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Bitcoinomics 101: principles of the Bitcoin market

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Abstract

Drawing on some some early literature in economics we develop a framework that assists the consideration of Bitcoin as a novel economic good. We highlight an essential tension between scarcity and concentration as having an overarching impact on Bitcoin's value. In conjunction with the structural features of its blockchain and consensus protocol, as instantiated by the mechanism of its code, the role of provisioning for future demand and production places a keener emphasis on the role of inventory management. This creates an interesting dynamic in Bitcoin between its structurally regulated supply and organic reservation demand for bitcoins by miners on the one hand and its broader market demand on the other. Understanding the features of this dynamic as a foundation for Bitcoin gives us some simple insights on its price path.

The impetus to begin work on this project came from an interesting conversation the author had with an individual on Twitter with the anonymous account handle, @ParabolicTrav. The author thanks him for his generosity of time and ready willingness to discuss ideas.
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1 Introduction

1.1 Scarcity & Concentration

Besides serving as a decentralized peer-to-peer method of payment, a key narrative for Bitcoin has been that of casting it as 'digital gold'. The idea is that, like gold, it too represents an asset class that derives its inherent value from verifiable *scarcity*. And this provable scarcity makes Bitcoin a natural long-term store of value.[1] Yet there are aspects of Bitcoin that make it fundamentally different to gold, not merely as a financial asset[2] but more fundamentally as a unique kind of good in economics.

Scarcity of a good manifests itself as inelastic supply, and the Bitcoin network features a perfectly inelastic long-run supply of bitcoins.[3] As the stock of bitcoins approaches their fixed long-term value of 21 million and their flow per unit of time approaches 0, the ratio of stock-to-flow explodes well past that of any other commodity we ordinarily view as scarce.[4] When a good has an entirely inflexible supply, elementary economics suggests that its market value depends on just one degree of freedom, exaggerating the impact of variations in demand on its price. Indeed, if bitcoins are to be used as a digitally-native method of payment, their long-run velocity would depend entirely on their growth in relative value to currencies and on the willingness and ability of its holders to use it more broadly as a medium of transaction. When supply is fixed for a good, their stocks, holdings, and inventories play a crucial role, as indeed they do with Bitcoin, and the role of demand is exacerbated yet more emphatically.

While understanding the relevance of scarcity to Bitcoin's perceived value and contrasting this with other commodities like gold or silver – or indeed with other currencies – is interesting, it detracts from at least two essential aspects of interest to the basic economic principles of Bitcoin. The first of these is simply that, while scarcity is indeed important, its import comes from an understanding of how the *relative* elasticity of demand for the good evolves over the course of a business cycle and how this impacts its price path.

Second, it sidesteps the issue of *concentration* in the holdings of the overall stock of a good over time. Concentration can result from two main sources. It may be a result of consumers who buy and hold bitcoins for the long term. The elasticity of supply from such consumers is much lower than the average consumer, which is to say that they are less responsive to variations in the exchange rate of bitcoin. A study conducted by *Unchained Capital,* a Bitcoin financial services firm, resulted in a vivid illustration of the relative age of bitcoins since they were last used in a transaction. It shows a steady increase in the set of bitcoins that have been unspent for a period greater than 5 years, although many in this category may arguably be permanently lost). It also shows a propensity for bitcoins to be held for progressively longer periods of time.[5] Concentration can also be a result of the

[1] Bouoiyour, et al. (2018) tests this relationship between gold and Bitcoin empirically, finding an incipient complementary effect.

[2] On this comparison, see the interesting research effort by Dyhrberg (2016) and Baur et al. (2018).

[3] Throughout this paper, the word Bitcoin refers to the Bitcoin network and overall Bitcoin 'ecosystem', whereas the word bitcoins refers to the digital tokens it creates.

[4] The last bitcoin is expected to be mined in the year 2140, and roughly 18.17 million have already been mined as of mid-January, 2020. It is also estimated that between three and four million bitcoins may have been permanently lost.

[5] The illustration can be found at this address: https://plot.ly/~unchained/37/bitcoin-utxo-age-

investment horizons of miners, especially when their decisions on production result in the addition of large quantities of bitcoins to their inventories.

A key result of variations in concentration is to create concomitant variations in the *perceived* level of scarcity. Excess concentration reduces the velocity of bitcoins in markets, since goods that have a lower stock can *appear* less scarce than those with higher stocks provided they have a higher velocity. This brings the role of inventories yet more front and center.

It is instructive to briefly examine the importance of this idea of concentration with respect to gold – the default commodity of reference for Bitcoin. In 2018 the World Gold Council estimated that the central banks of the world had stockpiled almost $34,000$ tonnes of gold. It also estimated that households in India alone held roughly $25,000$ tonnes. But concentrated holdings in gold aren't a recent phenomenon. Well before Roosevelt issued Executive Order 6102 in 1933 – prohibiting private ownership of gold and requiring the sale of privately held stocks to the government at a significant discount to the world price – the Federal Reserve banks had already started accumulating most of the stock. By some estimates, owing largely to European payments during World War I, the Federal Reserve owned three-fourths of the country's total stock and about 40 per cent of the world's total supply of gold *before* the order was issued.[6]

However, it is in examining the *interplay* of gold's scarcity with the concentration of its holdings that a few interesting observations emerge. Since the very outset of its discovery in the Paleolithic gold has held social value on account of its association with prestige, wealth, and power. As Schoenberger (2010) argues, it is from the deliberate accumulation of its stock that social and political power has been built and then sustained since antiquity, and it is with the careful management of its circulation that such power has then been transmuted into economic power and the expansion of sociopolitical bases of power.

In other words, concentration and scarcity are two sides of the same coin: There is little use of building a concentrated inventory of a scarce good if that inventory cannot then be transmuted between real social, economic, and political value; there is also little use in having a scarce good as a subjective medium of value if its concentration is immutable. There are, after all, elements on the periodic table that are far rarer than gold, but are worthless beyond the confines of a laboratory because their stocks cannot be transmuted between wider circulation and concentrated inventories in any meaningful way.

In this paper, we look at some simple economic theory that helps provide a useful framework for considering these issues systematically for Bitcoin. Bitcoin's emphasis on verifiable scarcity and transactional utility makes it a good and a market unlike any other for students of economics, giving us a singular opportunity to reacquaint ourselves with some fundamental principles in economics.

1.2 A Bitcoin Refresher

Since there is a now a wealth of literature on Bitcoin and its blockchain, we only need a brief refresher on some fundamental aspects of Bitcoin relevant to this analysis.

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distribution/#/

[6] See Lockhart (1924) for an especially interesting analysis of this era.

The Bitcoin blockchain is secured by a consensus algorithm called proof of work. (Nakamoto, 2008) Bitcoin's miners competitively solve a computationally costly problem in order to earn the right to propose a valid block of transactions; the successful miner provides proof of costly work done to other nodes on the network, who can then verify this claim relatively cheaply. The miner then appends its block of collated transactions to the last block on an extant chain of blocks that are all serially interlinked, extending the overall height of the blockchain; the current state of the blockchain compactly includes an immutable cumulative record of all transactions ever made from the very beginning.

The cost of computation is determined by a number of interrelated factors. To understand these links it is useful to appreciate that the metric used to measure a miner's effort to solve the computational problem (comprising using the SHA-256 hashing function twice, which essentially compresses arbitrary sized inputs into a fixed-length output) is hashes per second or $^{h}/_{s}$. A miner's intrinsic competitive ability is therefore determined by the overall *hashrate* that their hardware can muster. Since Bitcoin first came into existence the computational efforts by its miners has increased exponentially: In January of 2009 the network's cumulative hashing power, deployed by all miners, stood at around 5 megahashes per second or $5,000,000$ $^{h}/_{s}$; by June 2019 the network had nearly 67 exahashes per second or 67 x 10^{18} $^{h}/_{s}$.

A key reason for this growth is that the *difficulty* of the cryptographic problem is dynamically adjusted in order to achieve a 10-minute per block average rate of generation; 10 minutes was selected as the ideal duration between blocks to allow sufficient time to elapse between newly proposed blocks so that the most recent block has time to propagate throughout the Bitcoin network and for its cryptographic signature to be validated across a vast majority of the nodes. Thus, difficulty and hashrate move together, though short-term deviations do occur since the difficulty level is only adjusted every 2016 blocks.

Naturally, this scale of costly work by miners on the Bitcoin network must be adequately incentivized, and in Bitcoin this is accomplished with the *block reward* a miner receives for finding a valid block, comprising a predetermined number of bitcoins per block. A miner's interest in the Bitcoin network is, therefore, to derive an income that is largely independent of the market value of the transactions that each block represents.[7]

The panels in *Figure 1* present a visual overview of some of these key metrics over time.

While evidence of price manipulation in Bitcoin is compelling[8], it is also true that these and other fundamental aspects of Bitcoin's basic design exert *structural* effects on its market price. This is especially evident in relation to the market supply of bitcoins. Unlike most other goods we are accustomed to examining, Bitcoin has some unique features that govern its supply that make it an especially interesting case.[9]

[7] This is not quite accurate since a much smaller and variable transaction fee can also be paid to miners. Its level is conditioned on the features of a given transaction (such as its value, time sensitivity, dependence on other content, and so on). Transaction fees are largely designed to counter the level of network externalities from congestion and latency that are extant across in the network at the time.

[8] See Gandal et al. (2018), for example.

[9] Perhaps the closest analogy is one of competitive extraction of a natural resource, such as crude, from a reservoir of fixed size. An oil well's life cycle comprises three distinct stages during extraction, each

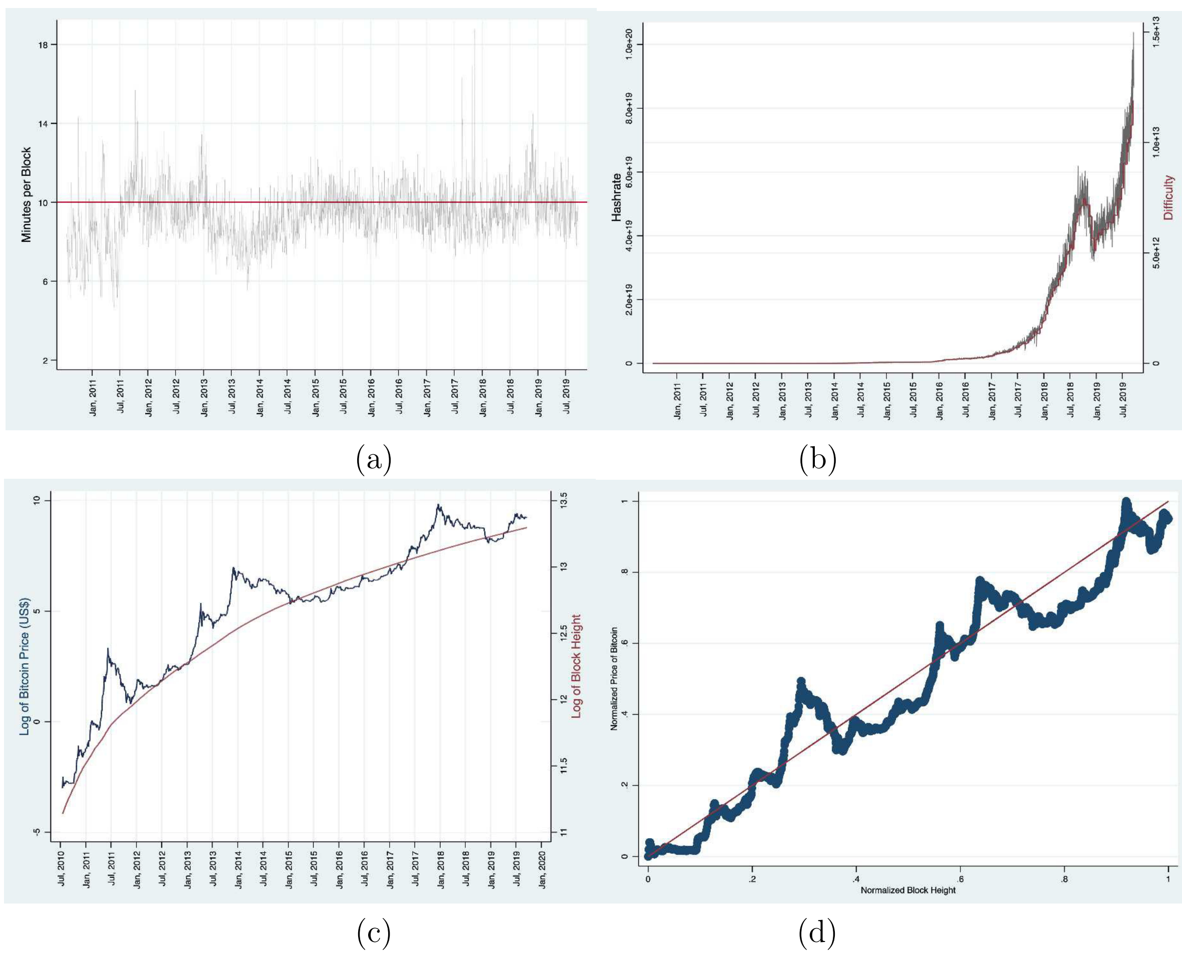

Figure 1: Some key metrics in Bitcoin. (a) The network targets 10-minutes for the *time per block*, though deviations from this target occur as *hashrate* fluctuates between the adjustment period for the network's *difficulty*. (b) Thus, hashrate and difficulty move together over time. (c) Bitcoin's *market price* has followed its *block height*, which can be seen as a measure of the network's use by miners and users. (d) This can be seen as a price elasticity for use of the network.

First, since the maximum number of bitcoins in circulation is capped at 21 million mining is an intensely competitive activity, in that each miner increases its chances of acquiring a larger portion of the fixed available supply by investing in more computing power and by joining a group of miners, or a mining pool, to ensure that they are party to a coalition of miners that has a higher probability of frequent success. As the difficulty in the system increases, and the requisite hashing power necessary to successfully mine blocks increases commensurately, the relevance of this imperative grows in lock step.

Second, the block reward halves every $210,000$ blocks; it began at 50 bitcoins per block at Bitcoin's inception in 2009 and has halved twice to the current level of 12.5 bitcoins per block. This creates two effects: an increasing sense of scarcity in the long term through a stock-to-flow ratio that keeps expanding and a periodic realignment of the investment efforts by miners as the next halving date becomes more apparent.

Finally, the most important costs of mining are not just the fixed costs of the mining 'rigs' and the variable cost of the energy used to run them efficiently, but also a wildly variable regulatory environment that creates an unpredictable regulatory burden. As governments begin to see Bitcoin as a clearer threat to their national currencies and legacy transfer systems, and as the speculative frenzy of the market inspires regulatory input on behalf of consumers, the risk of imminent rule changes that can serve to disrupt the Bitcoin ecosystem in the short term begin to impose real costs.[10]

Together these features have the effect of coupling the supply of bitcoins – from block rewards and from miner inventories – with its market price. Miners must provision in the present for their operational and capital expenditures in the future, as well as hedge against regulatory and systemic risks that are likely to arise. This has two interlinked effects which we shall examine below: the responsiveness of supply and periodicity in the market price.

2 An analytic modeling exercise

2.1 Baseline equilibrium

Let us develop some insights by beginning with first principles. Consider the simplest of situations where the miner's quantity of bitcoins supplied to the market is determined by $Q^s = a + bP + \psi W$, where P is the market price of a bitcoin and W is the block reward that the miner retains as its provisioning capital. Thus, $0 \leq \psi \leq 1$. Assume demand can be

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constituting a higher level of difficulty than the stage before in terms of the ease of access to the crude, and representing a higher marginal cost per barrel recovered. To prevent wasteful competitive extraction under the rule of capture, alternate institutional arrangements in oil extraction include unitization and prorationing. Unitization of fields is a mechanism similar in effect to mining pools, in that well operators combine their fields and extract collaboratively in order to reduce the waste from competitive extraction, but crucially in the case of Bitcoin, there are at least mining pools of varying size, and so unitization is far from complete. See Khoury (169) for a review of the various institutional mechanisms in the oil industry, in addition to other useful specifics.

[10] The threat of software changes that result in forks off the main blockchain are yet another form of risk that miners routinely contend with; their decisions on whether to devote part of their computational resources, if any, to mine on the new blockchain, or indeed other cryptocurrencies, is an important aspect that we do not consider in this paper.

expressed as $Q^d = m - nP + \nu R$, where R is a regulatory burden that impacts the ability of consumers to enter and exit the Bitcoin market and $\nu \leq 0$.[11]

In equilibrium,

$$m - nP + \nu R = a + bP + \psi W \qquad (1)$$

or, equivalently,

$$P = {}^{(m+\nu R-a-\psi W)}/_{b+n} \qquad (2).$$

The comparative statics suggest that

$$^{dP^*}/_{dW} = -\tfrac{\psi}{(b+n)} \qquad (3a),$$

and

$$^{dP^*}/_{dR} = \tfrac{\nu}{(b+n)} \qquad (3b).$$

We could re-examine this result as more directly a production problem for the miners by considering $Q^s = Q^s(E, R)$, where E is the resource cost for mining and R is the regulatory burden for production. Further, imagine that the cost of production is $c = rE + \kappa R$.

We can now explicitly introduce the provisioning capital, J, requirement by examining the optimization problem,

$$\min c = rE + \kappa R \text{ s.t. } Q^s(E, R) \geq J \qquad (4).$$

Alternatively,

$$\max \mathit{\Gamma} = -(rE + \kappa R) + \lambda \{Q^s(E, R) - J\} \qquad (5),$$

where λ can loosely be interpreted as a cost benefit to the miner from an incremental change in the excess bitcoins it supplies to the market, over the amount that it sets aside for provisioning.

The first-order conditions yield,

$$\tfrac{\partial \Gamma}{\partial E} = -r + \lambda Q^s_E \leq 0;\ E \geq 0 \text{ and } E(-r + \lambda Q^s_E) = 0 \qquad (6a);$$

$$\tfrac{\partial \Gamma}{\partial R} = -\kappa + \lambda Q^s_R \leq 0;\ R \geq 0 \text{ and } R(-\kappa + \lambda Q^s_R) = 0 \qquad (6b);$$

and

$$\tfrac{\partial \Gamma}{\partial \lambda} = \{Q^s(E, R) - W\} \geq 0;\ \lambda \geq 0 \text{ and } \lambda \{Q^s(E, R) - J\} = 0 \qquad (6c).$$

Since the miner must make positive expenditures – on energy and on ameliorating the regulatory burden – we can rearrange the first two conditions to give us the result

$$\lambda = \tfrac{r}{Q^s_E} = \tfrac{\kappa}{Q^s_R} > 0 \qquad (7).$$

The third condition would then suggest that, in competitive equilibrium, the quantity supplied would be equal the provisioning amount,

$$Q^s(E, R) = J \qquad (8).$$

As we might have expected, the ability that miners have to retain bitcoins for provisioning in their inventories depends directly on the competitiveness of the mining market.

[11] The functional form for demand here is a simplification. In reality, the demand for bitcoins is very likely not as straightforward. As a speculative asset its demand is arguably upward sloping for at least some of its consumers. Conversely, the effect of price in the short term has arguably been muted by its long-term holders (colloquially called the 'HODLers') who have resisted selling even in the face of repeated bearish cycles. See the work cited in footnote 5 above.

2.2 Off-equilibrium behavior

However, the interesting features of provisioning are swept aside when the market is in equilibrium. Specifically, we are interested in what happens when the miners must provision for the next period using some part of their inventories and the block rewards earned in the current period.

While the price of a bitcoin at time t affects the miners' efforts in that period, their decision on how many bitcoins to supply to the market is only made in $t+1$. For a market-clearing condition using a similar functional form as above, we would now have $Q_t^s = bP_{t-1} - a$ and $Q_t^d = m - nP_t$.

The reduced first-order difference non-homogeneous equation

$$P_{t+1} + {}^{b}\!/_{n} P_t = \tfrac{a+m}{n} \qquad (9)$$

can be solved for the time path $P(t)$ for some initial value of price, P_0. This yields

$$P_t = \hat{P} + \left(P_0 - \hat{P}\right)\left(-\tfrac{b}{n}\right)^t \qquad (10),$$

where $\hat{P} = \left(\frac{a+m}{b+n}\right)$ represents a stationary equilibrium value and $\left(P_0 - \hat{P}\right)$ suggests the directions of the off-equilibrium deviations in price.

3 Analysis

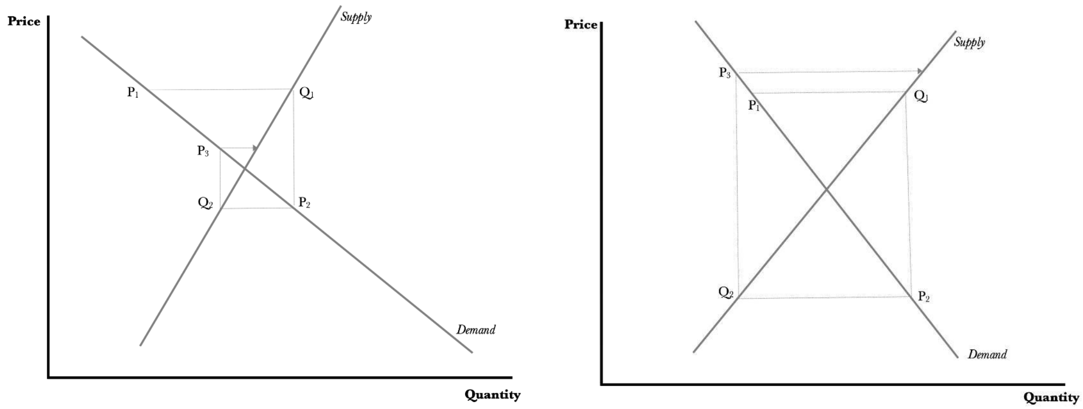
In our simple model inspired by the Bitcoin market we have highlighted the relevance of two aspects. Besides emphasizing the idea of retained production and the inventory of miners, the term $\left(\frac{b}{n}\right)$ on the right-hand side of equation (10) also suggests a key role for the *relative* elasticities of supply and demand. In order to examine the combined impact of these effects along the price path it is worthwhile considering a framework that aids in the grounding of the entire analysis. For this purpose the cobweb supply model is useful and illustrative.

The model expressly considers the effect of the relative elasticities in a dynamic path for price and quantity adjustments in a market. Moreover, since the cobweb supply model was specifically inspired by agricultural commodity markets where time lags were common in the response of supply to prevailing market conditions, it also considers the effect that such adjustments exert on the overall price path of a good.

3.1 Cobweb Supply

Kaldor (1934) attributes the model to a monograph written in German by Schultz (1930), where the primary application is to the sugar market. In a seminal article on the topic, Ezekiel (1938) provides a useful review of the literature that the model initially inspired; he considers a number of interesting effects in price dynamics that obtain from lags in supply that have a duration greater than one period (specifically, two- and three-year lags) that can reproduce a variety of markets that exhibit cyclicality in price and quantity.

The panels in *Figure 2* depict the two price paths that the cobweb supply model essentially describes, depending on whether supply is relatively more or less elastic than demand.



(a) (b)

Figure 2: Cobweb Supply: Convergent (a) and Divergent (b) Price Paths

Panel (a) shows a *convergent* price path and panel (b) depicts a *divergent* path for price. The associated story for either case begins with a prevailing market price of P_1 that inspires a lagged response in quantity to Q_1, which then serves to depress prices to P_2, and so forth. The price path becomes explosive when supply is relatively more elastic than demand and it can dampen towards the static equilibrium if supply is relatively more inelastic. It is easy to see that one might also construct a situation of a *volatile* price path around the traditional equilibrium that neither converges towards it nor diverges away from it when the relative elasticities are comparable.

A broader point to note is that the cobweb model gathered attention because it addressed the process of adjustment in markets where the static equilibrium is less insightful. For a market like Bitcoin, where a true underlying equilibrium price is a particularly unhelpful concept, the cobweb model gives us a very helpful analytic benchmark. Unlike most other goods, with Bitcoin the dynamics of demand and especially of supply are rather more convoluted for the reasons mentioned above.

Kaldor and Ezekiel both critiqued the static view of a market equilibrium and its associated price, expressing two key essential concerns: 1. Instances where there are exogenous reasons for a delay in the response of price to changes in the factors that affect equilibrium; what we might call *asynchronicity*, and 2. Situations where more than one price might abide by the conditions of a static market equilibrium; we can refer to this as a problem of *multiplicity*.

In Kaldor's analysis of these situations, using the cobweb supply model, he proposed considering markets that are characterized by 'completely discontinuous' quantity adjustments in their response to changes in price. In section 3.2, we shall consider the significance of these factors in the context of Bitcoin by placing emphasis on the role that inventories play more directly in the behavior of miners.

In the years that followed its introduction to broader awareness, the conspicuous absence of expectations in the cobweb supply model was highlighted. Nerlove (1958) provides an interesting discussion of this point by placing his argument in contrast to Åkerman (1957), which doubts the conclusions of the cobweb model for agricultural products. Ferguson (1960) suggests the role of entrepreneurial expectations within a simplified general equilibrium model. For a broad review Pashigian (1970) is instructive; it suggests how price cycles could in fact exist in the presence of adaptive expectations depending on the error in recent and past forecasts.

3.2 Inventory

The issue of production lags and its effect on price dynamics remains a matter of research beyond the cobweb supply model, especially when inventories play a pivotal role. The central idea that drives research on the role of inventories is the production-smoothing model, which simply suggests that, when faced with variable demand and convex costs, firms use inventories in order to smooth variability in production. This model, however, does not explain the empirical fact that inventories are rarely used to smooth production and are in fact pro-cyclical. Alternate explanations offer amendments to this model. Wen (2011) suggests that inventories may be used for a stockout-avoidance objective. Particularly pertinent to the case of Bitcoin, where the halving of block rewards acts as a programmed rebasing of the production decisions of miners, is the suggestion in Blinder (1986) that inventories may be used for intertemporal substitution possibilities in production when production is characterized by cost shocks.

Delayed responses by suppliers, a key feature of the cobweb model, have been examined as well. For instance, in studying the effects of production lags of varying lengths on price in a model that also incorporates inventory with an associated holding cost, Lai and Pauly (1992) proves some interesting propositions. As one would perhaps intuit, they establish that firms with higher inventories produce less; further, in a setting with higher-duration production lags — where the product can be at different stages of completion in the production cycle — they go on to show that volatility in prices serves as a buffer against adjustments in sales and that this volatility is more keenly linked to goods in the latter stages of the production cycle. Kryvtsov and Midrigan (2013) shows that when firms face sticky costs they have a greater incentive to build up short-term inventories that they can then dispose of in future periods when their markups may have declined making the value of their inventories decrease as a result.

3.3 Reservation Demand

While Bitcoin, by design, has a textbook perfectly inelastic long-run supply it features a schedule in its codebase that instantiates a decelerating rate of growth in output owing to the halving of the block reward every $210,000$ blocks. This places miners in a situation where they can forecast, with a relatively high degree of accuracy, exactly when the block reward will halve. They can do this by seeing the current block height and comparing it to the dynamic adjustments between the overall hashrate of the miners and the level of difficulty set by the Bitcoin network. The block height for Bitcoin's blockchain as of mid-January, 2020 stood at just over $613,000$. This suggests that the next halving date for Bitcoin is expected to be around the middle of May, 2020.

Since this halving is entirely independent of market demand – which is highly variable – miners must provision for future operations through retained profit or by maintaining an inventory of bitcoins which they can sell during times when a lower market price constricts their margins. This has two interrelated effects: The schedule makes asynchronicity a reified feature of Bitcoin and it does this because it inspires a natural *reservation demand* for bitcoins among the miners, further adding to the volatility of demand.[12] Every successive halving of the block reward reduces the rate at which bitcoins can be accumulated for this purpose, which serves to exacerbate reservation demand for mined bitcoins prior to the halving date, which, though known approximately, is not known precisely until it approaches much closer. The propensity to store bitcoins is thus partly inspired by speculators and steadfast believers of Bitcoin's unique merits in the market, but partly also because of reservation demand for bitcoins that arises from Bitcoin's structurally induced asynchronicity.

The presence of a reservation demand may, of course, serve to exacerbate the convergent or divergent time paths for price that the cobweb supply model suggests; note that this is for reasons pertaining to decisions on inventory management alone, and not directly a result of the excess demand it creates. To see this point algebraically, one need only consider a simple model. Observe that the equilibrium price, P^*, for a market with supply $Q^s = a + bP$ and demand $Q^d = m + nP$, is simply given by ${}^{(m-a)}/_{(b-n)}$. With reservation demand, Q^r, as an additional source for demand in Bitcoin, we then have a time-varying price:

$$\hat{P} = {}^{dp}/_{dt} = \gamma Q^r, \text{ where } \gamma > 0.$$

The condition for $\hat{P}$ to converge to the equilibrium price can be expressed as

$$\hat{P} = \gamma(Q^d - Q^s) = \gamma[(m + nP) - (a + bP)] \qquad (11).$$

The solution in terms of a complementary function and particular integral gives

$$\hat{P} = e^{-(\gamma(b-n)dt)} \left(C + \int(\gamma(m-a)e^{\int \gamma(b-n)dt)}\right) = Ce^{-\gamma(b-n)t} + {}^{((m-a))}/_{(b-n))} \qquad (12).$$

Contrasting from the price, P^0, at $t = 0$, the time path with reservation demand can be written as

$$\hat{P} = (P^0 - P^*)\, e^{-\gamma(b-n)t} + P^* \qquad (13).$$

So, in the limit, $\hat{P}$ converges to P^* so long as the term $(b-n)$ is greater than 0, suggesting that such a convergence is assured so long as the demand for bitcoins isn't positively-sloped, with $n > 0$.[13]

Capital expenditures by miners has grown by several orders of magnitude since 2009, bringing more hashpower into the system and, commensurately, requiring the difficulty level

[12]Naturally, miners aren't obliged to declare their strategies on the mined bitcoin that they retain as inventory. However, since *Hut 8*, a relatively smaller Canadian miner in Bitcoin, is the largest publicly traded miner, we have the benefit of examining their financial statements. During the bull market of 2017, when the price of bitcoin rose roughly 1500%, *Hut 8* mined 5,592 bitcoins and sold 1,719 while using a further 1,342 to finance capital purchases; during the bear market of 2018, which saw the price of bitcoin fall by roughly 80%, *Hut 8* mined 5,221 bitcoins and sold 3,168 using none for capital expenditures. URL: https://hut8mining.com/wp-content/uploads/2019/08/Hut-8-FS-Q2-2019.pdf. Accessed September, 2019.

[13]We exclude the cases where Bitcoin might be considered a Veblen good (a key attraction is anonymity among the transactors!) or even a speculative asset in the long run.

to be raised by several orders of magnitude. This has raised the marginal cost of bitcoins to a level where mining bitcoins is no longer feasible by amateur participants on the Bitcoin network. Paradoxically, it is when the price of bitcoin is below its marginal cost of production that miners are most inclined to sell from reserves, potentially further dousing the market price.[14] Since the largest component of variable input costs come from the price of electricity and the risk of adverse regulations, miners also engage in geographical arbitrage in locating their operations.

3.4 Cycles

There is a rather large literature in economics on the subject of business cycles inspired by inventories. It would be fair to say that a seminal contribution was on the classification of business cycles presented in Schumpeter (1939).

Schumpeter, who named the cycles after those who originally proposed them, suggested that business cycles were motivated by the interplay of innovations and entrepreneurship. Since innovations usually cluster around one another, there are natural variations in the rate at which innovations can exert their influence over various aspects of economic activity. Similarly, the attendant efforts of entrepreneurs to benefit from and counter the effects of these swings in innovations also vary according to their abilities.

The cycle of longest duration, spanning several decades – roughly 50 years – are the Kondratieff waves; Juglar waves last less than a decade, and Kitchin waves last less than four years. Schumpeter further suggested that the waves would align in such a manner that their relative peaks and troughs would coincide when adjusted for their frequencies. The precise length of the cycles is less relevant since a raft of papers followed Schumpeter's work claiming that the data did not quite exhibit the cyclicality that he had claimed.[15]

Cyclicality *is* especially evident in Bitcoin. At the most basic level, competition across miners in Bitcoin is temporal as well as spatial in nature. Its temporal dimension depends on the length of the blockchain, or the block height, which directly determines the date when the block reward next halves. Its spatial dimension depends on the requisite hashrate, which increases as a function of the hashrate that other miners deploy at any given point in time.

Since the block reward halves every $210,000$ blocks and the system targets an average rate of 10-minutes per block, assuming a year constitutes $525,600$ minutes, a halving of the block reward should occur once every 4 years. This structural aspect, reified in Bitcoin's code, interacts with the incentives of miners and the overall demand for bitcoins in the market. In practice, the mean time between blocks since July 2010 to September 2019 has been 9.35 minutes, making the halving frequency closer to 3 years and 9 months.[16] Nevertheless, we should expect a cyclical adjustment of the behavior of miners that coincides roughly with this duration.

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[14] According to a study by *Coinshares Research* published in November 2018 the estimated marginal cost of a bitcoin was approximately \$6,500. (Bendiksen et al., 2018) In that month the market price of bitcoin, which had been hovering around that level for several weeks, precipitously declined over a matter of days to a low of roughly \$3,100.

[15] See, for example, Kuznets (1940) and Fels (1952).

[16] The first halving occurred after a little short of 3 years and 11 months. The second halving took a little over 3 years and 7 months.

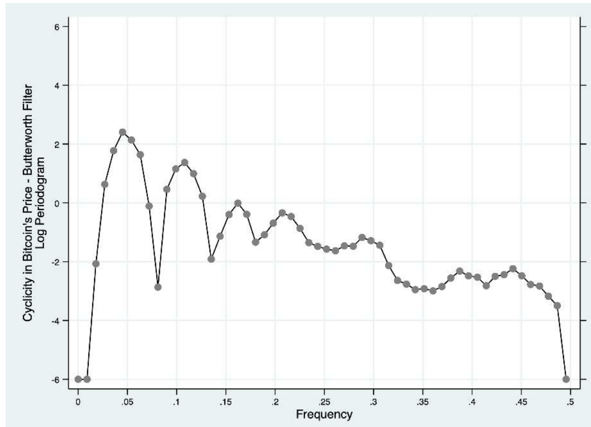

Figure 3: Bitcoin's spectral density function

Figure 3 presents the spectral density function for Bitcoin's monthly price after filtering the data for its cyclical and trend components. The peak at a value of 0.045 suggests the presence of a cyclical component in the data at a little less than 2 years, suggesting a shorter cycle a play.

Thus, empirically the most evident cycle length for Bitcoin's market price is positioned roughly midway between the cycle length that the structural characteristics of Bitcoin would suggest. Reservation demand for bitcoins from miners and their overall approach to inventory management cannot alone be expected to explain the discrepancy between these cycles. However it does hint at an interesting effect: Inventories oscillate around structural aspects as well as market effects that extend beyond the role of miners alone (indeed, panel (c) of *Figure 1* suggests this effect vividly). Nurske (1954), for example, proposes how the flows of inventories can oscillate around the ideal stocks of inventories that firms intend to maintain, creating cycles of varying lengths.

4 Concluding Remarks

It is rare that we get the opportunity in economics to consider a fundamentally novel good that requires a reconsideration or restatement of basic economic theory. Most often this novelty is skin deep. But when it *is* genuine, it suggests exciting new avenues for growth in the field. That Bitcoin represents such an opportunity is a proposition that is becoming increasingly hard to refute. Besides its intentions to rethink money and monetary policy, Bitcoin even has fundamental implications for contract theory and the theory of the firm.[17]

Much of those claims may turn out to be largely theoretical in the end. However, the way in which it is structured and has operated over the course of the first decade of its existence suggests that it has interesting implications for considering its essential nature as a market. Thankfully, as we have seen in this paper, no new models are needed to evaluate Bitcoin; virtually all the literature this paper relies on is drawn from the history of economics. What

[17]See Ammous (2018) on the former and Goorha (2018) on the latter.

is needed, however, is a greater willingness to reconsider their inherent merit for the case of Bitcoin.

References

[1] Åkerman, G. (1957) "The Cobweb Theorem: A Reconsideration" *The Quarterly Journal of Economics* **71**(1), 151-160.

[2] Ammous, S. (2018). *The Bitcoin Standard: The Decentralized Alternative to Central Banking.* Wiley.

[3] Baur, D.G.; T. Dimpfl and K. Kuck (2018) "Bitcoin, gold and the US dollar – A replication and extension" *Finance Research Letters* **25**, 103-110.

[4] Bendiksen, C.; S. Gibbons and E. Lim (2018) "The Bitcoin Mining Network" *CoinShares Research.* URL*:* https://coinshares.co.uk/assets/resources/Research/bitcoin-mining-network-november-2018.pdf

[5] Blinder, A.S. (1986) "Can the Production Smoothing Model of Inventory Behavior be Saved?" *The Quarterly Journal of Economics* **101**(3), 431-453.

[6] Bouoiyour, J.; R. Selmi and M. E. Wohar (2018) "Bitcoin: competitor or complement to gold?" *Economics Bulletin* **39**(1), URL: http://www.accessecon.com/Pubs/EB/2019/Volume39/EB-19-V39-I1-P19.pdf

[7] Dyhrberg, A.H. (2016) "Bitcoin, gold and the dollar – a GARCH volatility analysis" *Finance Research Letters* **16**, 85–92.

[8] Ezekiel, M. (1938) "The Cobweb Theorem" *The Quarterly Journal of Economics* **52**(2), 255-280.

[9] Fels, R. (1952) "The Theory of Business Cycles" *The Quarterly Journal of Economics* **66**(1), 25-42.

[10] Ferguson, C. E. (1960) "Learning, Expectations, and the Cobweb Model" *Zeitschrift Für Nationalökonomie/Journal of Economics* **20**(3/4), 297-315.

[11] Gandal, N.; J.T. Hamrick; T. Moore and T. Oberman (2018) "Price Manipulation in the Bitcoin ecosystem" *Journal of Monetary Economics* **95**, 86-96.

[12] Goorha, P. (2018) "Blockchains as Implementable Mechanisms: Crypto-Ricardian Rent and a Crypto-Coase Theorem'' *Journal of British Blockchain Association* **1**(2), URL: https://jbba.scholasticahq.com/article/4838-blockchains-as-implementable-mechanisms-crypto-ricardian-rent-and-a-crypto-coase-theorem.

[13] Kaldor, N. (1934) "A Classificatory Note on the Determinateness of Equilibrium" *The Review of Economic Studies* **1**(2), 122-136.

[14] Khoury, N.T. (1969) “Prorationing and the Economic Efficiency of Crude Oil Production” *The Canadian Journal of Economics/Revue Canadienne D'Economique* **2**(3), 443-448.

[15] Kryvtsov, O. and V. Midrigan (2013) “Inventories, Markups, and Real Rigidities in Menu Cost Models” *The Review of Economic Studies* **80**(1), 249-276.

[16] Kuznets, S. (1940) “Schumpeter's Business Cycles” *The American Economic Review* **30**(2), 257-271.

[17] Lai, K.S. and P. Pauly (1992) “Production Lags and Price Behaviour” *Economica* **59**(233), new series, 53-62.

[18] Lockhart, O. (1924) “The Denominations of the Currency in Relation to the Gold Problem” *The Quarterly Journal of Economics* **38**(2), 234-249.

[19] Nakamoto, S. (2008). ‘Bitcoin: A Peer-to-Peer Electronic Cash System’.

[20] Nerlove, M. (1958) “Adaptive Expectations and the Cobweb Phenomenon” *The Quarterly Journal of Economics* **72**(2), 227-240

[21] Nurkse, R. (1954) “Period Analysis and Inventory Cycles” *Oxford Economic Papers* **6**(3), 203-225.

[22] Pashigian, B.P. (1970) “Rational Expectations and the Cobweb Theory” *Journal of Political Economy* **78**(2), 338-352.

[23] Schoenberger, E. (2010) “Why is gold valuable? Nature, social power and the value of things” *Cultural Geographies* **18**(10), 3-24.

[24] Schultz, H. (1930) *The Meaning of Statistical Demand Curves.* (See Kaldor (1934); no English copy available).

[25] Schumpeter, J. A. (1939) *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process*, McGraw-Hill.

[26] Wen, Y. (2011) “Input and output Inventory Dynamics” *American Economic Journal: Macroeconomics* **3**(4), 181-212.