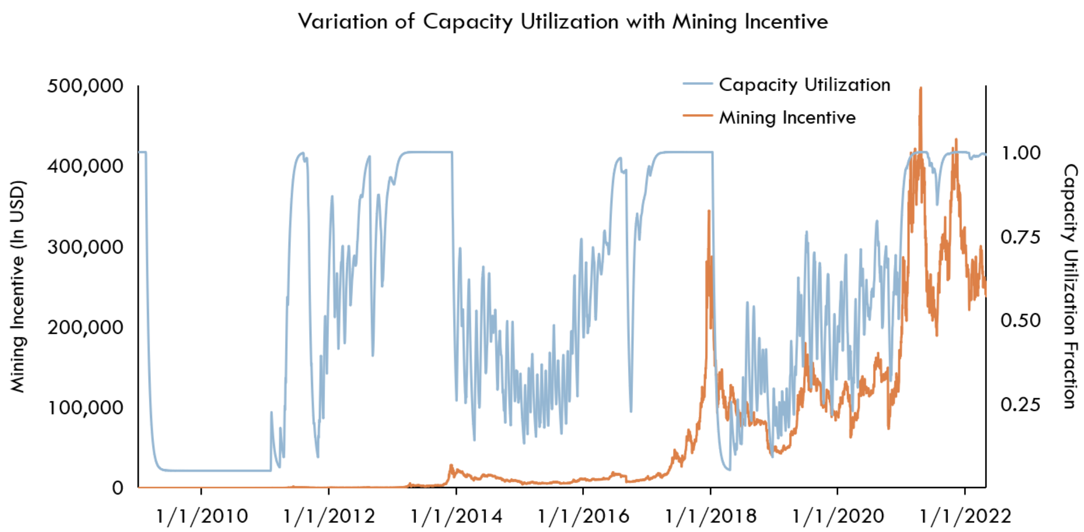

Figure 14: Variation of Compute Power Capacity Utilization Fraction with Mining Incentive

3. Residence Time ~2550 days. This says that miners tend to spend roughly seven years on the network.
4. Discount Rate for Mining ~0.125. This discount level (12.5%) per year seems reasonable for high-tech endeavors such as cryptocurrency mining.
5. Reference ROI per Annum ~0.13. This says that cryptocurrency mining is a risky endeavor that people enter only if the return on investment is comparable to 13% per year and can be considered reasonable.
6. Average Lifetime of Mining Hardware~1570 days. Mining rigs are estimated to last 3-5 years [26], and this value falls squarely in that range. Hence, it seems to reflect reality reasonably well.

Market-Side Calibration

The critical state variable calibrated was the BTC Market Price on the market side. Transaction data in the form it has been structured in the model is not available to calibrate against and hence, is an issue for robustness. The calibrated output and the data are seen to almost exactly match, with a goodness-of-fit R-Squared measure value of 0.998. The two price lines are nearly indistinguishable and hence, a plot of the endogenous and exogenous values for price will not add insight.

The main reason for this almost exact matching is that the model is using the price data as input to the calibration as well. Essentially, it is only calibrating to the deviations in price endogenously through the market-clearing structure. The actual fit is being done against changes in price, as opposed to price itself. This hints at the absence of a structure driving the price itself in the model, and will be discussed more later.

A table of the final calibrated parametric values for the market-side calibration is provided in Table 2. Note that all the sensitivity parametric values are dimensionless.

Table 2: Market-Side Calibrated Parametric Values

Parameter Name	**Calibrated Value**	**Upper Limit**	**Lower Limit**
Sensitivity of Momentum to Shortterm return	3.56546	4	0.1
Sensitivity of Price to Demand Supply Balance	0.001	4	0.001
Sensitivity of User Entry to Long Term Trends[Chartist]	0.001	2	0.001
Sensitivity of User Entry to Long Term Trends[Fundamentalist]	4	4	0.5
Sensitivity of User Entry to Long Term Trends[Transacter]	0.80105	1	0.01
Forward Looking Time Horizon (Day)	1004.19	1095	180
Time to Close the Gap Between Desired and Current (Day)	122.714	180	1
BTC Price Adjustment Time (Day)	1.15944	45	0.001

Time for Miners to Supply (Day)	0.0001	30	0.0001
User Entry Adjustment Time (Day)	256.165	365	1
Pressure Sensitivity to Price Gap	0.640741	4	0.01
Short Term Reference Return (%)	0.424236	1	0.001
Short Term Investment Horizon (Day)	36.9718	90	5
Sensitivity of User Entry to Short Term Trends[Chartist]	2.18508	4	0.5
Sensitivity of User Entry to Short Term Trends[Fundamentalist]	0.001	1	0.001
Sensitivity of User Entry to Short Term Trends[Transacter]	0.620093	1	0.01
Sensitivity of User Exit to Long Term Trends[Chartist]	2	2	0.1
Sensitivity of User Exit to Long Term Trends[Fundamentalist]	0.281271	4	0.25
Sensitivity of User Exit to Long Term Trends[Transacter]	0.01	1	0.01
Sensitivity of User Exit to Short Term Trends[Chartist]	2.67397	4	0.25
Sensitivity of User Exit to Short Term Trends[Fundamentalist]	0.001	1	0.001
Sensitivity of User Exit to Short Term Trends[Transacter]	0.0160989	1	0.01
Sensitivity to Longterm Pressure[Chartist]	0.0001	2	0.0001
Sensitivity to Longterm Pressure[Fundamentalist]	0.521562	4	0.5
Sensitivity to Longterm Pressure[Transacter]	0.0001	1	0.0001
Sensitivity to Momentum Pressure[Chartist]	0.5	8	0.5
Sensitivity to Momentum Pressure[Fundamentalist]	4	4	0.1
Sensitivity to Momentum Pressure[Transacter]	0.0450337	1	0.01
Maximum Holding per User[Chartist] (BTC/User)	1	1000	1
Maximum Holding per User[Fundamentalist] (BTC/User)	972.548	1000	1
Maximum Holding per User[Transacter] (BTC/User)	1121.76	2000	1
User Residence Time[Chartist] (Day)	16.6181	90	7
User Residence Time[Fundamentalist] (Day)	1445.22	3650	180
User Residence Time[Transacter] (Day)	1605.36	3650	90
Proportion of Dedicated Users[Chartist] (Fraction)	0.0397101	0.2	0
Proportion of Dedicated Users[Fundamentalist] (Fraction)	0.054395	0.2	0
Proportion of Dedicated Users[Transacter] (Fraction)	0.198768	0.2	0
Reference ROI per Annum for User[Chartist] (%/Year)	3.0276	5	0
Reference ROI per Annum for User[Fundamentalist] (%/Year)	4.51136	5	0
Reference ROI per Annum for User[Transacter] (%/Year)	3.40378	5	0

Short Trend Average Time (Day)	7	45	7
Long Trend Average Time (Day)	718.166	730	90
Minimum Holding of BTC Allowed (BTC/User)	0.242103	1	1.00E-08

1. Sensitivity of price to demand-supply balance ~0.001. This is somewhat surprising, indicating that price is almost insensitive to the demand-supply balance. This merits further investigation.
2. Sensitivity of User Entry to Short-Term Trends [Chartist, Fundamentalist, Transacter] ~ [2.19, 0.001, 0.62]. This shows that chartists are most sensitive to short-term trends (as expected) and that fundamentalists are relatively insensitive to them (also reasonable). Transacters showing some sensitivity to short-term trends is interesting and indicates that they tend to transact more when prices are going up and hold when prices go down in the short term.
3. User Residence Time [Chartist, Fundamentalist, Transacter] ~ [16.7 days, 1445 days, 1605 days]. This indicates that chartists tend to spend a little over two weeks in the market, while fundamentalists and transacters tend to spend around four years. The values are, therefore, broadly as expected.
4. Reference ROI per Annum for User [Chartist, Fundamentalist, Transacter] ~ [303%, 451%, 340%]. This indicates that annualized reference returns per annum are over 300% for a user to consider entering the BTC market. Considering the trajectory of BTC prices, this may not be all that surprising, but it does seem somewhat unreasonable that users expect the trends to indicate this level of return.

Discussion

The calibrated values on the production/supply-side seemed reasonable and produced behavior indicative of the system. This side of the system can be used for scenario analysis and insight into specific policies' implications. Some ideas for such an exercise are proposed in the final chapter and will be carried out in future work.

On the market/demand side, some parameters whose calibrated values seem somewhat surprising and hint that some structures may be missing and require the addition to make it more robust. Some limitations and ideas for improvement are as follows:

1. The size and composition of the users in the market and its historical trend over time aren't known. Unfortunately, no readily available dataset provided or estimated these numbers. This could have provided a way to calibrate and fit the 'Number of Users' state variable if available.
2. Transaction information is available on the blockchain, but actual or estimated data and the historical trend for the BTC deltas among different user types are not available. This would also have helped calibrate the model to the User BTC Holding state variable. The construct used to classify users in the model into the three categories is conceptual and reasonable but, unfortunately, tricky to match real-world data.
3. The BTC whitepaper [4] envisioned the price of BTC to be derived from the work put in to create it. In this case, the 'work' is applying computing power to solve the hashing problem in the network. A notion of the cost of this 'work' is the variable cost of producing one unit of the currency. Additionally, the presence of actors in the system who believe in the currency (and this can be notionally estimated as the sum of all users and miners in the network) can be considered to lend it value. These two pieces could be helpful structural additions that provide some basis for the valuation of BTC and drive price endogenously.

Chapter 6
Conclusion and Future Work

Traditional currencies trace their history back nearly five millennia, with the first recorded currency purported to be the Mesopotamian shekel, which was equivalent to about 1/3rd an ounce of silver in 2500B.C [27]. On the other hand, cryptocurrencies have existed for a little over a decade. It is still an extremely new concept and is the subject of a large body of research and development work. Understanding what drove the behavior of BTC, the oldest recorded cryptocurrency has been the subject of a large body of research over the past few years.

This thesis report synthesizes a lot of the ideas present in the literature and describes a System Dynamics modeling approach to explain what has happened so far in its history. Trying to bring all the pieces and mechanisms governing this complex system together in one model is an ambitious endeavor, and some outstanding work remains to refine it. Still, most structures affecting the system have been formulated, and parameters have been calibrated to actual data where possible.

Further refinements to and work planned in this project include:

1. Adding in the drivers of intrinsic value of BTC in the model. This was covered in some detail in the preceding chapter.
2. Base case scenario analysis. Once the additional formulations, especially to drive price, are included and parameters calibrated, a base case scenario analysis is required to understand the trajectory of the critical state variables – difficulty, network hash rate (and by extension, the number of mining units), and market price.

3. Alternative scenarios. Some ideas for alternative scenarios include:
    a. Changing BTC design – factors such as difficulty adjustment interval, halving interval, the cap on the amount of BTC that can be mined, target block generation time, BTC block rewards, and the hashing algorithm. Particular policies such as a 'coin split' similar to stock splits can also be considered if they are of interest.
    b. Energy subsidies – this directly affects the cost structure and, therefore, the decisions governing mining. A thought experiment considering the feedback structures present in the model would say that regulatory push to support mining of BTC would increase the network hash rates, thereby increasing the difficulty and making it harder for new miners who do not stay in a region with these subsidies to be competitive. On the flip side, if energy costs, especially carbon-intensive generation, go up because of policies like a high carbon tax, this could depress mining activity. However, we cannot say for sure unless we can simulate these scenarios.
    c. Mining Hardware subsidies – similar to the previous point, the cost structure is directly affected. Simulating scenarios where the fixed cost is subsidized will provide valuable insights.

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Appendix

A github repository has been setup with all the files (data, model, scripts, support files) required to replicate the model in the state this report has been created for. This can be found at https://github.com/AthenaTheOwl/MIT-SDM-Thesis-on-System-Dynamics-Modeling-of-Bitcoin.

Further updates to the model will be in a separate folder in the same repository.

Additionally, all code is reproduced from hereon.

<u>Data Pull Code:</u> DataPull.py

```
import numpy as np
import pandas as pd
import requests
from datetime import datetime
import csv
import glob
import os

path = 'D:/MIT Coursework/Thesis/DataFiles/'

#this makes some datasets super large - market cap,
transactions per second, mempool count and size
url_list=['https://api.blockchain.info/charts/transaction
-fees?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/transactions-per-
second?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/cost-per-
transaction?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/miners-
revenue?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/market-
price?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/avg-block-
size?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/median-confirmation-
time?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/mempool-
size?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/mempool-
count?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/market-
cap?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/n-
transactions?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/n-transactions-per-
```

```
block?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/output-
volume?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/my-wallet-n-
users?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/hash-
rate?timespan=15years&format=csv&sampled=false',
'https://api.blockchain.info/charts/difficulty?timespan=1
5years&format=csv&sampled=false']


filename_list = ['Transaction-Fees.csv',
'Transactions-Per-Second.csv',
'Cost-Per-Transaction.csv',
'Miners-Revenue.csv',
'Market-Price.csv',
'Avg-Block-Size.csv',
'Median-Confirmation-Time.csv',
'Mempool-Size.csv',
'Mempool-Count.csv',
'Market-Cap.csv',
'Number-of-Transactions.csv',
'Number-of-Transactions-Per-Block.csv',
'Output-Volume.csv',
'Wallet-User-Numbers.csv',
'Hash-Rate.csv',
'Difficulty.csv']

for i in range(0,len(url_list)):
    with requests.Session() as s:
        download = s.get(url_list[i])
        decoded_content = download.content.decode('utf-
8')
        cr = csv.reader(decoded_content.splitlines(),
delimiter=',')
        data_list = list(cr)
    fieldname=filename_list[i][:-4]
    df =
pd.DataFrame(data_list,columns=['DateTime',fieldname])
    df['DateTime'] =
pd.to_datetime(df['DateTime']).apply(lambda x: x.date())
    df[fieldname]=pd.to_numeric(df[fieldname])
    df=df.groupby('DateTime').mean()
    df.to_csv(path+filename_list[i])

csv_files = glob.glob(os.path.join(path, "*.csv"))

all_data = pd.DataFrame(columns = ['DateTime'])

for f in csv_files:
    df = pd.read_csv(f)
```

```
all_data=pd.merge(all_data,df,on='DateTime',how='outer')

all_data.DateTime = pd.to_datetime(all_data.DateTime)

energy=pd.read_csv('D:/MIT
Coursework/Thesis/DataFiles/Energy/bitcoin-energy-
consumption-index.csv')

energy.DateTime = pd.to_datetime(energy.DateTime)

all_data=pd.merge(all_data,energy,on='DateTime',how='oute
r')

all_data=all_data.sort_values(by=['DateTime'])
all_data=all_data.reset_index(drop=True)

all_data.to_csv(path+'ConsolidatedData.csv')
```

Model Code: thesis_checkpoint.mdl

```
{UTF-8}
Desired BTC Per User[User]=
     MAX(Minimum Holding of BTC Allowed,Current BTC Per
User[User]*Indicated Expansion Fraction\
          [User]*Impact of Reaching Maximum[User])
     ~    BTC/user
     ~    Desired level of BTC holding per user for each user type.
     |

"20TH Rig"=
     2e+13
     ~    hash/second
     ~         |

Block Generation Time Mins=
     Block Generation Time*Minutes in a Day
     ~    minute/block
     ~         |

BTC Price to Use=
     MAX(0.01,Endogenous Market Price*Endogenous Switch for Market
Price + Exogenous Market Price\
          *Exogenous Switch for Market Price)
     ~    dollar/BTC
     ~    The price of BTC to use for new balancing.
     |

Endogenous Switch for Market Price=
     if then else (Time>Endogenous Switchover Time for Market
Price, 1,0)
     ~    Dimensionless
     ~         |

Endogenous Switchover Time for Market Price=
     10000
     ~    Day
     ~         |

Average Transaction Fee in BTC:INTERPOLATE::=
     "Transaction-Fees"/"Number-of-Transactions"
     ~    BTC/transaction
     ~    Average fee per transaction confirmed in a block
     |

Average Transaction Fee in Dollars=
     BTC Price to Use*Average Transaction Fee in BTC
     ~    dollar/transaction
     ~         |
```

```
Mining Incentive Per Block=
	BTC Awarded per Block*BTC Price+Transactions Per Block*Average
Transaction Fee in Dollars
	~	dollar/block
	~	Total current incentive for mining a block in the
blockchain = BTC reward \
		+ Transaction fee reward. Additionally includes a factor
for growth of BTC \
		price.
	|

BTC Price=
	BTC Price to Use
	~	dollar/BTC
	~	Market Price of one BTC
	|

Indicated Market Price of BTC=
	BTC Price to Use*(Demand Supply Balance^Sensitivity of Price
to Demand Supply Balance\
		)
	~	dollar/BTC
	~	The indicated market price of BTC based on the demand-
supply balance in \
		the market.
	|

Minimum Holding of BTC Allowed=
	0.01
	~	BTC/user
	~		|

BTC Price Long Term Trend=
	TREND(BTC Price to Use, Long Trend Average Time ,Initial Trend
)
	~	1/Day
	~	The long term price trend of BTC.
	|

Initial Trend=
	0
	~	1/Day
	~		|

BTC Price Short Term Trend=
	TREND(BTC Price to Use, Short Trend Average Time, Initial
Trend)
	~	1/Day
	~	Short-term trend of BTC price.
	|
```

```
Price Weight=
     1/(1000)
     ~    Dimensionless
     ~         |

Exogenous Market Price=
     "Market-Price"
     ~    dollar/BTC
     ~         |

Endogenous Market Price=
     BTC Market Price
     ~    dollar/BTC
     ~         |

Exogenous Switch for Market Price=
     1-Endogenous Switch for Market Price
     ~    Dimensionless
     ~         |

Reference ROI per Annum for User[User]=
     0.6,0.125,0.05
     ~    1/Year
     ~         |

Fractional User Growth Rate[User]=
     MAX(0,Long Term ROI Per Annum/Reference ROI per Annum for
User[User])^Sensitivity of User Entry to Long Term Trends\
          [User] + MAX(0,Short Term ROI Per Annum/Reference ROI per
Annum for User[User])^Sensitivity of User Entry to Short Term
Trends\
          [User]
     ~    Dimensionless
     ~         |

BTC Held By Users[User]= INTEG (
     User BTC Holding Adjustment[User]-User BTC Holding
Reduction[User],
          Initial BTC Held By Users[User])
     ~    BTC
     ~    BTC held by each category of user
     |

Long Term ROI Per Annum=
     MIN(5,BTC Price Long Term Trend*Days in a Year)
     ~    1/Year
     ~         |

User Exit Adjustment from ROI[User]=
     MAX(0,XIDZ(Reference ROI per Annum for User[User],Long Term
```

```
ROI Per Annum,10))^Sensitivity of User Exit to Long Term Trends\
          [User] + MAX(0,XIDZ(Reference ROI per Annum for
User[User],Short Term ROI Per Annum\
          ,10))^Sensitivity of User Exit to Short Term Trends[User]
     ~    Dimensionless
     ~         |

Forward Looking Time Horizon=
     915
     ~    Day
     ~    The forward looking time horizon to calculate indicated
true value of BTC
     |

Short Term ROI Per Annum=
     MIN(10,BTC Price Short Term Trend*Days in a Year)
     ~    1/Year
     ~         |

Gap Between Expected Price and Actual Price of BTC=
     Indicated Market Price of BTC-BTC Market Price
     ~    dollar/BTC
     ~    The difference between indicated and real market price of
BTC.
     |

Short Trend Average Time=
     30
     ~    Day
     ~    Time considered for short-term trend of BTC price.
     |

BTC Held By Miners=
     BTC in Circulation-SUM(BTC Held By Users[User!])
     ~    BTC
     ~    Amount of BTC held by miners is the total BTC in
circulation minus the BTC \
          held by users.
     |

Long Trend Average Time=
     365
     ~    Day
     ~    Time considered for long-term trend.
     |

Sensitivity of Price to Demand Supply Balance=
     0.5
     ~    Dimensionless
     ~    Sensitivity of the price of BTC to demand supply balance.
     |
```

```
Sensitivity of User Entry to Long Term Trends[User]=
     0.01,0.1,0.001
     ~    Dimensionless
     ~         |

Bitcoins Transacted=
     MIN(Total Demand,Total Supply)
     ~    BTC/Day
     ~    Minimum of supply and demand gives us the number of BTC
bought or sold per \
          day.
     |

Sensitivity of User Exit to Long Term Trends[User]=
     0.001,0.01,0.001
     ~    Dimensionless
     ~         |

Maximum Holding per User[User]=
     50,50,50
     ~    BTC/user
     ~    Maximum BTC holding by each user per user type.
     |

Sensitivity to Longterm Pressure[User]=
     0.001,0.01,0.005
     ~    Dimensionless
     ~    Sensitivity of users to long-term price signals.
     |

Sensitivity to Momentum Pressure[User]=
     0.01,0.001,0.001
     ~    Dimensionless
     ~    Sensitivity of each user type to short term price
signals.
     |

Short Term Investment Horizon=
     30
     ~    Day
     ~    Investment horizon of short term investor.
     |

Short Term Reference Return=
     0.05
     ~    Dimensionless
     ~    Expected ROI over investment horizon in the short term.
     |

Supply of BTC=
```

```
	SUM(Supply By User[User!])
	~	BTC/Day
	~	Total supply of BTC by the users in the market (excluding
miner supply)
	|

Indicated True Value of BTC=
	BTC Price to Use*(1+BTC Price Long Term Trend*Forward Looking
Time Horizon)
	~	dollar/BTC
	~	Indicated true value of BTC based on long-term trend
(fundamentals)
	|

Demand Supply Balance=
	XIDZ(Total Demand,Supply of BTC,0)
	~	Dimensionless
	~	The ratio of demand to supply of BTC in the market.
	|

Inflow of Users[User]=
	MAX(0,Fractional User Growth Rate[User] * Number of
Users[User]/User Entry Adjustment Time\
		)
	~	user/Day
	~	Inflow of users into each category.
	|

Desired Bitcoin by User Type[User]=
	Desired BTC Per User[User]*Number of Users[User]
	~	BTC
	~	The total amount of BTC each user type seeks to hold.
	|

BTC Market Price= INTEG (
	BTC Price Adjustment Rate,
		Initial BTC Market Price)
	~	dollar/BTC
	~	Current market price of 1 BTC.
	|

Desired Daily Return Rate=
	Short Term Reference Return/Short Term Investment Horizon
	~	1/Day
	~	Desired ROI per day for a short term investment.
	|

BTC Price Adjustment Rate=
	Gap Between Expected Price and Actual Price of BTC/BTC Price
Adjustment Time
	~	(dollar/BTC)/Day
```

```
	~	Rate of change of BTC price.
	|

BTC Price Adjustment Time=
	1
	~	Day
	~	Time taken to adjust BTC price.
	|

Fraction Supply Fulfilled=
	XIDZ(Bitcoins Transacted,Total Supply,0)
	~	Dimensionless
	~	Fraction of sell orders fulfilled.
	|

Supply Fulfilled[User]=
	Fraction Supply Fulfilled*Supply By User[User]
	~	BTC/Day
	~	The amount of BTC actually sold per user type.
	|

Time to Close the Gap Between Desired and Current=
	1
	~	Day
	~	Amount of time taken to close the gap between desired and
currently held \
		BTC.
	|

Initial BTC Market Price=
	0.01
	~	dollar/BTC
	~	Initial price of 1 BTC.
	|

Demand Fulfilled[User]=
	Fraction Demand Fulfilled*Demand By User[User]
	~	BTC/Day
	~	Demand fulfilled per user type.
	|

Sensitivity of Momentum to Shortterm return=
	0.1
	~	Dimensionless
	~	Sensitivity of momentum traders to shortterm returns.
	|

Pressure to Buy BTC from Momentum=
	MAX(0,XIDZ(BTC Price Short Term Trend,Desired Daily Return
Rate,0))^Sensitivity of Momentum to Shortterm return
	~	Dimensionless
```

```
	~	Buying pressure from momentum trades.
	|

Time for Miners to Supply=
	1
	~	Day
	~	Amount of time taken for miners to supply BTC.
	|

Sensitivity of User Entry to Short Term Trends[User]=
	0.1,0.01,0.001
	~	Dimensionless
	~		|

Supply from Miners=
	BTC Held By Miners/Time for Miners to Supply
	~	BTC/Day
	~	Rate of supply of BTC from miners.
	|

Pressure Sensitivity to Price Gap=
	0.1
	~	Dimensionless
	~	Sensitivity of pressure to buy from fundamentals to ratio
of true price to \
		current price.
	|

Pressure to Buy BTC from Fundamentals=
	Ratio of True to Current Price^Pressure Sensitivity to Price
Gap
	~	Dimensionless
	~	Pressure to buy BTC based on indicated true value and
current value
	|

User BTC Holding Reduction[User]=
	Supply Fulfilled[User]
	~	BTC/Day
	~	The outflow of BTC per day from a user type is the closed
sales of supply \
		of BTC they are willing to provide.
	|

Total Supply=
	Supply from Miners+SUM(Supply By User[User!])
	~	BTC/Day
	~	Total supply of BTC available.
	|

Fraction Demand Fulfilled=
```

```
	XIDZ(Bitcoins Transacted,Total Demand,0)
	~	Dimensionless
	~	Fraction of demand for BTC fulfilled.
	|

Ratio of True to Current Price=
	MAX(0,XIDZ(Indicated True Value of BTC,BTC Price to Use,1))
	~	Dimensionless
	~	Ratio of true value to current price of BTC.
	|

Sensitivity of User Exit to Short Term Trends[User]=
	0.01,0.001,0.001
	~	Dimensionless
	~		|

User Entry Adjustment Time=
	365
	~	Day
	~		|

Impact of Reaching Maximum[User]=
	if then else(Current BTC Per User[User]*Indicated Expansion
Fraction[User]>Maximum Holding per User\
		[User],Maximum Holding per User[User]/(Current BTC Per
User[User]*Indicated Expansion Fraction\
		[User]),1)
	~	Dimensionless
	~	Maximum holding caps the expansion of desired BTC holding
per user.
	|

Indicated Expansion Fraction[User]=
	Pressure to Buy BTC from Fundamentals^Sensitivity to Longterm
Pressure[User]*Pressure to Buy BTC from Momentum
	^Sensitivity to Momentum Pressure[User]
	~	Dimensionless
	~	Indicated expansion fraction is a measure of how much
more BTC users want \
		to buy based on signals from the market.
	|

Demand By User[User]=
	MAX(0,Desired Adjustment in BTC[User])
	~	BTC/Day
	~		|

Supply By User[User]=
	MAX(0,-Desired Adjustment in BTC[User])
	~	BTC/Day
	~	The total supply of BTC offered by each user type for
```

```
sale.
     |

Desired Adjustment in BTC[User]=
     (Desired Bitcoin by User Type[User]-BTC Held By
Users[User])/Time to Close the Gap Between Desired and Current
     ~    BTC/Day
     ~         |

User BTC Holding Adjustment[User]=
     Demand Fulfilled[User]
     ~    BTC/Day
     ~    The inflow of BTC per day into a user category is the buy
demand served.
     |

User Residence Time[User]=
     7,180,180
     ~    Day
     ~         |

Initial Number of Users[User]=
     1,1,1
     ~    user
     ~         |

Number of Users[User]= INTEG (
     Inflow of Users[User]-User Leave Rate[User],
          Initial Number of Users[User])
     ~    user
     ~    Number of users of BTC - chartists, fundamentalists,
transacters.
     ~    :SUPPLEMENTARY
     |

Current BTC Per User[User]=
     BTC Held By Users[User]/Number of Users[User]
     ~    BTC/user
     ~    Current average BTC held per user type.
     |

Total Demand=
     SUM(Demand By User[User!])
     ~    BTC/Day
     ~    Total demand for BTC per day from all users in the
market.
     |

User:
     Chartist, Fundamentalist, Transacter
     ~    user
```

```
	~	Subscript to define 3 types of users in the BTC demand
side.
	|

Dedicated Users[User]=
	MAX(1, INTEGER(Number of Users[User]*Proportion of Dedicated
Users[User]))
	~	user
	~		|

Initial BTC Held By Users[User]=
	Initial BTC Per User[User]*Initial Number of Users[User]
	~	BTC
	~	Initial BTC held by each category of user.
	|

User Leave Rate[User]=
	MAX(0,((Number of Users[User]-Dedicated Users[User])*User Exit
Adjustment from ROI[User\
		]/User Residence Time[User]))
	~	user/Day
	~	Leave rate of users
	|

Proportion of Dedicated Users[User]=
	0,0.01,0.01
	~	Dimensionless
	~	Proportion of users who will always stay in the BTC
network.
	|

Initial BTC Per User[User]=
	0,0,0
	~	BTC/user
	~	Initial BTC held per user in each category.
	|

Cost of 20TH per Second Rig=
	Cost of Mining Unit Per Hash Per Second*"20TH Rig"
	~	dollar
	~		|

Cost of Mining Unit Per Hash Per Second=
	250000/10^12+RAMP( -249850/(5000*10^12) ,0,5000)
	~	dollar/(hash/second)
	~	Referring to
https://en.bitcoin.it/wiki/Mining_hardware_comparison
		Per TH/s cost went from 250,000$ to 150$
	|

Fixed Cost of Mining Hardware=
```

```
	MIN(Maximum Mining Unit Cost,Average Compute Power Per
Miner*Cost of Mining Unit Per Hash Per Second\
		*Single Miner)
	~	dollar
	~	State of the art Antminer S9 costs 10k$ commercially,
this considers a \
		fraction of that
	|

Maximum Mining Unit Cost=
	50000
	~	dollar
	~	Most expensive mining unit cost as an upper bound
	|

Indicated Number of Miners=
	MAX(Number of Miners*(1+Fractional Growth Rate of
Miners*Effective Residence Time),Dedicated Miners\
		)
	~	miner
	~	Indicated miner count based on the cost-benefit state of
the system
	|

Minimum Exit Adjustment=
	0.05
	~	Dimensionless
	~		|

Energy Consumption per TH per Second=
	Energy Consumption per Hash Rate Compute Power*10^12
	~	watt/(hash/second)
	~		|

Minimum Utilization=
	0.4
	~	Dimensionless
	~		|

Indicated Compute Power Capacity Utilization=
	MAX(Minimum Utilization,(1-XIDZ( Daily Variable Cost of Mining
, Daily Expected Benefit from Mining\
		 , 1 )^Sensitivity of Capacity Utilization to Costs
	))
	~	Dimensionless
	~	Indicated capacity utilization prior to decision point, a
value of 0.5 is \
		considered minimum since miners will keep rig operating
at low utilization \
		even under low or no incentive.
	|
```

```
Expected Time for a Miner to Mine a Block at Full Power=
     Expected time to Mine a Block*Network Hash Rate/(Average
Compute Power Per Miner*Single Miner\
          )
     ~    Day/block
     ~    A miner can expect to successfully mine a block at a rate
roughly \
          commensurate with his input into the network.
     |

Discount Rate For Mining Per Annum=
     0.025
     ~    Dimensionless
     ~         |

Fractional Growth Rate of Miners=
     (MAX(0,(ROI Per Annum From Mining/Reference ROI Per
Annum))^Sensitivity of Miners to ROI\
          )/Effective Residence Time
     ~    1/Day
     ~    Growth rate of miners as a function of ROI, sensitivity
and residence time
     |

ROI Per Annum From Mining=
     SMOOTHI(Indicated ROI Per Annum From Mining, Time To Adjust
ROI Perception , Initial Perception of Mining ROI\
           )
     ~    Dimensionless
     ~    Decision ROI variable for mining entry
     |

Average Fixed Cost over Active Mining Period=
     Fixed Cost of Mining Hardware
     ~    dollar [0,20000]
     ~    Total fixed cost over active period of mining is
essentially hw cost \
          multiplied by the number of times hw needs to be
upgraded.
     |

Time To Adjust Number of Miners=
     60
     ~    Day
     ~    Miners can enter or exit the network in a day
     |

Indicated ROI Per Annum From Mining=
     MIN(3,XIDZ(Time Adjusted Return over Active Mining
Period,Average Fixed Cost over Active Mining Period\
```

```
        ,2)-1)
	~	Dimensionless
	~	The expected ROI per annum of mining
	|

Effective Active Period of Mining Unit=
	MIN(Effective Residence Time,Average Life of Mining Hardware)
	~	Day
	~	The period for which a mining unit/miner is active in the 
network, is the \
		minimum of average life of hw and effective residence 
time.
	|

Inflow of Miners=
	MAX(0,(Indicated Number of Miners-Number of Miners))/Time To 
Adjust Number of Miners
	~	miner/Day
	~	Miners entering the network
	|

Daily Revenue Stream from Mining=
	Daily Expected Benefit from Mining-Daily Variable Cost of 
Mining
	~	dollar/Day
	~	Every day, the revenue stream that the mining activity 
provides is the \
		difference of the expected benefit and expected cost
	|

Time Adjusted Return over Active Mining Period=
	Daily Revenue Stream from Mining*Effective Active Period of 
Mining Unit*(1-(Discount Rate For Mining Per Annum\
		/365)^Effective Active Period of Mining Unit)/(1-
(Discount Rate For Mining Per Annum\
		/365))
	~	dollar
	~	The time adjusted return over the entire active period of 
a mining unit is \
		the revenue stream over the active period discounted 
daily using the \
		reference rate of return to incorporate the time value of 
money. This will \
		be compared with the fixed cost of mining unit arising 
from the hardware. \
		The geometric series summation is a * (1-r^n)/(1-r)
	|

Single Miner=
	1
	~	miner
```

```
	~		|

Daily Expected Benefit from Mining=
	Daily Chance Of Mining A Block*Mining Incentive Per Block
	~	dollar/Day
	~	Estimated daily benefit from mining is the chance of 
mining a block \
		multiplied by the incentive from mining it
	|

Initial Perception of Mining ROI=
	0.1
	~	Dimensionless
	~	Initial perception of ROI from Mining
	|

Exit Adjustment from ROI=
	MIN(MAX(Minimum Exit Adjustment,XIDZ( Reference ROI Per Annum
, ROI Per Annum From Mining\
		, 100 ))^Sensitivity of Miner Exit to ROI
	,5)
	~	Dimensionless
	~	Mining exit rate as a function of reference and mining 
ROI
	|

Daily Variable Cost of Mining=
	Average Variable Cost of Mining Per Block/Expected Time for a 
Miner to Mine a Block at Full Power
	~	dollar/Day
	~	Mining cost per day
	|

Days in a Year=
	365
	~	Day/Year
	~		|

Time To Adjust ROI Perception=
	30
	~	Day
	~	Time it takes for miners to adjust their ROI perception 
of mining
	|

Daily Chance Of Mining A Block=
	1/Expected Time for a Miner to Mine a Block at Full Power
	~	block/Day
	~	The probability of mining a block on a given day
	|
```

```
Effective Residence Time=
     MIN(3650,XIDZ(Number of Miners,Outflow of Miners,Residence
Time))
     ~    Day
     ~    Effective period every mining unit stays in the network,
capped at 10 years
     |

Initial BTC Left to Mine=
     2*Halving Interval*Initial BTC Reward
     ~    BTC
     ~    A policy decision taken during the design of bitcoin
limits the number of \
          bitcoin that can exist to 21 million
     |

Minimum Ratio of Difficulty from One Time Period to Next=
     0.25
     ~    Dimensionless
     ~    The difficulty adjustment can only be to a value 0.25
times the previous \
          period difficulty by policy
     |

Maximum Ratio of Difficulty From One Time Period To Next=
     4
     ~    Dimensionless
     ~    The difficulty adjustment can only be to a value 4 times
the previous \
          period difficulty by policy
     |

Minutes in a Day=
     1440
     ~    minute/Day
     ~    Minutes in a day
     |

Target Block Generation Time in Minutes=
     10
     ~    minute
     ~    Target Block Generation Time in minutes
     |

Target Block Generation Time=
     Target Block Generation Time in Minutes/(Minutes in a
Day*Singular Block)
     ~    Day/block
     ~    Target block generation time, currently set to 10 minutes
by policy and \
          design
```

```
	|

Magnitude of Difficulty Adjustment=
	MAX(Minimum Ratio of Difficulty from One Time Period to 
Next*Current Difficulty,MIN(\
		Target Difficulty,Maximum Ratio of Difficulty From One 
Time Period To Next*Current Difficulty\
		))-Current Difficulty
	~	Dimensionless
	~	The delta between target and current difficulty for each 
difficulty \
		adjustment.
	|

Current Difficulty=
	(Endogenous Switch for Difficulty*Endogenous Difficulty)+(1-
Endogenous Switch for Difficulty\
		)*Exogenous Difficulty
	~	Dimensionless
	~	Current difficulty for adjustment with target
	|

Proportion of Dedicated Miners=
	0.01
	~	Dimensionless [-1,1]
	~	Proportion of miners who never leave the network
	|

Dedicated Miners=
	MAX(1,INTEGER(Proportion of Dedicated Miners * Number of 
Miners))
	~	miner
	~	Miners who always believe in bitcoin and will never leave 
the network
	|

Difficulty Weight=
	1/(7e+12)
	~	Dmnl
	~		|

"Network Hash Rate in TH/s"=
	Network Hash Rate/10^12
	~	hash/second
	~		|

Hash Weight=
	1/(5e+07)
	~	Dmnl
	~		|
```

```
Total BTC= INTEG (
     -BTC Creation Rate,
          Initial BTC Left to Mine)
     ~    BTC
     ~    Maximum number of BTC that can ever be mined, policy-
driven
     |

Energy Consumption per Hash Rate Compute Power=
     10000/10^12+RAMP( -9900/(3500*10^12) ,0,3500)
     ~    watt/(hash/second)
     ~    The energy cost per unit of compute power - the minimum
is taken from \
          least power-efficient rig. The left hand term of the min
value is based on \
          initial cost of 10000W/(TH/s) going down to 100W/(TH/s)
present day.
     |

Network Hash Rate=
     MAX(Dedicated Miners*Average Compute Power Per
Miner,Endogenous Network Hash Rate)*Endogenous Switch for Hash
Rate\
          +Exogenous Network Hash Rate*(1-Endogenous Switch for
Hash Rate
     )
     ~    hash/second
     ~    The actually utilized hash rate in the network
     |

Singular Block=
     1
     ~    block
     ~         |

Energy Required per Block=
     Expected time to Mine a Block*Network Hash Rate*Energy
Consumption per Hash Rate Compute Power
     ~    Day*watt/block
     ~    The energy required to mine a block is a multiplicative
function of energy \
          efficiency, hash rate, and time.
     |

Endogenous Network Hash Rate=
     Available Hash Rate*Compute Power Capacity Utilization
     ~    hash/second
     ~    Hash rate endogenously generated by the model, non-zero
value if switch is \
          set to 1.
     |
```

```
Time to Adjust Capacity Utilization=
	7
	~	Day [0,500]
	~	Assume capacity utilization decision is made every
quarter
	|

Compute Power Capacity Utilization=
	SMOOTHI(Indicated Compute Power Capacity Utilization,Time to
Adjust Capacity Utilization\
		,1)
	~	Dimensionless
	~	Utilized compute power capacity depends on marginal cost
of hashing blocks \
		(cost/profit) and shocks to the system (such as
regulation). The \
		utilization is close to 1 when cost is negligible, and
approaches 0 as \
		cost becomes comparable to profit.
	|

Outflow of Miners=
	(Number of Miners-Dedicated Miners)*Exit Adjustment from
ROI/Residence Time
	~	miner/Day
	~	Miners flowing out of the network
	|

Sensitivity of Capacity Utilization to Costs=
	8
	~	Dimensionless [0,10]
	~	Sensitivity factor provides the exponent to the capacity
utilization \
		equation.
	|

Endogenous Difficulty=
	MAX(1,Difficulty of Computation)
	~	Dimensionless
	~	The difficulty value endogenously generated by the model,
has a value \
		other than 0 if the switch is set to 1 and is
dimensionless since the \
		difficulty value is a scaling factor.
	|

Minimum TWh per Year:INTERPOLATE:
	~	watt
	~	Digiconomist's minimum daily estimate of power
consumption of bitcoin in \
```

```
		TWh per year
	|

Exogenous Difficulty=
	MAX(1,Difficulty)
	~	Dimensionless
	~	The difficulty value exogenously provided by the dataset 
fed into the \
		model, has a value other than 0 if the switch is set to 0 
and is \
		dimensionless since the difficulty value is a scaling 
factor.
	|

Estimated TWh per Year:INTERPOLATE:
	~	hour*watt/Year
	~	Digiconomist's daily estimate of power consumption of 
bitcoin in TWh per \
		year
	|

Exogenous Network Hash Rate=
	MAX(7*10^6,"Hash-Rate"*Tera Multiplier)
	~	hash/second
	~	Hash rate exogenous input used dataset, and has non-zero 
value if \
		endogenous switch is 0.
	|

Hours in a Day=
	24
	~	hour/Day
	~		|

Number of Halving Intervals before all BTC is mined=
	MIN( 64 , LOG(Initial BTC Reward/Minimum Possible BTC Reward, 
2 ) )
	~	Dimensionless
	~	All bitcoin is expected to be mined by a certain number 
of halving \
		intervals
	|

Minimum Possible BTC Reward=
	1e-08
	~	BTC/block
	~	Minimum reward is 1 Satoshi
	|

Average Variable Cost of Mining Per Block=
	(Cost Of Energy*Energy Required per Block)
```

```
	~	dollar/block
	~	Average expected cost of mining a block in the blockchain
is the sum of \
		hardware cost and energy cost.
	|

Average Unique Hash Attempts to Find a Block=
	4.29497e+09
	~	hash/block
	~	The expected number of hash algorithm runs to find a
solution. This is a \
		function of BTC's blockchain design using the SHA256
algorithm
	|

Estimated Time for all BTC to be mined=
	Halving Interval*Target Block Generation Time*Number of
Halving Intervals before all BTC is mined
	~	Day
	~	The amount of time estimated for all bitcoin to be mined
(expected by 2140)
	|

Tera Multiplier=
	10^12
	~	Dimensionless
	~	Hash rate dataset is in TH/s, so multiply with 10^12 to
make it H/s
	|

Expected time to Mine a Block=
	(Difficulty of Computation*Average Unique Hash Attempts to
Find a Block)/(Network Hash Rate\
		*Seconds Per Day)
	~	Day/block
	~	The amount of time in days it takes to find a block in
the network \
		(expected to be close to 10 min)
	|

Target Difficulty=
	MAX(1,(Seconds Per Day*Target Block Generation Time*Network
Hash Rate/Average Unique Hash Attempts to Find a Block\
		))
	~	Dimensionless
	~	Target difficulty is recalibrated every pre-defined
number of blocks \
		(policy is 2016 blocks at the moment) so that block
generation time is at \
		target (policy is 10 min per block at present). It is a
ratio or scaling \
```

```
		factor to determine how hard it is to find the hash 
string, hence \
		dimensionless.
	|

BTC Loss Rate=
	BTC in Circulation*Loss Rate of BTC/Estimated Time for all BTC 
to be mined
	~	BTC/Day
	~	Loss rate of bitcoin from the network
	|

Loss Rate of BTC=
	0.2
	~	Dimensionless
	~	BTC lost in the network due to various factors - theft, 
lost wallets, etc.,
	|

Endogenous Switch for Hash Rate=
	1
	~	Dimensionless [0,1]
	~	Switch for hash rate dynamics, if set to 0, data source 
is used
	|

Block Generation Time=
	Difficulty of Computation*Average Unique Hash Attempts to Find 
a Block/(Network Hash Rate\
		*Seconds Per Day)
	~	Day/block
	~	Block generation time refers to the amount of time it 
takes to generate \
		each block in the blockchain.
	|

Endogenous Switch for Difficulty=
	1
	~	Dimensionless [0,1]
	~	Switch to enable difficulty dynamics, if set to 0, data 
source is used
	|

Transactions Per Block=
	"Number-of-Transactions-Per-Block"
	~	transaction/block
	~	Average number of transactions validated per block of the 
blockchain
	|

Time Period of One Day=
```

```
	1
	~	Day
	~		|

Difficulty:INTERPOLATE:
	~	Dimensionless
	~	Scaling factor to determine difficulty of the hashing 
problem to be solved \
		to mine a block
	|

Initial BTC Reward=
	50
	~	BTC/block
	~	The initial reward for mining a block of the blockchain
	|

"Number-of-Transactions-Per-Block":INTERPOLATE:
	~	transaction/block
	~	Number of transactions included per block mined on 
average per day
	|

"Avg-Block-Size":INTERPOLATE:
	~	mb/block
	~	The average block size over each day in MB
	|

"Market-Price":INTERPOLATE:
	~	dollar/BTC
	~	Market price of BTC
	|

Block Difficulty Adjustment Interval=
	2016
	~	block
	~	The number of blocks mined at current difficulty before 
difficulty is \
		adjusted.
	|

Sensitivity of Miner Exit to ROI=
	0.0625
	~	Dimensionless [-1,1]
	~	Exponent value to denote sensitivity of miners to ROI of 
mining to exit \
		the network
	|

Sensitivity of Miners to ROI=
	0.8
```

```
	~	Dimensionless [-1,2]
	~	Exponent value to denote sensitivity of miners to ROI 
from mining to enter \
		the network
	|

"Output-Volume":INTERPOLATE:
	~	dollar/Day
	~	The total value of all transaction outputs per day. This 
includes coins \
		returned to the sender as change.
	|

Seconds Per Day=
	86400
	~	second/Day
	~	Seconds in a day to reconcile hash rate in hash/second to 
hash/day
	|

"Number-of-Transactions":INTERPOLATE:
	~	transaction/Day
	~	Number of transactions per day
	|

"Miners-Revenue":INTERPOLATE:
	~	dollar/Day
	~	Total value in USD of coinbase block rewards and 
transaction fees paid to \
		miners.
	|

"Transaction-Fees":INTERPOLATE:
	~	BTC/Day
	~	Average transaction fees in BTC per transaction.
	|

"Median-Confirmation-Time":INTERPOLATE:
	~	minute/transaction
	~	The median time for a transaction with miner fees to be 
included in a \
		mined block and added to the public ledger.
	|

Difficulty Adjustment Rate=
	Magnitude of Difficulty Adjustment/Difficulty Adjustment 
Interval
	~	1/Day
	~	Current difficulty of the hashing problem in the network 
should match \
		target calculated every interval
```

```
	|

Average Compute Power Per Miner=
	MAX(7*10^6,Available Hash Rate/Number of Miners)
	~	(hash/second)/miner
	~	The average compute power each miner brings to the 
network
	|

Inflow of Compute Hash Rate=
	Average Compute Power Per Miner*Inflow of Miners*Ratio of 
Entering Hash Rate to Average Hash Rate
	~	hash/second/Day
	~	Compute power in terms of hash rate coming in to the 
network with new \
		miners
	|

Average Life of Mining Hardware=
	1825
	~	Day [0,8000]
	~	Roughly 4 year life for semiconductor device
	|

Initial Miners=
	1
	~	miner [-1,5]
	~	Initially, only the originator mined bitcoin
	|

Difficulty of Computation= INTEG (
	Difficulty Adjustment Rate,
		Initial Difficulty)
	~	Dimensionless
	~	The current difficulty of mining in the network. It is a 
ratio or scaling \
		factor to determine how hard it is to find the hash 
string, hence \
		dimensionless.
	|

Cost Of Energy=
	0.003
	~	dollar/(watt*Day) [-1,1]
	~	Assume per unit of energy consumption - 1kWh costs 10c - 
which means \
		1kWday costs 2.4$ which means 1 Wday costs 2.4 * 10^-3
	|

Outflow of Compute Hash Rate=
	Average Compute Power Per Miner*Outflow of Miners*Ratio of 
```

```
Leaving Hash Rate to Average Hash Rate
	~	hash/second/Day
	~	Compute power in terms of hash rate going out of the 
network with miners \
		exiting
	|

Available Hash Rate= INTEG (
	Inflow of Compute Hash Rate-Outflow of Compute Hash Rate,
		Initial Compute Power)
	~	hash/second
	~	The total hash rate available in the system for use
	|

Difficulty Adjustment Interval=
	Block Generation Time*Block Difficulty Adjustment Interval
	~	Day
	~	The difficulty adjustment interval is a function of the 
number of blocks \
		that needs to be mined for each adjustment and the time 
taken to mine each \
		one of those blocks.
	|

Residence Time=
	1825
	~	Day [0,10000]
	~	The average amount of time a miner spends on the network
	|

Initial Compute Power=
	4.5e+08
	~	hash/second [0,5e+08]
	~	Initial compute power is set to 100MH/s
	|

Ratio of Leaving Hash Rate to Average Hash Rate=
	0.6
	~	Dimensionless [-1,2]
	~	Leaving miners typically take out less hash rate/compute 
power than the \
		average available in network because they have less 
sophisticated systems.
	|

Ratio of Entering Hash Rate to Average Hash Rate=
	1.825
	~	Dimensionless [-10,20]
	~	Entering miners typically add in more hash rate/compute 
power than the \
		average available in network because they have newer,
```

```
more sophisticated \
          systems.
     |

Initial Difficulty=
     1
     ~    Dimensionless
     ~    Initial difficulty set to 1, for first block mined
     |

Reference ROI Per Annum=
     0.05
     ~    Dimensionless [-1,1]
     ~    Reference rate of return per year to compare against to
justify benefit of \
          mining
     |

Number of Miners= INTEG (
     Inflow of Miners-Outflow of Miners,
          Initial Miners)
     ~    miner
     ~    Number of active miners in network
     |

"Market-Cap":INTERPOLATE:
     ~    dollar
     ~    The total USD value of bitcoin in circulation.
     |

"Hash-Rate":INTERPOLATE:
     ~    hash/second
     ~    Hash rate dataset in TH/s, multiplier is used to
reconcile
     |

Block Creation Rate=
     1/Block Generation Time
     ~    block/Day
     ~    Rate of creation of blocks in the blockchain
     |

BTC Awarded per Block=
     Initial BTC Reward/(2^INTEGER(Blockchain Size/Halving
Interval))
     ~    BTC/block
     ~    BTC awarded per mined block
     |

BTC in Circulation= INTEG (
     BTC Creation Rate-BTC Loss Rate,
```

```
		0)
	~	BTC
	~		|

Noise Standard Deviation=
	0.02
	~	Dimensionless
	~	The standard deviation in the random noise.  The random 
fluctuation is \
		drawn from a normal distribution with min and max values 
of +/-  4.  The \
		user can also specify the random number seed to replicate 
simulations.  To \
		generate a different random number sequence, change the 
random number seed.
	|

Noise Start Time=
	4112
	~	Day
	~	The time at which the random noise in the input begins.
	|

Pulse Quantity=
	0
	~	Dimensionless*Day
	~	The quantity added to the input at the pulse time.
	|

Sine Amplitude=
	0
	~	Dimensionless
	~	The amplitude of the sine wave in the input.
	|

Sine Period=
	10
	~	Day
	~	The period of the sine wave in the input.
	|

Noise Seed=
	1000
	~	Dimensionless
	~	Varying the random number seed changes the sequence of 
realizations for \
		the random variable.
	|

Ramp Start Time=
	0
```

```
	~	Day
	~	The time at which the ramp in the input begins.
	|

Input=
	1+STEP(Step Height,Step Time)+
	(Pulse Quantity/TIME STEP)*PULSE(Pulse Time,TIME STEP)+
	RAMP(Ramp Slope,Ramp Start Time,Ramp End 
Time)+STEP(1,Exponential Growth Time)*(EXP(\
		Exponential Growth Rate*Time)-1)+
	STEP(1,Sine Start Time)*Sine Amplitude*SIN(2*3.14159*Time/Sine 
Period)+STEP(1,Noise Start Time\
		)*RANDOM NORMAL( -4 , 4 , 0 , Noise Standard Deviation , 
Noise Seed )
	~	Dimensionless
	~	The test input can be configured to generate a step, 
pulse, linear ramp, \
		exponential growth, sine wave, and random variation.  The 
initial value of \
		the input is 1 and each test input begins at a particular 
start time.  The \
		magnitudes are expressed as fractions of the initial 
value.
	|

Step Height=
	0
	~	Dimensionless
	~	The height of the step increase in the input.
	|

Pulse Time=
	0
	~	Day
	~	The time at which the pulse increase in the input occurs.
	|

Exponential Growth Rate=
	0
	~	1/Day
	~	The exponential growth rate in the input.
	|

Exponential Growth Time=
	0
	~	Day
	~	The time at which the exponential growth in the input 
begins.
	|

Sine Start Time=
```

```
	0
	~	Day
	~	The time at which the sine wave fluctuation in the input
begins.
	|

Ramp Slope=
	0
	~	1/Day
	~	The slope of the linear ramp in the input.
	|

Step Time=
	0
	~	Day
	~	The time at which the step increase in the input occurs.
	|

Ramp End Time=
	1e+09
	~	Day
	~	The end time for the ramp input.
	|

BTC Creation Rate=
	Block Creation Rate*BTC Awarded per Block
	~	BTC/Day
	~	Rate of creation of BTC as blocks are mined
	|

Blockchain Size= INTEG (
	Block Creation Rate,
		0)
	~	block
	~	The current size of the blockchain
	|

Halving Interval=
	210000
	~	block
	~	The number of blocks mined before the seignorage (or BTC
unit) reward is \
		halved
	|

********************************************************
	.Control
********************************************************~
		Simulation Control Parameters
	|
```

```
FINAL TIME  = 5000
     ~    Day
     ~    The final time for the simulation.
     |

INITIAL TIME  = 0
     ~    Day
     ~    The initial time for the simulation.
     |

SAVEPER  =
        TIME STEP
     ~    Day [0,?]
     ~    The frequency with which output is stored.
     |

TIME STEP  = 1
     ~    Day [0,?]
     ~    The time step for the simulation.
     |

\\\---/// Sketch information - do not modify anything except names
V300  Do not put anything below this section - it will be ignored
*Mining
$192-192-192,0,Times New Roman|12||0-0-0|0-0-0|0-0-255|-1--1--1|-1-
-1--1|96,96,75,0
10,1,Total BTC,258,779,46,13,3,3,0,0,0,0,0,0,0,0,0,0,0,0
10,2,BTC in Circulation,526,778,46,20,3,131,0,0,0,0,0,0,0,0,0,0,0,0
1,3,5,2,4,0,0,22,0,0,0,-1--1--1,,1|(436,778)|
1,4,5,1,100,0,0,22,0,0,0,-1--1--1,,1|(341,778)|
11,5,0,386,778,7,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
10,6,BTC Creation Rate,386,816,75,30,40,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,7,Blockchain Size,562,642,73,23,3,131,0,0,0,0,0,0,0,0,0,0,0,0
12,8,48,275,642,10,8,0,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,9,11,7,4,0,0,22,0,0,0,-1--1--1,,1|(441,642)|
1,10,11,8,100,0,0,22,0,0,0,-1--1--1,,1|(332,642)|
11,11,0,386,642,7,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
10,12,Block Creation Rate,386,680,75,30,40,131,0,0,-
1,0,0,0,0,0,0,0,0,0
1,13,12,6,1,0,43,0,2,0,0,-1--1--1,|||0-0-0,1|(354,728)|
10,14,BTC Awarded per
Block,561,980,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,15,14,6,1,0,43,0,2,0,0,-1--1--1,|||0-0-0,1|(422,932)|
1,16,7,14,1,0,45,0,2,0,0,-1--1--1,|||0-0-0,1|(993,954)|
10,17,Halving Interval,321,1129,75,30,8,131,0,0,0,0,0,0,0,0,0,0,0,0
1,18,17,14,1,0,45,0,2,0,0,-1--1--1,|||0-0-0,1|(495,1084)|
12,19,48,710,772,10,8,0,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,20,22,2,100,0,0,22,0,192,0,-1--1--1,,1|(596,772)|
1,21,22,19,4,0,0,22,0,192,0,-1--1--1,,1|(666,772)|
11,22,0,627,772,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
10,23,BTC Loss Rate,627,810,75,30,40,3,0,0,-1,0,0,0,0,0,0,0,0,0
```

10,24,Cost Of Energy,2370,640,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,25,Energy Required per Block,2003,601,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,26,Average Fixed Cost over Active Mining Period,893,-
881,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,27,Average Variable Cost of Mining Per
Block,2212,546,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,28,Average Life of Mining Hardware,1105,-727,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,29,24,27,1,0,0,0,0,192,0,-1--1--1,,1|(2291,609)|
10,30,Transactions Per Block,294,-196,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,31,Difficulty Adjustment Interval,605,450,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,32,Block Generation Time,348,344,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,33,32,12,1,0,0,0,0,192,0,-1--1--1,,1|(310,448)|
10,34,Number of Miners,1257,-333,46,20,3,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,35,Available Hash Rate,1283,169,61,20,3,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,36,Difficulty of Computation,959,345,54,20,3,3,0,0,-
1,0,0,0,0,0,0,0,0,0
12,37,48,1061,-324,10,8,0,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,38,40,37,100,0,0,22,0,192,0,-1--1--1,,1|(1141,-324)|
1,39,40,34,4,0,0,22,0,192,0,-1--1--1,,1|(1179,-333)|
11,40,0,1141,-333,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
10,41,Inflow of Miners,1141,-295,75,30,40,3,0,0,-
1,0,0,0,0,0,0,0,0,0
12,42,48,1464,-329,10,8,0,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,43,45,34,100,0,0,22,0,192,0,-1--1--1,,1|(1335,-329)|
1,44,45,42,4,0,0,22,0,192,0,-1--1--1,,1|(1417,-329)|
11,45,0,1374,-329,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
10,46,Outflow of Miners,1374,-291,75,30,40,3,0,0,-
1,0,0,0,0,0,0,0,0,0
12,47,48,1037,174,10,8,0,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,48,50,47,100,0,0,22,0,192,0,-1--1--1,,1|(1086,174)|
1,49,50,35,4,0,0,22,0,192,0,-1--1--1,,1|(1179,174)|
11,50,0,1131,174,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
10,51,Inflow of Compute Hash Rate,1131,212,75,30,40,3,0,0,-
1,0,0,0,0,0,0,0,0,0
12,52,48,1525,173,10,8,0,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,53,55,35,100,0,0,22,0,192,0,-1--1--1,,1|(1380,173)|
1,54,55,52,4,0,0,22,0,192,0,-1--1--1,,1|(1471,173)|
11,55,0,1422,173,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
10,56,Outflow of Compute Hash Rate,1422,211,75,30,40,3,0,0,-
1,0,0,0,0,0,0,0,0,0
12,57,48,768,343,10,8,0,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,58,60,57,100,0,0,22,0,192,0,-1--1--1,,1|(814,343)|
1,59,60,36,4,0,0,22,0,192,0,-1--1--1,,1|(883,343)|
11,60,0,856,343,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
10,61,Difficulty Adjustment Rate,856,381,75,30,40,3,0,0,-

```
1,0,0,0,0,0,0,0,0,0
1,62,41,51,1,0,0,0,0,192,0,-1--1--1,,1|(1049,-136)|
1,63,46,56,1,0,0,0,0,192,0,-1--1--1,,1|(1567,-31)|
10,64,Initial Miners,1338,-99,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,65,64,34,1,0,0,0,0,192,1,-1--1--1,,1|(1344,-212)|
10,66,Target Difficulty,742,226,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,67,Magnitude of Difficulty Adjustment,867,-5,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,68,66,67,1,0,0,0,0,192,0,-1--1--1,,1|(700,106)|
1,69,67,61,1,0,0,0,0,192,0,-1--1--1,,1|(936,186)|
10,70,Average Transaction Fee in BTC,133,-260,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,71,Mining Incentive Per Block,494,-389,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,72,BTC Price,192,-467,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,73,BTC Awarded per Block,141,-393,75,30,8,2,0,3,-1,0,0,0,128-
128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
1,74,73,71,1,0,0,0,0,192,0,-1--1--1,,1|(330,-371)|
1,75,72,71,1,0,0,0,0,192,0,-1--1--1,,1|(336,-474)|
1,76,70,338,1,0,0,0,0,192,0,-1--1--1,,1|(244,-251)|
10,77,Difficulty of Computation,2312,758,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,78,Expected time to Mine a Block,2015,732,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,79,78,25,1,0,0,0,0,192,0,-1--1--1,,1|(2033,709)|
1,80,25,27,1,0,0,0,0,192,0,-1--1--1,,1|(2059,571)|
1,81,30,71,1,0,0,0,0,192,0,-1--1--1,,1|(404,-180)|
10,82,Fractional Growth Rate of Miners,1061,-509,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,83,"Market-Cap",260,-1408,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,84,"Hash-Rate",1621,607,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,85,Initial Compute Power,1297,4,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,86,85,35,1,0,0,0,0,192,1,-1--1--1,,1|(1284,81)|
10,87,Average Compute Power Per Miner,1159,-96,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,88,35,87,1,0,0,0,0,192,0,-1--1--1,,1|(1178,23)|
10,89,Reference ROI Per Annum,1239,-672,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,90,Indicated ROI Per Annum From Mining,1187,-978,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,91,Average Variable Cost of Mining Per Block,780,-
988,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-
128,0,0,0,0,0,0
10,92,Residence Time,1391,-502,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,93,92,46,1,0,0,0,0,192,0,-1--1--1,,1|(1424,-426)|
1,94,34,46,1,0,0,0,0,192,0,-1--1--1,,1|(1340,-366)|
1,95,34,87,1,0,0,0,0,192,0,-1--1--1,,1|(1164,-205)|
1,96,87,51,1,0,0,0,0,192,0,-1--1--1,,1|(1119,37)|
10,97,Ratio of Entering Hash Rate to Average Hash Rate,1010,-
228,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
```

1,98,97,51,1,0,0,0,0,192,0,-1--1--1,,1|(1004,-31)|
1,99,87,56,1,0,0,0,0,192,0,-1--1--1,,1|(1377,8)|
10,100,Ratio of Leaving Hash Rate to Average Hash Rate,1495,-
95,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0
1,101,100,56,1,0,0,0,0,192,0,-1--1--1,,1|(1495,4)|
10,102,Energy Consumption per Hash Rate Compute
Power,1707,275,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0
1,103,77,78,1,0,0,0,0,192,0,-1--1--1,,1|(2216,798)|
1,104,32,31,1,0,0,0,0,192,0,-1--1--1,,1|(435,395)|
1,105,31,61,1,0,0,0,0,192,0,-1--1--1,,1|(785,440)|
10,106,Initial Difficulty,1147,453,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0
1,107,106,36,1,0,0,0,0,192,1,-1--1--1,,1|(1072,363)|
1,108,89,82,1,0,0,0,0,192,0,-1--1--1,,1|(1190,-577)|
1,109,2,23,1,0,0,0,0,192,0,-1--1--1,,1|(581,711)|
10,110,"Number-of-Transactions",-119,-198,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0
10,111,"Number-of-Transactions-Per-Block",95,-121,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0
10,112,"Transaction-Fees",-134,-285,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0
10,113,"Market-Price",-88,-531,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0
10,114,"Median-Confirmation-Time",855,-1408,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0
10,115,Difficulty,444,-139,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0
12,116,0,517,-1499,85,24,0,7,0,8,-1,0,0,0,-1--1--1,0-0-0,|30||0-0-
0,0,0,0,0,0,0
Data Pulls
10,117,"Avg-Block-Size",641,-1413,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0
10,118,"Output-Volume",448,-1411,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0
10,119,"Miners-Revenue",98,-1420,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0
12,120,0,129,-65,297,11,0,7,0,0,-1,0,0,0,0,0,0,0,0
Transaction fees in terms of BTC value (BTC price * Transaction
fees = Transaction fees in USD)
10,121,Exit Adjustment from ROI,1617,-470,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0
1,122,89,121,1,0,0,0,0,192,0,-1--1--1,,1|(1383,-620)|
1,123,121,46,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,124,Sensitivity of Miners to ROI,984,-419,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0
1,125,124,82,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,126,Sensitivity of Miner Exit to ROI,1669,-277,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0
1,127,126,121,1,0,0,0,0,64,0,-1--1--1,,1|(1665,-384)|
10,128,Seconds Per Day,687,365,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0
1,129,128,66,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,130,Block Difficulty Adjustment Interval,415,570,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0
1,131,130,31,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,132,Initial BTC Reward,643,1185,75,30,8,3,0,0,-

1,0,0,0,0,0,0,0,0,0
1,133,132,14,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
12,134,0,1775,1044,512,11,0,7,0,0,-1,0,0,0,0,0,0,0,0,0
Compute power Capacity Utilization function of shocks + marginal cost of hashing blocks (ratio of cost to profit) - utilization 1 at cost close to 0, drops as it approaches 1
12,135,0,2026,1111,263,11,0,7,0,0,-1,0,0,0,0,0,0,0,0,0
Change compute power to hash rate - hash rate = compute power * utilization function
10,136,Compute Power Capacity Utilization,1257,658,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,137,Network Hash Rate,1354,372,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,138,137,66,1,0,0,0,0,192,0,-1--1--1,,1|(1102,251)|
1,139,112,70,1,0,0,0,0,192,0,-1--1--1,,1|(-15,-255)|
1,140,111,30,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,141,Expected time to Mine a Block,361,-877,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,142,Seconds Per Day,2066,918,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
1,143,142,78,1,0,0,0,0,192,0,-1--1--1,,1|(2049,802)|
10,144,Average Unique Hash Attempts to Find a Block,1828,837,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,145,144,78,1,0,0,0,0,192,0,-1--1--1,,1|(1934,795)|
10,146,Average Unique Hash Attempts to Find a Block,602,140,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
1,147,146,66,1,0,0,0,0,192,0,-1--1--1,,1|(665,189)|
10,148,Difficulty of Computation,27,229,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,149,Network Hash Rate,10,312,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
1,150,148,32,1,0,0,0,0,192,0,-1--1--1,,1|(173,199)|
1,151,149,32,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,152,Average Compute Power Per Miner,2714,838,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,153,Seconds Per Day,24,389,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,154,Average Unique Hash Attempts to Find a Block,7,475,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
1,155,153,32,1,0,0,0,0,192,0,-1--1--1,,1|(162,386)|
1,156,154,32,1,0,0,0,0,192,0,-1--1--1,,1|(173,468)|
10,157,Loss Rate of BTC,821,729,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,158,157,23,1,0,0,0,0,192,0,-1--1--1,,1|(747,807)|
10,159,Target Block Generation Time,482,192,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,160,159,66,1,0,0,0,0,192,0,-1--1--1,,1|(596,220)|
10,161,Target Block Generation Time,743,936,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,162,Halving Interval,870,981,75,30,8,2,0,3,-1,0,0,0,128-128-

128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,163,Endogenous Switch for Hash Rate,1344,529,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,164,Endogenous Switch for Difficulty,730,-200,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
12,165,0,1467,1176,229,11,0,7,0,0,-1,0,0,0,0,0,0,0,0,0
Add estimates for power, and then backtrack for power efficiency
per hash
12,166,0,1451,1107,180,11,0,7,0,0,-1,0,0,0,0,0,0,0,0,0
Add an intermediate variable for endogenous vs exogenous
10,167,Exogenous Difficulty,586,-101,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,168,Exogenous Network Hash Rate,1444,571,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,169,167,252,1,0,0,0,0,192,0,-1--1--1,,1|(575,-42)|
1,170,115,167,1,0,0,0,0,192,0,-1--1--1,,1|(523,-142)|
1,171,84,168,1,0,0,0,0,192,0,-1--1--1,,1|(1548,625)|
1,172,168,137,1,0,0,0,0,192,0,-1--1--1,,1|(1391,475)|
10,173,Endogenous Network Hash Rate,1232,544,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,174,173,137,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,175,Endogenous Difficulty,901,-216,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,176,36,175,1,0,0,0,0,192,0,-1--1--1,,1|(981,20)|
1,177,175,252,1,0,0,0,0,192,0,-1--1--1,,1|(762,-133)|
10,178,Estimated Time for all BTC to be
mined,797,874,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,179,161,178,1,0,0,0,0,192,0,-1--1--1,,1|(811,922)|
1,180,162,178,1,0,0,0,0,192,0,-1--1--1,,1|(890,922)|
1,181,178,23,1,0,0,0,0,192,0,-1--1--1,,1|(650,841)|
1,182,35,173,1,0,0,0,0,192,0,-1--1--1,,1|(1243,345)|
12,183,0,2057,1230,126,11,0,7,0,0,-1,0,0,0,0,0,0,0,0,0
How to get rid of shadow variables only?
1,184,137,78,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,185,Average Compute Power Per Miner,163,-838,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,186,Network Hash Rate,421,-997,75,30,8,2,0,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,187,Expected Time for a Miner to Mine a Block at Full
Power,492,-702,75,30,8,131,0,0,-1,0,0,0,0,0,0,0,0,0
1,188,141,187,1,0,0,0,0,192,0,-1--1--1,,1|(438,-801)|
1,189,186,187,1,0,0,0,0,192,0,-1--1--1,,1|(496,-847)|
10,190,Number of Halving Intervals before all BTC is
mined,899,803,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,191,190,178,1,0,0,0,0,192,0,-1--1--1,,1|(796,841)|
1,192,137,25,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
12,193,0,2035,-501,166,11,0,7,0,0,-1,0,0,0,0,0,0,0,0,0
Relative Attractiveness of Mining BTC vs other crypto
10,194,Tera Multiplier,1537,668,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,195,Initial BTC Reward,936,673,75,30,8,2,0,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0

1,196,195,190,1,0,0,0,0,192,0,-1--1--1,,1|(956,741)|
10,197,Minimum Possible BTC Reward,956,886,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,198,197,190,1,0,0,0,0,192,0,-1--1--1,,1|(958,856)|
10,199,Estimated TWh per Year,1700,133,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,200,Minimum TWh per Year,1043,-1403,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,201,Time Period of One Day,1588,379,75,30,8,2,0,3,-1,0,0,0,128-
128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,202,Hours in a Day,1714,394,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,203,163,137,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,204,164,252,1,0,0,0,0,192,0,-1--1--1,,1|(634,-66)|
1,205,194,168,1,0,0,0,0,192,0,-1--1--1,,1|(1405,620)|
12,206,0,1850,43,172,11,0,7,0,16,-1,0,0,0,-1--1--1,0-0-0,||B|0-0-
0,0,0,0,0,0,0
MAX formulations so values don't go below initial?
1,207,102,25,1,0,0,0,0,192,0,-1--1--1,,1|(1837,441)|
1,208,136,173,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,209,Indicated Compute Power Capacity
Utilization,1050,603,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,210,Sensitivity of Capacity Utilization to
Costs,893,513,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,211,210,209,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
1,212,209,136,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,213,Time to Adjust Capacity Utilization,1453,783,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,214,213,136,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,215,Dedicated Miners,1535,-283,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,216,215,46,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,217,Dedicated Miners,1311,271,75,30,8,2,0,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,218,Average Compute Power Per Miner,1411,268,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
1,219,217,137,1,0,0,0,0,192,0,-1--1--1,,1|(1357,335)|
1,220,218,137,1,0,0,0,0,192,0,-1--1--1,,1|(1392,321)|
12,221,0,-692,63,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Blockchain Size,Graph
12,222,0,-354,70,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Number of Miners,Graph
12,223,0,-694,392,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Available Hash Rate,Graph
12,224,0,-783,-397,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Network Hash Rate,Graph
12,225,0,-367,766,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Energy Required per Block,Graph
12,226,0,-314,407,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Average Compute Power Per Miner,Graph
12,227,0,-701,1083,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Average Variable Cost of Mining Per Block,Graph

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10,228,Block Generation Time Mins,511,284,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,229,32,228,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
12,230,0,-725,748,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Block Generation Time Mins,Graph
12,231,0,-396,-850,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Difficulty,Graph
12,232,0,-730,-865,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
"Hash-Rate",Graph
12,233,0,-544,-1088,83,17,0,7,0,24,-1,0,0,0,-1--1--1,0-0-0,|22|B|0-
0-0,0,0,0,0,0,0
Data Sources
12,234,0,-553,-603,110,17,0,7,0,24,-1,0,0,0,-1--1--1,0-0-0,|22|B|0-
0-0,0,0,0,0,0,0
Model Generated
10,235,Initial BTC Left to Mine,132,857,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,236,235,1,1,0,0,0,0,192,1,-1--1--1,,1|(166,798)|
12,237,0,-1074,56,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Mining Incentive Per Block,Graph
12,238,0,-1089,-860,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Average Transaction Fee in BTC,Graph
12,239,0,-1071,-1169,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
"Market-Price",Graph
10,240,Hash Weight,1831,-1158,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,241,Difficulty Weight,1836,-1070,75,30,8,131,0,0,-
1,0,0,0,0,0,0,0,0,0
10,242,"Network Hash Rate in TH/s",1534,303,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,243,137,242,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,244,110,70,1,0,0,0,0,192,0,-1--1--1,,1|(44,-199)|
12,245,0,-1143,-393,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
"Network Hash Rate in TH/s",Graph
10,246,Time,1535,-244,75,30,8,2,1,3,-1,0,0,0,128-128-128,0-0-
0,|||128-128-128,0,0,0,0,0,0
10,247,Proportion of Dedicated Miners,1579,-378,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,248,34,215,1,0,0,0,0,64,0,-1--1--1,,1|(1356,-219)|
1,249,247,215,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
12,250,0,-441,-408,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Difficulty of Computation,Graph
12,251,0,-1096,430,150,150,3,15,0,0,2,0,0,0,0,0,0,0,0,0
Indicated ROI Per Annum From Mining,Graph
10,252,Current Difficulty,579,49,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,253,252,67,1,0,0,0,0,192,0,-1--1--1,,1|(708,-25)|
10,254,Target Block Generation Time in
Minutes,250,123,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,255,254,159,0,0,0,0,0,128,0,-1--1--1,,1|(0,0)|
10,256,Minutes in a Day,477,87,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,257,256,159,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,258,Singular Block,388,268,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-
```

0-0,|||128-128-128,0,0,0,0,0,0
1,259,258,159,1,0,0,0,0,128,0,-1--1--1,,1|(399,216)|
10,260,Maximum Ratio of Difficulty From One Time Period To Next,850,-106,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,261,260,67,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,262,Minimum Ratio of Difficulty from One Time Period to Next,824,180,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,263,262,67,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
1,264,132,235,1,0,0,0,0,128,0,-1--1--1,,1|(234,1191)|
1,265,17,235,1,0,0,0,0,128,0,-1--1--1,,1|(261,989)|
10,266,Effective Residence Time,1490,-821,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,267,34,266,1,0,0,0,0,128,0,-1--1--1,,1|(1357,-688)|
1,268,46,266,1,0,0,0,0,128,0,-1--1--1,,1|(1558,-619)|
10,269,ROI Per Annum From Mining,855,-480,75,30,8,131,0,0,0,0,0,0,0,0,0,0,0,0
10,270,Initial Perception of Mining ROI,706,-316,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,271,270,269,1,0,0,0,0,64,0,-1--1--1,,1|(778,-386)|
1,272,90,269,1,0,0,0,0,64,0,-1--1--1,,1|(1017,-756)|
10,273,Time To Adjust ROI Perception,859,-292,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,274,273,269,1,0,0,0,0,64,0,-1--1--1,,1|(861,-377)|
1,275,269,82,1,0,0,0,0,128,0,-1--1--1,,1|(971,-529)|
10,276,Daily Chance Of Mining A Block,475,-545,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,277,187,276,1,0,0,0,0,128,0,-1--1--1,,1|(444,-626)|
10,278,Daily Variable Cost of Mining,710,-752,75,30,8,131,0,0,0,0,0,0,0,0,0,0,0,0
1,279,187,278,1,0,0,0,0,128,0,-1--1--1,,1|(607,-778)|
1,280,91,278,1,0,0,0,0,128,0,-1--1--1,,1|(736,-915)|
10,281,Daily Expected Benefit from Mining,633,-447,75,30,8,131,0,0,0,0,0,0,0,0,0,0,0,0
1,282,276,281,1,0,0,0,0,128,0,-1--1--1,,1|(520,-452)|
1,283,71,281,1,0,0,0,0,128,0,-1--1--1,,1|(569,-403)|
10,284,Days in a Year,1137,-1151,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,285,269,121,1,0,0,0,0,128,0,-1--1--1,,1|(1055,-580)|
1,286,92,266,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,287,Single Miner,653,-1156,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,288,287,187,1,0,0,0,0,128,0,-1--1--1,,1|(602,-960)|
10,289,Indicated Number of Miners,1165,-449,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
10,290,Effective Active Period of Mining Unit,1309,-772,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,291,266,290,1,0,0,0,0,128,0,-1--1--1,,1|(1375,-854)|
1,292,28,290,1,0,0,0,0,128,0,-1--1--1,,1|(1217,-745)|
10,293,Daily Revenue Stream from Mining,726,-600,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,294,278,293,1,0,0,0,0,128,0,-1--1--1,,1|(737,-664)|
1,295,281,293,0,0,0,0,0,128,0,-1--1--1,,1|(0,0)|
10,296,Time Adjusted Return over Active Mining Period,853,-

711,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,297,290,296,1,0,0,0,0,128,0,-1--1--1,,1|(1125,-840)|
1,298,293,296,1,0,0,0,0,128,0,-1--1--1,,1|(817,-640)|
10,299,Fixed Cost of Mining Hardware,880,-
1099,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,300,299,26,1,0,0,0,0,128,0,-1--1--1,,1|(934,-973)|
1,301,296,90,1,0,0,0,0,128,0,-1--1--1,,1|(938,-833)|
1,302,26,90,1,0,0,0,0,128,0,-1--1--1,,1|(1047,-979)|
1,303,34,289,1,0,0,0,0,128,0,-1--1--1,,1|(1211,-423)|
1,304,82,289,1,0,0,0,0,128,0,-1--1--1,,1|(1157,-476)|
1,305,215,289,1,0,0,0,0,128,0,-1--1--1,,1|(1342,-438)|
1,306,289,41,1,0,0,0,0,128,0,-1--1--1,,1|(1155,-402)|
1,307,34,41,1,0,0,0,0,128,0,-1--1--1,,1|(1189,-380)|
10,308,Time To Adjust Number of Miners,1046,-
369,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,309,308,41,1,0,0,0,0,128,0,-1--1--1,,1|(1127,-385)|
10,310,Daily Expected Benefit from Mining,1202,751,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,311,Daily Variable Cost of Mining,1118,818,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
1,312,311,209,1,0,0,0,0,128,0,-1--1--1,,1|(1102,716)|
1,313,310,209,1,0,0,0,0,128,0,-1--1--1,,1|(1138,676)|
1,314,266,82,1,0,0,0,0,128,0,-1--1--1,,1|(1337,-621)|
10,315,Discount Rate For Mining Per Annum,838,-564,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,316,315,296,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,317,Minimum
Utilization,977,440,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0
1,318,317,209,1,0,0,0,0,128,0,-1--1--1,,1|(1060,500)|
1,319,185,187,1,0,0,0,0,128,0,-1--1--1,,1|(289,-801)|
10,320,Energy Consumption per TH per
Second,2015,273,75,30,8,131,0,0,0,0,0,0,0,0,0,0,0
1,321,102,320,1,0,0,0,0,128,0,-1--1--1,,1|(1856,265)|
10,322,Minimum Exit Adjustment,1729,-585,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,323,322,121,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
1,324,185,299,1,0,0,0,0,128,0,-1--1--1,,1|(242,-1129)|
10,325,Cost of Mining Unit Per Hash Per Second,915,-
1258,75,30,8,131,0,0,0,0,0,0,0,0,0,0,0,0
1,326,325,299,1,0,0,0,0,128,0,-1--1--1,,1|(944,-1188)|
1,327,287,299,1,0,0,0,0,128,0,-1--1--1,,1|(767,-1150)|
1,328,266,289,1,0,0,0,0,128,0,-1--1--1,,1|(1306,-541)|
10,329,Maximum Mining Unit Cost,1049,-
1041,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,330,329,299,1,0,0,0,0,128,0,-1--1--1,,1|(995,-1099)|
10,331,Cost of 20TH per Second Rig,1138,-
1288,75,30,8,3,0,0,0,0,0,0,0,0,0,0,0,0
1,332,325,331,1,0,0,0,0,128,0,-1--1--1,,1|(1004,-1339)|
1,333,256,228,1,0,0,0,0,192,0,-1--1--1,,1|(542,168)|
10,334,"20TH Rig",1353,-1213,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0
1,335,334,331,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|

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10,336,BTC Price to Use,-34,-437,75,30,8,2,0,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
1,337,336,72,1,0,0,0,0,192,0,-1--1--1,,1|(86,-498)|
10,338,Average Transaction Fee in Dollars,389,-309,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,339,338,71,1,0,0,0,0,192,0,-1--1--1,,1|(472,-363)|
1,340,336,338,1,0,0,0,0,192,0,-1--1--1,,1|(163,-304)|
\\\---/// Sketch information - do not modify anything except names
V300  Do not put anything below this section - it will be ignored
*Supply Side Dashboard
$192-192-192,0,Times New Roman|12||0-0-0|0-0-0|0-0-255|-1--1--1|-1-
-1--1|96,96,80,0
12,1,0,567,271,200,180,3,44,0,0,1,0,0,0,0,0,0,0,0,0
Difficulty
12,2,0,972,269,203,177,3,44,0,0,1,0,0,0,0,0,0,0,0,0
Hash_Rate_1
12,3,0,1343,255,150,150,3,44,0,0,1,0,0,0,0,0,0,0,0,0
ROI_From_Mining
12,4,0,1246,620,150,150,3,44,0,0,1,0,0,0,0,0,0,0,0,0
Number_of_Miners
10,5,Average Fixed Cost over Active Mining
Period,595,944,75,30,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-
128-128,0,0,0,0,0,0
10,6,Average Unique Hash Attempts to Find a
Block,223,331,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-
128,0,0,0,0,0,0
10,7,Sensitivity of Miner Exit to ROI,967,1035,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,8,Sensitivity of Miners to ROI,954,904,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,9,Reference ROI Per Annum,782,1071,75,30,8,2,0,3,-1,0,0,0,128-
128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,10,Sensitivity of Capacity Utilization to
Costs,968,968,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-
128,0,0,0,0,0,0
10,11,Cost Of Energy,97,974,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-
0,|||128-128-128,0,0,0,0,0,0
10,12,Halving Interval,221,238,75,30,8,2,0,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,13,Block Difficulty Adjustment Interval,220,540,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,14,Time to Adjust Capacity Utilization,234,1076,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,15,Residence Time,592,1087,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-
0-0,|||128-128-128,0,0,0,0,0,0
10,16,Average Life of Mining Hardware,592,1036,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,17,Initial BTC Reward,217,391,75,30,8,2,0,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,18,Initial Compute Power,800,963,75,30,8,2,0,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
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10,19,Initial BTC Left to Mine,219,617,75,30,8,2,0,3,-1,0,0,0,128-
128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,20,Ratio of Entering Hash Rate to Average Hash
Rate,452,891,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-
128,0,0,0,0,0,0
10,21,Ratio of Leaving Hash Rate to Average Hash
Rate,440,957,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-
128,0,0,0,0,0,0
10,22,Initial Miners,799,923,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-
0-0,|||128-128-128,0,0,0,0,0,0
12,23,0,943,639,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Expected Time for a Miner to Mine a Block at Full Power,Graph
10,24,Target Block Generation Time in
Minutes,217,460,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-
128-128,0,0,0,0,0,0
10,25,Initial Difficulty,594,889,75,30,8,2,0,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
12,26,0,1668,534,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Mining Incentive Per Block,Graph
12,27,0,2061,514,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Energy Required per Block,Graph
12,28,0,1689,209,170,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Estimated Time for all BTC to be mined,Graph
12,29,0,2043,191,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Average Variable Cost of Mining Per Block,Graph
10,30,Minimum Possible BTC Reward,215,687,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
12,31,0,2058,826,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Effective Residence Time,Graph
12,32,0,1678,842,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Time Adjusted Return over Active Mining Period,Graph
10,33,Fixed Cost of Mining Hardware,243,1148,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,34,Minimum Utilization,230,875,75,30,8,2,0,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
12,35,0,568,647,209,179,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Compute Power Capacity Utilization,Graph
12,36,0,1675,1168,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Energy Consumption per TH per Second,Graph
10,37,Time To Adjust Number of Miners,236,969,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,38,Time To Adjust ROI Perception,229,1023,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
12,39,0,2050,1164,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Average Compute Power Per Miner,Graph
10,40,Maximum Mining Unit Cost,90,1017,75,30,8,2,0,3,-1,0,0,0,128-
128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,41,Discount Rate For Mining Per Annum,800,1013,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
\\\---/// Sketch information - do not modify anything except names
V300  Do not put anything below this section - it will be ignored
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*Noise
$192-192-192,0,Times New Roman|12||0-0-0|0-0-0|0-0-255|-1--1--1|-1-
-1--1|96,96,88,0
10,1,Input,316,188,75,30,0,3,0,48,-1,0,0,0,0-0-0,0-0-
0,Helvetica||B|0-0-0,0,0,0,0,0,0
10,2,Time,67,171,75,30,0,2,0,51,-1,0,0,0,128-128-128,0-0-
0,Helvetica||B|128-128-128,0,0,0,0,0,0
10,3,Step Time,73,120,75,30,0,3,0,48,-1,0,0,0,0-0-0,0-0-
0,Helvetica||B|0-0-0,0,0,0,0,0,0
10,4,Step Height,123,85,75,30,0,3,0,48,-1,0,0,0,0-0-0,0-0-
0,Helvetica||B|0-0-0,0,0,0,0,0,0
10,5,Pulse Time,188,57,75,30,0,3,0,48,-1,0,0,0,0-0-0,0-0-
0,Helvetica||B|0-0-0,0,0,0,0,0,0
10,6,Pulse Quantity,273,35,75,30,0,3,0,48,-1,0,0,0,0-0-0,0-0-
0,Helvetica||B|0-0-0,0,0,0,0,0,0
10,7,TIME STEP,69,231,75,30,0,2,0,51,-1,0,0,0,128-128-128,0-0-
0,Helvetica||B|128-128-128,0,0,0,0,0,0
10,8,Sine Amplitude,424,37,75,30,0,3,0,48,-1,0,0,0,0-0-0,0-0-
0,Helvetica||B|0-0-0,0,0,0,0,0,0
10,9,Sine Period,512,76,75,30,0,3,0,48,-1,0,0,0,0-0-0,0-0-
0,Helvetica||B|0-0-0,0,0,0,0,0,0
10,10,Ramp Slope,207,364,75,30,0,3,0,48,-1,0,0,0,0-0-0,0-0-
0,Helvetica||B|0-0-0,0,0,0,0,0,0
10,11,Ramp Start Time,128,328,75,30,0,3,0,48,-1,0,0,0,0-0-0,0-0-
0,Helvetica||B|0-0-0,0,0,0,0,0,0
10,12,Ramp End Time,83,284,75,30,0,3,0,48,-1,0,0,0,0-0-0,0-0-
0,Helvetica||B|0-0-0,0,0,0,0,0,0
1,13,2,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
1,14,7,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
1,15,3,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
1,16,4,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
1,17,5,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
1,18,6,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
1,19,8,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
1,20,9,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
1,21,10,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
1,22,11,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
1,23,12,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
10,24,Exponential Growth Rate,565,180,75,30,8,3,0,48,0,0,0,0,0-0-
0,0-0-0,Helvetica||B|0-0-0,0,0,0,0,0,0
10,25,Exponential Growth Time,551,241,75,30,8,3,0,48,0,0,0,0,0-0-
0,0-0-0,Helvetica||B|0-0-0,0,0,0,0,0,0
1,26,24,1,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
1,27,25,1,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,28,Noise Start Time,528,297,75,30,8,3,0,48,0,0,0,0,0-0-0,0-0-
0,Helvetica||B|0-0-0,0,0,0,0,0,0
10,29,Noise Standard Deviation,449,347,75,30,8,3,0,48,0,0,0,0,0-0-
0,0-0-0,Helvetica||B|0-0-0,0,0,0,0,0,0
1,30,28,1,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
1,31,29,1,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,32,Noise Seed,335,369,75,30,8,3,0,48,-1,0,0,0,128-128-128,0-0-
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0,Helvetica||B|128-128-128,0,0,0,0,0,0
1,33,32,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
10,34,Sine Start Time,556,121,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,35,34,1,0,0,0,0,0,0,0,-1--1--1,,1|(0,0)|
\\\---/// Sketch information - do not modify anything except names
V300  Do not put anything below this section - it will be ignored
*Testing
$192-192-192,0,Times New Roman|12||0-0-0|0-0-0|0-0-255|-1--1--
1|255-255-255|96,96,68,0
10,1,Average Fixed Cost over Active Mining
Period,282,1054,75,30,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-
128-128,0,0,0,0,0,0
10,2,Average Unique Hash Attempts to Find a
Block,377,244,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-
128,0,0,0,0,0,0
10,3,Sensitivity of Miner Exit to ROI,124,1072,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,4,Sensitivity of Miners to ROI,133,905,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,5,Reference ROI Per Annum,484,1027,75,30,8,2,0,3,-1,0,0,0,128-
128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,6,Sensitivity of Capacity Utilization to
Costs,294,873,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-
128,0,0,0,0,0,0
10,7,Cost Of Energy,280,1225,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-
0-0,|||128-128-128,0,0,0,0,0,0
10,8,Halving Interval,375,151,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-
0-0,|||128-128-128,0,0,0,0,0,0
10,9,Block Difficulty Adjustment Interval,374,453,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,10,Time to Adjust Capacity Utilization,126,999,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,11,Residence Time,485,958,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-
0-0,|||128-128-128,0,0,0,0,0,0
10,12,Average Life of Mining Hardware,285,1136,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,13,Initial BTC Reward,371,304,75,30,8,2,0,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,14,Initial Compute Power,483,1236,75,30,8,2,0,3,-1,0,0,0,128-
128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,15,Initial BTC Left to Mine,373,530,75,30,8,2,0,3,-1,0,0,0,128-
128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,16,Ratio of Entering Hash Rate to Average Hash
Rate,264,762,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-
128,0,0,0,0,0,0
10,17,Ratio of Leaving Hash Rate to Average Hash
Rate,492,1160,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-128-
128,0,0,0,0,0,0
10,18,Initial Miners,481,1089,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-
0-0,|||128-128-128,0,0,0,0,0,0
10,19,Target Block Generation Time in
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Minutes,371,373,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-
128-128,0,0,0,0,0,0
10,20,Initial Difficulty,280,958,75,30,8,2,0,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,21,Minimum Possible BTC Reward,369,600,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,22,Time To Adjust ROI Perception,448,751,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,23,Fixed Cost of Mining Hardware,463,844,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
12,24,0,1261,120,110,17,0,7,0,24,-1,0,0,0,-1--1--1,0-0-0,|22|B|0-0-
0,0,0,0,0,0,0
Model Generated
12,25,0,773,307,150,150,3,47,0,0,2,0,0,0,0,0,0,0,0,0
"Network Hash Rate in TH/s",Graph
12,26,0,1126,312,150,150,3,47,0,0,2,0,0,0,0,0,0,0,0,0
Difficulty of Computation,Graph
12,27,0,1828,600,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Mining Incentive Per Block,Graph
12,28,0,2196,535,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Energy Required per Block,Graph
12,29,0,1841,206,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Estimated Time for all BTC to be mined,Graph
12,30,0,2194,205,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Average Variable Cost of Mining Per Block,Graph
12,31,0,1859,984,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Effective Residence Time,Graph
12,32,0,2206,955,150,150,3,44,0,0,2,0,0,0,0,0,0,0,0,0
Time Adjusted Return over Active Mining Period,Graph
12,33,0,1468,626,150,150,3,47,0,0,2,0,0,0,0,0,0,0,0,0
Blockchain Size,Graph
12,34,0,1459,305,150,150,3,47,0,0,2,0,0,0,0,0,0,0,0,0
Number of Miners,Graph
12,35,0,1119,637,150,150,3,47,0,0,2,0,0,0,0,0,0,0,0,0
Available Hash Rate,Graph
12,36,0,768,633,150,150,3,47,0,0,2,0,0,0,0,0,0,0,0,0
Average Compute Power Per Miner,Graph
12,37,0,2512,200,150,150,3,47,0,0,2,0,0,0,0,0,0,0,0,0
Block Generation Time Mins,Graph
12,38,0,1475,968,150,150,3,47,0,0,2,0,0,0,0,0,0,0,0,0
Indicated ROI Per Annum From Mining,Graph
\\\---/// Sketch information - do not modify anything except names
V300  Do not put anything below this section - it will be ignored
*DemandSide_Trial
$192-192-192,0,Times New Roman|12||0-0-0|0-0-0|0-0-255|-1--1--
1|255-255-255|96,96,69,0
10,1,BTC Market Price,1449,1709,53,20,3,3,0,0,-1,0,0,0,0,0,0,0,0,0
12,2,48,1241,1716,10,8,0,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,3,5,2,100,0,0,22,0,192,0,-1--1--1,,1|(1284,1716)|
1,4,5,1,4,0,0,22,0,192,0,-1--1--1,,1|(1362,1716)|
11,5,0,1323,1716,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
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10,6,BTC Price Adjustment Rate,1323,1754,75,30,40,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,7,Indicated Market Price of BTC,1599,1925,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,8,Gap Between Expected Price and Actual Price of
BTC,1388,1928,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,9,7,8,1,0,0,0,0,192,0,-1--1--1,,1|(1499,1949)|
1,10,8,6,1,0,0,0,0,192,0,-1--1--1,,1|(1311,1848)|
10,11,BTC Price Adjustment Time,1224,1874,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,12,11,6,1,0,0,0,0,192,0,-1--1--1,,1|(1244,1799)|
10,13,BTC Awarded per Block,2942,848,75,30,8,2,0,3,-1,0,0,0,128-
128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,14,Average Variable Cost of Mining Per
Block,2935,1005,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-
128-128,0,0,0,0,0,0
10,15,Average Fixed Cost over Active Mining
Period,2951,1232,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-
128-128,0,0,0,0,0,0
10,16,Expected Time for a Miner to Mine a Block at Full
Power,3040,1118,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|||128-
128-128,0,0,0,0,0,0
10,17,BTC in Circulation,2458,1038,75,30,8,2,0,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,18,Number of Users,1653,491,46,20,3,3,0,0,-1,0,0,0,0,0,0,0,0,0
12,19,48,1442,495,10,8,0,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,20,22,19,100,0,0,22,0,192,0,-1--1--1,,1|(1487,495)|
1,21,22,18,4,0,0,22,0,192,0,-1--1--1,,1|(1571,495)|
11,22,0,1529,495,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
10,23,Inflow of Users,1529,533,75,30,40,3,0,0,-1,0,0,0,0,0,0,0,0,0
12,24,48,1869,491,10,8,0,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,25,27,18,100,0,0,22,0,192,0,-1--1--1,,1|(1736,491)|
1,26,27,24,4,0,0,22,0,192,0,-1--1--1,,1|(1822,491)|
11,27,0,1779,491,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
10,28,User Leave Rate,1779,529,75,30,40,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,29,User Residence Time,1848,274,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,30,Fractional User Growth Rate,1426,381,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,31,Initial Number of Users,1664,395,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,32,31,18,0,0,0,0,0,64,1,-1--1--1,,1|(0,0)|
1,33,30,23,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
1,34,18,23,1,0,0,0,0,64,0,-1--1--1,,1|(1570,572)|
10,35,Dedicated Users,1741,620,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,36,35,28,1,0,0,0,0,64,0,-1--1--1,,1|(1747,584)|
1,37,18,28,1,0,0,0,0,64,0,-1--1--1,,1|(1695,541)|
10,38,User Exit Adjustment from ROI,1917,638,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,39,38,28,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
1,40,29,28,1,0,0,0,0,64,0,-1--1--1,,1|(1826,397)|
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1,41,18,35,1,0,0,0,0,64,0,-1--1--1,,1|(1699,570)|
10,42,Proportion of Dedicated Users,1763,719,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,43,42,35,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,44,Supply of BTC,1159,1500,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,45,Demand Supply Balance,1613,1591,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,46,Sensitivity of Price to Demand Supply
Balance,1458,2139,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,47,44,45,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,48,46,7,1,0,0,0,0,192,0,-1--1--1,,1|(1485,2072)|
1,49,45,7,1,0,0,0,0,192,0,-1--1--1,,1|(1620,1730)|
1,50,1,8,1,0,0,0,0,192,0,-1--1--1,,1|(1472,1839)|
10,51,BTC Held By Users,2077,949,57,20,3,3,0,0,-1,0,0,0,0,0,0,0,0,0
12,52,48,1823,949,10,8,0,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,53,55,52,100,0,0,22,0,192,0,-1--1--1,,1|(1874,949)|
1,54,55,51,4,0,0,22,0,192,0,-1--1--1,,1|(1974,949)|
11,55,0,1922,949,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
10,56,User BTC Holding Adjustment,1922,987,75,30,40,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,57,BTC Held By Miners,2372,853,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,58,51,57,1,0,0,0,0,192,0,-1--1--1,,1|(2163,868)|
1,59,17,57,1,0,0,0,0,192,0,-1--1--1,,1|(2438,941)|
10,60,Desired BTC Per User,1887,1181,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,61,Current BTC Per User,1646,943,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,62,61,60,1,0,0,0,0,64,0,-1--1--1,,1|(1729,1063)|
1,63,18,61,1,0,0,0,0,192,0,-1--1--1,,1|(1681,716)|
1,64,51,61,1,0,0,0,0,192,0,-1--1--1,,1|(1894,867)|
10,65,Initial BTC Held By Users,2144,719,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,66,65,51,0,0,0,0,0,64,1,-1--1--1,,1|(0,0)|
1,67,31,65,1,0,0,0,0,192,0,-1--1--1,,1|(1918,455)|
10,68,Initial BTC Per User,1944,773,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,69,68,65,1,0,0,0,0,192,0,-1--1--1,,1|(2085,743)|
10,70,Total Demand,1105,879,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,71,Demand By User,1157,960,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,72,71,70,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,73,Total Supply,1150,710,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,74,Time to Close the Gap Between Desired and
Current,1220,1374,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,75,Bitcoins Transacted,1186,780,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,76,73,75,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,77,70,75,1,0,0,0,0,192,0,-1--1--1,,1|(1098,829)|
10,78,Fraction Supply Fulfilled,1363,745,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,79,Fraction Demand Fulfilled,1347,864,75,30,8,3,0,0,-
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1,0,0,0,0,0,0,0,0,0
1,80,70,79,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,81,75,79,1,0,0,0,0,192,0,-1--1--1,,1|(1291,819)|
1,82,75,78,1,0,0,0,0,192,0,-1--1--1,,1|(1256,756)|
1,83,73,78,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,84,Demand Fulfilled,1413,977,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,85,71,84,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,86,79,84,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,87,Supply Fulfilled,1493,689,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,88,78,87,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,89,Supply By User,1109,597,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,90,89,73,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,91,89,87,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,92,84,56,1,0,0,0,0,192,0,-1--1--1,,1|(1671,822)|
12,93,48,2328,949,10,8,0,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,94,96,51,100,0,0,22,0,192,0,-1--1--1,,1|(2177,949)|
1,95,96,93,4,0,0,22,0,192,0,-1--1--1,,1|(2275,949)|
11,96,0,2226,949,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0,0
10,97,User BTC Holding Reduction,2226,987,75,30,40,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,98,87,96,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,99,Desired Bitcoin by User Type,1555,1057,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,100,60,99,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,101,18,99,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,102,99,105,1,0,0,0,0,192,0,-1--1--1,,1|(1382,1099)|
1,103,74,105,1,0,0,0,0,192,0,-1--1--1,,1|(1259,1330)|
1,104,51,105,1,0,0,0,0,192,0,-1--1--1,,1|(1908,1070)|
10,105,Desired Adjustment in BTC,1228,1214,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,106,105,71,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,107,105,89,1,0,0,0,0,192,0,-1--1--1,,1|(939,757)|
10,108,Supply from Miners,924,591,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,109,108,73,1,0,0,0,0,192,0,-1--1--1,,1|(1035,673)|
1,110,57,108,1,0,0,0,0,192,0,-1--1--1,,1|(1108,440)|
10,111,Time for Miners to Supply,739,628,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,112,111,108,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,113,89,44,1,0,0,0,0,192,0,-1--1--1,,1|(1023,1236)|
1,114,70,45,1,0,0,0,0,192,0,-1--1--1,,1|(1587,1386)|
10,115,BTC Price Long Term Trend,2315,1832,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,116,BTC Price to Use,1832,1733,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,117,1,198,1,0,0,0,0,192,0,-1--1--1,,1|(1643,1717)|
1,118,116,115,1,0,0,0,0,192,0,-1--1--1,,1|(2130,1852)|
10,119,Long Trend Average Time,2139,1770,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,120,119,115,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,121,Indicated True Value of BTC,2697,1813,75,30,8,3,0,0,-
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1,0,0,0,0,0,0,0,0,0
10,122,Ratio of True to Current Price,2373,1633,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,123,Pressure to Buy BTC from
Fundamentals,2240,1337,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,124,115,121,1,0,0,0,0,192,0,-1--1--1,,1|(2497,1880)|
1,125,116,122,1,0,0,0,0,192,0,-1--1--1,,1|(2101,1723)|
10,126,Pressure to Buy BTC from Momentum,2093,1316,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,127,BTC Price Short Term Trend,2056,1507,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,128,116,127,1,0,0,0,0,192,0,-1--1--1,,1|(2024,1623)|
10,129,Short Trend Average Time,2229,1542,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,130,129,127,1,0,0,0,0,192,0,-1--1--1,,1|(2164,1505)|
1,131,121,122,1,0,0,0,0,192,0,-1--1--1,,1|(2537,1757)|
10,132,Sensitivity to Longterm Pressure,1694,1366,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,133,Sensitivity to Momentum Pressure,1720,1278,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,134,122,123,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,135,Pressure Sensitivity to Price Gap,2433,1314,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,136,135,123,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,137,127,126,1,0,0,0,0,192,0,-1--1--1,,1|(2097,1426)|
10,138,Desired Daily Return Rate,1860,1521,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,139,138,126,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,140,Sensitivity of Momentum to Shortterm
return,1763,1440,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,141,140,126,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,142,Maximum Holding per User,2230,1143,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,143,Impact of Reaching Maximum,2012,1085,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,144,143,60,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,145,Indicated Expansion Fraction,2076,1176,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,146,145,60,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
1,147,123,145,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
1,148,126,145,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
1,149,132,145,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
1,150,133,145,0,0,0,0,0,64,0,-1--1--1,,1|(0,0)|
1,151,142,143,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,152,61,143,1,0,0,0,0,192,0,-1--1--1,,1|(1778,1060)|
1,153,145,143,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,154,Block Generation Time,2849,1776,75,30,8,2,1,3,-1,0,0,0,128-
128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,155,Initial BTC Market Price,1451,1619,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,156,155,1,0,0,0,0,0,64,1,-1--1--1,,1|(0,0)|
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10,157,Short Term Reference Return,1731,1631,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,158,Short Term Investment Horizon,1822,1633,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,159,157,138,1,0,0,0,0,192,0,-1--1--1,,1|(1751,1559)|
1,160,158,138,1,0,0,0,0,192,0,-1--1--1,,1|(1861,1595)|
1,161,116,121,1,0,0,0,0,192,0,-1--1--1,,1|(2367,1945)|
10,162,BTC Price Long Term Trend,2090,-123,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,163,BTC Price Short Term Trend,1694,-99,75,30,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,164,Sensitivity of User Exit to Short Term
Trends,2393,414,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,165,164,38,1,0,0,0,0,192,0,-1--1--1,,1|(2325,532)|
10,166,Sensitivity of User Exit to Long Term
Trends,2303,325,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,167,Sensitivity of User Entry to Short Term
Trends,1303,184,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,168,Sensitivity of User Entry to Long Term
Trends,1184,203,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,169,168,30,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,170,167,30,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
10,171,User Entry Adjustment Time,1631,211,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,172,171,23,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
12,173,0,990,55,361,28,0,7,0,24,-1,0,0,0,-1--1--1,0-0-0,|18|B|0-0-
0,0,0,0,0,0,0
Map indicated growth rate from trends - trend * investment horizon?
10,174,Block Generation Time,1224,1920,75,30,8,2,1,3,-1,0,0,0,128-
128-128,0-0-0,|||128-128-128,0,0,0,0,0,0
10,175,Forward Looking Time Horizon,2761,1684,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,176,175,121,1,0,0,0,0,192,0,-1--1--1,,1|(2786,1737)|
1,177,166,38,1,0,0,0,0,192,0,-1--1--1,,1|(2103,557)|
10,178,Reference ROI per Annum for User,1634,133,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,179,178,30,1,0,0,0,0,192,0,-1--1--1,,1|(1497,195)|
1,180,178,38,1,0,0,0,0,192,0,-1--1--1,,1|(1967,194)|
10,181,Short Term ROI Per Annum,1791,34,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,182,Long Term ROI Per Annum,2112,104,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,183,163,181,1,0,0,0,0,192,0,-1--1--1,,1|(1706,-39)|
1,184,162,182,1,0,0,0,0,192,0,-1--1--1,,1|(2104,-45)|
10,185,Days in a Year,1940,147,75,30,8,2,1,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
1,186,185,181,0,1,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,187,Days in a Year,2112,150,75,30,8,2,1,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
1,188,187,182,0,1,0,0,0,64,0,-1--1--1,,1|(0,0)|
10,189,Days in a Year,1862,-118,75,30,8,2,0,3,-1,0,0,0,128-128-

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128,0-0-0,|||128-128-128,0,0,0,0,0,0
1,190,189,181,1,0,0,0,0,192,0,-1--1--1,,1|(1834,-81)|
1,191,189,182,1,0,0,0,0,192,0,-1--1--1,,1|(2022,-48)|
1,192,181,30,1,0,0,0,0,192,0,-1--1--1,,1|(1419,126)|
1,193,182,30,1,0,0,0,0,192,0,-1--1--1,,1|(1768,207)|
1,194,182,38,1,0,0,0,0,192,0,-1--1--1,,1|(2154,345)|
1,195,181,38,1,0,0,0,0,192,0,-1--1--1,,1|(2086,305)|
10,196,Endogenous Switch for Market Price,1734,1942,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,197,Exogenous Switch for Market Price,1819,2024,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,198,Endogenous Market Price,1698,1761,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,199,Exogenous Market Price,1936,1926,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
1,200,198,116,1,0,0,0,0,192,0,-1--1--1,,1|(1739,1729)|
1,201,196,116,1,0,0,0,0,192,0,-1--1--1,,1|(1781,1862)|
1,202,199,116,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,203,197,116,1,0,0,0,0,192,0,-1--1--1,,1|(1846,1923)|
1,204,196,197,1,0,0,0,0,192,0,-1--1--1,,1|(1738,2016)|
10,205,Price Weight,1229,2214,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
10,206,"Market-Price",1936,1965,75,30,8,2,1,3,-1,0,0,0,128-128-
128,0-0-0,|||128-128-128,0,0,0,0,0,0
1,207,206,199,0,1,0,0,0,64,0,-1--1--1,,1|(0,0)|
12,208,0,552,1021,353,31,0,7,0,24,-1,0,0,0,-1--1--1,0-0-0,|20|B|0-
0-0,0,0,0,0,0,0
Also calibrate transaction numbers with a notional per-transaction
BTC?
1,209,116,7,1,0,0,0,0,192,0,-1--1--1,,1|(1742,1829)|
10,210,Minimum Holding of BTC Allowed,1626,1235,75,30,8,3,0,0,-
1,0,0,0,0,0,0,0,0,0
10,211,Initial Trend,2211,2028,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,212,211,127,1,0,0,0,0,192,0,-1--1--1,,1|(2052,1705)|
1,213,211,115,1,0,0,0,0,192,0,-1--1--1,,1|(2294,1930)|
10,214,Time,1946,2106,75,30,8,2,0,3,-1,0,0,0,128-128-128,0-0-
0,|||128-128-128,0,0,0,0,0,0
1,215,214,196,1,0,0,0,0,192,0,-1--1--1,,1|(1686,2074)|
10,216,Endogenous Switchover Time for Market
Price,1641,2222,75,30,8,3,0,0,-1,0,0,0,0,0,0,0,0,0
1,217,216,196,1,0,0,0,0,192,0,-1--1--1,,1|(1609,2038)|
1,218,210,60,1,0,0,0,0,192,0,-1--1--1,,1|(1753,1198)|
\\\---/// Sketch information - do not modify anything except names
V300  Do not put anything below this section - it will be ignored
*Demand Side Dashboard
$-1--1--1,0,|12||-1--1--1|-1--1--1|-1--1--1|-1--1--1|-1--1--
1|96,96,121,0
12,1,0,758,164,215,141,8,79,0,0,2,0,0,0,0,0,0,0,0,0
Number of Users,Graph
12,2,0,1114,524,179,148,8,79,0,0,2,0,0,0,0,0,0,0,0,0
Fractional User Growth Rate,Graph
12,3,0,1356,176,189,149,8,79,0,0,2,0,0,0,0,0,0,0,0,0
```

```
User Exit Adjustment from ROI,Graph
12,4,0,330,138,198,170,8,79,0,0,2,0,0,0,0,0,0,0,0,0
BTC Market Price,Graph
12,5,0,490,536,314,199,8,79,0,0,1,0,0,0,0,0,0,0,0,0
BTC_Price_Comparison
///---\\\
:GRAPH Hash_Rate_1
:TITLE Hash Rate
:X-MIN 0
:X-MAX 6000
:SCALE
:VAR "Hash-Rate"
:VAR "Network Hash Rate in TH/s"

:GRAPH Difficulty
:TITLE Difficulty
:X-MIN 0
:X-MAX 6000
:SCALE
:VAR Difficulty
:VAR Difficulty of Computation

:GRAPH Number_of_Miners
:TITLE Number of Miners
:X-AXIS Time
:X-LABEL Time
:X-MIN 0
:X-MAX 6000
:SCALE
:VAR Number of Miners

:GRAPH ROI_From_Mining
:TITLE ROI From Mining
:X-AXIS Time
:X-LABEL Time (Day)
:X-DIV 13
:X-MIN 0
:X-MAX 6000
:SCALE
:VAR ROI Per Annum From Mining

:GRAPH BTC_Price_Comparison
:TITLE BTC Price Modeled Vs Actual
:X-AXIS Time
:X-LABEL Time (Day)
:X-DIV 13
:Y-DIV 12
:X-MIN 0
:X-MAX 10000
:SCALE
:VAR BTC Market Price
```

```
:VAR "Market-Price"

:GRAPH Hash_Rate_Shortfall
:TITLE Hash Rate Shortfall
:X-AXIS Time
:X-LABEL Time (Day)
:X-DIV 13
:Y-DIV 15
:X-MIN 1500
:X-MAX 4100
:SCALE
:VAR Hash Rate Shortfall|GH/s
:Y-MIN -3e+10
:Y-MAX 4.2e+11

:GRAPH Mining_Profit_Future
:TITLE Mining Economy (Future)
:X-AXIS Time
:X-LABEL Time (Day)
:Y-DIV 10
:X-MIN 4100
:SCALE
:VAR Mining Revenues
:UNITS $/day
:Y-MIN -7.5e+06
:Y-MAX 1.75e+07
:VAR Mining Cost
:VAR Mining Profit

:GRAPH Hash_Rate_Shortfall_Future
:TITLE Hash Rate Shortfall (Future)
:Y-DIV 12
:X-MIN 4100
:SCALE
:VAR Hash Rate Shortfall
:Y-MIN -6e+10
:Y-MAX 3e+10

:GRAPH Height_of_the_Blockchain
:TITLE Height of the Blockchain
:X-MAX 4100
:SCALE
:VAR Target Height of the Blockchain
:VAR Historic Height of the Blockchain

:GRAPH Hash_Rate_4
:TITLE Hash Rate
:Y-DIV 12
:X-MIN 2500
:SCALE
:VAR Hash Rate
```

```
:Y-MIN 0
:Y-MAX 1.2e+11
:L□<%^E!@
1:combined.vdfx
1:D:\MIT Coursework\Thesis\DataFiles\ConsolidatedData.vdfx
4:Time
5:Dedicated Users[User]
6:Chartist
6:Fundamentalist
6:Transacter
9:combined
19:69,4
24:0
25:5000
26:5000
10:supply_side_calibration.out,demand_side_calibration.out
11:bitcoin_demand.voc
12:opt_demand.vpd
13:DataFiles\ConsolidatedData.vdfx
23:0
15:1,0,0,0,0,0
27:0,
34:0,
42:1
72:0
73:0
35:Date
36:YYYY-MM-DD
37:2009
38:1
39:3
40:4
41:0
95:0
96:0
97:0
77:0
78:0
102:1
93:0
94:0
92:0
91:0
90:0
87:0
75:
43:
103:8,8,8,3,8
105:0,0,0,0,0,0,0,0,0,0
104:Courier|12||0-0-0|0-0-0|-1--1--1|0-0-255|192-192-192|-1--1--1
```

Calibration Output Files: supply_side_calibration.out

```
:COMSYS After 139723 simulations
:COMSYS Best payoff is -591.032
:COMSYS Normally terminated optimization
:OPTIMIZER=Powell
:SENSITIVITY=Off
:MULTIPLE_START=RRandom
:RANDOM_NUMBER=Default
:OUTPUT_LEVEL=On
:TRACE=Off
:MAX_ITERATIONS=70000
:SIMS_MAX=200
:RESTART_MAX=700
:PASS_LIMIT=2
:FRACTIONAL_TOLERANCE=0.0003
:TOLERANCE_MULTIPLIER=21
:ABSOLUTE_TOLERANCE=1
:SCALE_ABSOLUTE=1
:VECTOR_POINTS=25
:MCLIMIT=0
:MCJUMP=0.05
:MCBURNIN=0
:MCDELTA=0.0001
:MCTEMP=1
:MCNCHAINS=2
:MCUPDATEPAIRS=2
:MCSCHEDULE=0
:MCOUTLIER=0.05
:MCXOVER=0.2
:MCCOOLING=1000
:MCINITMETHOD=0
:MCPAYOFFTYPE=0
:MCGAMMA=1
:MCRECORD=0
:MCKNN=0
:MCEPSILON=0.01
:MCFTEMP=1
100000 <= Maximum Mining Unit Cost = 245569  <= 1e+06
0.0015 <= Cost Of Energy = 0.00171387  <= 0.0048
0.05 <= Minimum Utilization = 0.05  <= 0.5
2 <= Sensitivity of Capacity Utilization to Costs =
16.2644  <= 32
0.0125 <= Sensitivity of Miner Exit to ROI = 0.250439  <=
2
0.0125 <= Sensitivity of Miners to ROI = 0.225785  <= 2
700 <= Residence Time = 2544.75  <= 3650
0 <= Discount Rate For Mining Per Annum = 0.125  <= 0.125
0.03 <= Reference ROI Per Annum = 0.130689  <= 0.15
7 <= Time To Adjust Number of Miners = 10.2485  <= 30
15 <= Time To Adjust ROI Perception = 44.2409  <= 90
```

```
1 <= Time to Adjust Capacity Utilization = 17.1221  <= 45
700 <= Average Life of Mining Hardware = 1565.5  <= 1825
```

Calibration Output Files: demand_side_calibration.out

```
:COMSYS After 902137 simulations
:COMSYS Best payoff is -1769.49
:COMSYS Normally terminated optimization
:OPTIMIZER=Powell
:SENSITIVITY=Off
:MULTIPLE_START=RRandom
:RANDOM_NUMBER=Mersenne
:OUTPUT_LEVEL=On
:TRACE=Off
:MAX_ITERATIONS=70000
:SIMS_MAX=500
:RESTART_MAX=7000
:PASS_LIMIT=2
:FRACTIONAL_TOLERANCE=0.0003
:TOLERANCE_MULTIPLIER=21
:ABSOLUTE_TOLERANCE=1
:SCALE_ABSOLUTE=1
:VECTOR_POINTS=25
:MCLIMIT=0
:MCJUMP=0.05
:MCBURNIN=0
:MCDELTA=0.0001
:MCTEMP=1
:MCNCHAINS=2
:MCUPDATEPAIRS=2
:MCSCHEDULE=0
:MCOUTLIER=0.05
:MCXOVER=0.2
:MCCOOLING=1000
:MCINITMETHOD=0
:MCPAYOFFTYPE=0
:MCGAMMA=1
:MCRECORD=0
:MCKNN=0
:MCEPSILON=0.01
:MCFTEMP=1
0.1 <= Sensitivity of Momentum to Shortterm return =
3.56546  <= 4
0.001 <= Sensitivity of Price to Demand Supply Balance =
0.001  <= 4
0.001 <= Sensitivity of User Entry to Long Term
Trends[Chartist] = 0.001  <= 2
0.5 <= Sensitivity of User Entry to Long Term
Trends[Fundamentalist] = 4  <= 4
0.01 <= Sensitivity of User Entry to Long Term
Trends[Transacter] = 0.80105  <= 1
180 <= Forward Looking Time Horizon = 1004.19  <= 1095
1 <= Time to Close the Gap Between Desired and Current =
122.714  <= 180
0.001 <= BTC Price Adjustment Time = 1.15944  <= 45
```

```
0.0001 <= Time for Miners to Supply = 0.0001  <= 30
1 <= User Entry Adjustment Time = 256.165  <= 365
0.01 <= Pressure Sensitivity to Price Gap = 0.640741  <=
4
0.001 <= Short Term Reference Return = 0.424236  <= 1
5 <= Short Term Investment Horizon = 36.9718  <= 90
0.5 <= Sensitivity of User Entry to Short Term
Trends[Chartist] = 2.18508  <= 4
0.001 <= Sensitivity of User Entry to Short Term
Trends[Fundamentalist] = 0.001  <= 1
0.01 <= Sensitivity of User Entry to Short Term
Trends[Transacter] = 0.620093  <= 1
0.1 <= Sensitivity of User Exit to Long Term
Trends[Chartist] = 2  <= 2
0.25 <= Sensitivity of User Exit to Long Term
Trends[Fundamentalist] = 0.281271  <= 4
0.01 <= Sensitivity of User Exit to Long Term
Trends[Transacter] = 0.01  <= 1
0.25 <= Sensitivity of User Exit to Short Term
Trends[Chartist] = 2.67397  <= 4
0.001 <= Sensitivity of User Exit to Short Term
Trends[Fundamentalist] = 0.001  <= 1
0.01 <= Sensitivity of User Exit to Short Term
Trends[Transacter] = 0.0160989  <= 1
0.0001 <= Sensitivity to Longterm Pressure[Chartist] =
0.0001  <= 2
0.5 <= Sensitivity to Longterm Pressure[Fundamentalist] =
0.521562  <= 4
0.0001 <= Sensitivity to Longterm Pressure[Transacter] =
0.0001  <= 1
0.5 <= Sensitivity to Momentum Pressure[Chartist] = 0.5
<= 8
0.1 <= Sensitivity to Momentum Pressure[Fundamentalist] =
4  <= 4
0.01 <= Sensitivity to Momentum Pressure[Transacter] =
0.0450337  <= 1
1 <= Maximum Holding per User[Chartist] = 1  <= 1000
1 <= Maximum Holding per User[Fundamentalist] = 972.548
<= 1000
1 <= Maximum Holding per User[Transacter] = 1121.76  <=
2000
7 <= User Residence Time[Chartist] = 16.6181  <= 90
180 <= User Residence Time[Fundamentalist] = 1445.22  <=
3650
90 <= User Residence Time[Transacter] = 1605.36  <= 3650
0 <= Proportion of Dedicated Users[Chartist] = 0.0397101
<= 0.2
0 <= Proportion of Dedicated Users[Fundamentalist] =
0.054395  <= 0.2
0 <= Proportion of Dedicated Users[Transacter] = 0.198768
<= 0.2
```

```
0 <= Reference ROI per Annum for User[Chartist] = 3.0276
<= 5
0 <= Reference ROI per Annum for User[Fundamentalist] =
4.51136  <= 5
0 <= Reference ROI per Annum for User[Transacter] =
3.40378  <= 5
7 <= Short Trend Average Time = 7  <= 45
90 <= Long Trend Average Time = 718.166  <= 730
1e-08 <= Minimum Holding of BTC Allowed = 0.242103  <= 1
```