How to Make a Digital Currency on a Blockchain Stable

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Abstract

Bitcoin and other similar digital currencies on blockchains are not ideal means for payment, because their prices tend to go up in the long term (thus people are incentivized to hoard those currencies), and to fluctuate widely in the short term (thus people would want to avoid risks of losing values).

The reason why those blockchain currencies based on proof of work are unstable may be found in their designs that the supplies of currencies do not respond to their positive and negative demand shocks, as the authors have formulated in our past work.

Continuing from our past work, this paper proposes minimal changes to the design of blockchain currencies so that their market prices are automatically stabilized, absorbing both positive and negative demand shocks of the currencies by autonomously controlling their supplies. Those changes are: 1) limiting re-adjustment of proof-of-work targets, 2) making mining rewards variable according to the observed over-threshold changes of block intervals, and 3) enforcing negative interests to remove old coins in circulation. We have made basic design checks of these measures through simple simulations.

In addition to stabilization of prices, the proposed measures may have effects of making those currencies preferred means for payment by disincentivizing hoarding, and improving sustainability of the currency systems by making rewards to miners perpetual.

Keywords: digital currency, cryptocurrency, Bitcoin, blockchain, proof of work

1. Introduction

Digital currencies such as BTC on Bitcoin\textsuperscript{[1]} blockchain and Ether on Ethereum\textsuperscript{[2]} blockchain are now well-known, and are accepted means for payment in some
countries. However, these currencies are not ideal as methods of payment because of instability of their market prices. Their prices tend to go up in the long term, and to fluctuate widely in the short term. Therefore, people are incentivized to hoard those currencies, and would want to avoid risks of losing values by using them for payment. Stability of their market prices needs to be achieved if these currencies are intended to be used as monetary media instead of as investment products.

In the authors’ past work published as a discussion paper, we have formulated the mechanism of instability by analyzing the economics of those blockchain currencies based on proof of work. We have also proposed measures to stabilize the market prices of such currencies.

The contributions of this paper are refinements of the work as follows:

1. We have refined the formulation of the economic model of blockchain currencies based on proof of work, using abstractions closer to actual currency system designs, and
2. We have refined our proposed measures for stabilization of market prices of the currencies that would absorb both positive and negative demand shocks.

The proposed measures went through basic design checks by simple simulations.

Our proposals are primarily targeted for Bitcoin and its descendants. For information of the design of Bitcoin, in addition to the original design paper, we have referred to more up-to-date resources from the project web page and the code itself.

2. Blockchain Currency based on Proof of Work

First, we clarify the design of blockchain currencies based on proof of work. Any participant in the blockchain network may construct and broadcast (by flooding) a transaction of coins of which they have control. Figure 1 shows an example of transaction data structure found in Bitcoin. A transaction may have a list of inputs each referring to an existing coin as a container of value (represented as an output of a past transaction), and a non-empty list of outputs each representing a new coin or null coin (an output used for applications). A transaction is digitally signed in each input, which is verifiable with the public key also included in the input. The digest of the public key needs to match the digest to which the referred output is addressed. This structure is self-contained, and its validity can be verified by anyone.

The objective of the blockchain’s consensus algorithm (Nakamoto consensus hereafter) is to maintain a single history of blocks such that it does not involve any invalid or contradicting transactions. An example of the latter is double spending of one digital coin, which cannot be prevented by the transaction data structure alone. Presumably, the designer (or designers) of this technology first

1[https://github.com/bitcoin/bitcoin/](https://github.com/bitcoin/bitcoin/)
called it distributed timestamp server because it is intended to keep track of relative timing of events. As Figure 2 shows, each block contains the cryptographic digest of the previous block, except the very first block sometimes called the genesis block. Such a digest must meet a certain criterion; it needs to be less than or equal to the pre-adjusted and agreed target stored in or calculated from the block (we call this structure hash chain with proof of work hereafter). Since the digest is calculated by a one-way function whose outputs are evenly distributed, no one can intentionally configure a block to satisfy the criterion. Instead, they need to partake repetitive trials to change the values of some nonce in the block they are creating until they get a right digest. Therefore, creation of a block is a probabilistic process.

The necessity of repetitive trials functions as a proof-of-work mechanism intended to be a protection against falsification. A transaction itself cannot be falsified unless digital signatures are compromised. But it is conceivable to
remove some transactions from a past block or to add fabricated transactions that did not really exist. If one tries so, the digest of the block is changed and is typically greater than the target. Then they would have to retry the proof of work for the block. This changes the digest stored in the next block, which in turn means that the digest of the next block is also changed and is typically greater than the target, and so on. In short, ones with a malicious intention would have to redo the proof of work from where they want to change, and outdo the ongoing process of adding blocks eventually to make the change valid, which has generally been considered highly difficult.

Such proof of work can also limit the number of proposed blocks at one time. But there still is a possibility of multiple participants each proposing a new block at roughly the same time, which may be accepted by different sets of participants. Then the hash chain may have multiple ends that are extended independently from one another, resulting in a fork of the blockchain with multiple (and possibly, contradicting) histories of blocks. If this happens, roughly speaking, the longest branch is considered to be correct. More precisely, to avoid the case of branches with artificially raised targets, the branch that is the most difficult to produce is chosen by all participants. This reflects the total cost cast in the creation of the hash chain branch. Because of proof of work, any chain branch requires the same cost paid for its creation when it is tried to be falsified. In short, Nakamoto consensus tries to enforce that the most difficult chain branch to falsify is chosen as the single correct history.

3. Market Price Mechanism of a Blockchain Currency based on Proof of Work

3.1. Supply and Demand

The price of a blockchain currency and proof of work are closely related, because proof of work is closely related to supply of the coins, and the price in general is a reflection of supply and demand.

The authors have discussed this in detail in our past work\(^2\), and reasoned that the cause of instability of BTC price is that supply of coins does not respond to demand shocks.

Figure 3 shows the supply and demand curves of Bitcoin.

Usually for any goods (including money), demand curve slopes downwards from left to right (negatively sloped) while supply curve slopes positively. The price is found at the intersection of both curves. If the demand curve shifts left (demand drops) or right (demand rises), the supply curve would naturally respond (also shifts left to decreases supply or right to increase) to ease the shock of demand changes and subsequent price changes.

On the other hand, BTC coins are only newly supplied as the reward in every new block. There just is a rule that the reward is halved every 210,000

\(^2\)For imperfection of the design of Nakamoto consensus, readers are referred to a past work by the first author of this paper.
blocks. Therefore the supply curve is vertical (more precisely, the supply curve is slightly positively sloped, because when the demand rises and the price goes up, there will be slightly more supply before the proof-of-work target is adjusted. When the demand drops and the price goes down, there will be the opposite effect). Shifting the demand curve directly affects the price $P$ in the figure.

3.2. Consequences of Proof of Work

Here, we present a revised simpler version of the formulation in our past work\cite{1} to describe the economics of proof of work.

We start by the number of participants. Suppose $M$ miners participate. For simplicity, computation power of all miners are considered equal. Thus, $M$ is rather the total number of mining units with the same hash rate (how many digests can be calculated in an interval), and the number can increase or decrease to represent entry and exit of miners.

Let $\lambda$ be the average number of occurrences of an event that a miner with one mining unit finds a nonce satisfying the required criterion in an interval. We ignore the cost of communication, so that discoveries of a right nonce are independent events that can globally occur $M\lambda$ times within the interval.

We consider the average interval between successes $\theta$:

$$\theta = \frac{1}{M\lambda}$$

We assume a cryptographic hash function $H$ with range $R$. For example, in case of SHA-256, $R = 2^{256}$. We define the proof-of-work criterion as follows: the cryptographic digest of a block by $H$ must be less than or equal to target $G$. We define target-reachability $g$ as below.
Conceptually, difficulty of proof of work is inverse of the target-reachability $g^{-1}$.

Suppose that one mining unit tries $h$ times in an interval, so that $h$ represents the average hash rate of a mining unit. Therefore,

$$\lambda = hg$$

and

$$\theta = \frac{1}{Mhg}$$

Let $V$ be the reward of a successful proof of work. Then the reward for the winners of the mining competition is fixed as about $Z$ altogether per interval.

$$Z = \frac{V}{\theta} = VMhg$$

The expected benefit $B_m$ per mining unit per interval is therefore,

$$B_m = \frac{Z}{M} = Vhg$$

If the market value of bitcoin is given as $P$, the market value of the expected benefit is $PB_m$.

Now, we consider the cost $C_m$ for operating one mining unit. if $C_m < PB_m$, more mining units will participate ($M$ is increased). This in turn will result in shorter $\theta$, and eventually $g$ will be adjusted with smaller $G$ to maintain the reference $\theta$ (10 minutes in the case of Bitcoin). This will result in $B_m$ getting smaller. Conversely if $C_m > PB_m$, less mining units will participate ($M$ is decreased). Then $\theta$ is prolonged, and eventually $g$ will be adjusted with larger $G$, resulting in $B_m$ getting larger. In the long run, the following equilibrium is reached.

$$C_m = PB_m$$

In other form,

$$C_m = PVhg$$

In the case of Bitcoin, the right side of the equation is contributed as follows:

$P$: Goes up and down mainly by speculation.

$V$: Starts at 50BTC, and halved at every 210,000 blocks (12.5BTC as of year 2018).

$h$: Increases by technological advance.

$g$: Target $G$ is adjusted every 2,016 blocks to maintain the same reference value of $\theta$ (10 minutes).
4. Measures against Positive Demand Shock

4.1. Limited Target Re-adjustments

To mitigate the effects of positive demand shock, in our past work\cite{3}, we have suggested no adjustment to target $G$ unless $\theta$ is very short. The reason is that we would like to increase the supply of coins by increasing $Z$ when the demand increases. To do so, we can only increase $V$ or shorten $\theta$. What miners can do autonomously through their own decisions is to increase $M$ (by making more investments), and thereby shorten $\theta$.

But how short is very short, where adjustment of $G$ is eventually needed? To prevent the blockchain from accidental forks as described in \cite{6}, $\theta$ should have the minimum limit. Let it be $\theta_{\text{min}}$. $G$ should be adjusted well before $\theta$ reaches $\theta_{\text{min}}$. So we will adjust $G$ when a certain threshold $\theta'$ is reached where $\theta' > \theta_{\text{min}}$.

4.2. Target Re-adjustments for Positive Shock

We propose that $\theta'$ shall be the half of the reference $\theta$ (10 minutes in the case of Bitcoin), where $G$ must get halved. At the same time, we double $V$ to maintain the same pace of the supply of coins.

To make this happen, the system needs to refer to real time, which had been considered difficult for blockchains where timestamps in blocks can be untrue. But now, we have the concept of MTP (Mean Time Past; the median time of the 11 blocks in the past) as a standard measure for the purpose. We check the average interval between blocks using MTP, every after 100 blocks, for example.

In the case of Bitcoin, because the reference $\theta$ is 10 minutes, 100 blocks takes about 17 hours. When $\theta$ is halved, it can be detected within a half day or so.

5. Measures against Negative Demand Shock

5.1. Two-fold Propositions

We propose the measures to mitigate the effects of negative demand shock in two fold:

1. No adjustment to target $G$ unless the maximal tolerable average interval $\theta_{\text{max}}$ is reached.
2. Continuous removal of coins in circulation so that less total supply of coins can be achieved, not only new supply.

For the former, we propose the following adjustment rule for $G$: when 20% of $M$ is observed to have left ($\theta$ is observed to be $2 \frac{\theta}{3}$ times longer than the reference value), make $G \frac{3}{4}$ times larger. At the same time, make $V$ 80% of the reward at the time to maintain the same pace of supply of coins. This adjustment will likely to occur within a couple of days after a negative demand shock. We think that this asymmetry in the rules against positive and negative demand shocks is necessary because time measured with block creations is prolonged as $\theta$ gets prolonged.
For the latter above, we must invent something new, because blockchain currency protocols usually include the currency supply rule, but does not have a currency absorption or write-off rule.

5.2. Negative Interests

In our past work[3], we have suggested an implicit inflation target. But in this paper, we propose an implementation of negative interests, and no halving rule for $V$.

Let us consider coinage eras, where each era is, for example, consecutive 2016 blocks. Hereafter in this section, time is measured by the coinage eras.

Let $Z_t$ be the amount of produced coins at time $t$ (if $t$ is the current coinage era, $Z_t$ denotes the amount of produced coins in the era so far).

We define a depreciation rule so that effective values of coins are depreciated as time elapses. This depreciation can be like 1% of the original value as of production of the coin, after every coinage era elapses. Let the amount of depreciation of coins produced at time $t$ evaluated at time $T$ to be $D_t(T)$.

The total supply of coins in circulation $S(T)$ at time $T$ is, then

$$S(T) = \sum_{t=0}^{T} (Z_t - D_t(T))$$

which is expected to remain constant except during positive or negative demand shocks. $D_t(T)$ can be a function like below, in the case of 1% depreciation of the original at every coinage era.

$$D_t(T) = \min(Z_t, Z_t \times 0.01(T - t))$$

5.3. Implementation for UTXO Structure

Figure 4 shows how depreciation is implemented on a UTXO structure. In the figure, transaction 1 happened in coinage era $E$, transaction 2 happened in some coinage era between $E'$ and $E''$, and transaction 3 is happening in coinage era $E''$.

Because coins produced in different eras have different depreciation levels, they need to be treated separately in a transaction. In transaction 3 in the figure, unlike the original design of Bitcoin transactions, inputs referring to the coin values originated from era $E$ and era $E'$ are connected separately to different outputs to give total of value 30 to user $B$. Because coins originated at greater than or equal to 100 eras before do not exist with the 1%-per-era depreciation rule (they are evaluated as value 0, so they cannot be referred to), at-most 100 kinds of these inputs-outputs connections are expressed in a single transaction.

A series of inputs-outputs connections originated in an era forms a coinage era graph that takes a form of directed acyclic graph. In the figure, there are two of such graphs, one originated in era $E$ and another originated in era $E'$.

To evaluate the depreciated coin value of an input, a wallet software to build a new transaction data or a miner to verify the correctness of the data
does not need to look for all sources and distributions of the coinage era graph in question. It just needs to know 1) which era the graph is originated, 2) to which era the transaction being referred to belongs, and 3) the era to which the created transaction is intended to belong. For example, in the figure, to evaluate the depreciated value at era \(E''\) of the output of transaction 2, one just need to divide 23.75 with 0.95 (because of 5\% depreciation at transaction 2) to get the original amount, and subtract 10\% from the amount to get 22.5.

With this depreciation rule, when it is near the border of two coinage eras, a transaction might not make it in the block of the intended era. If that happens, the transaction data needs to be discarded (or verification of the transaction would fail anyway because its outputs would be more than allowed), and the wallet software needs to recreate the transaction intended for the new era. Because of further depreciation in the new era, the wallet may need to reform the transaction to output the intended amount.

6. Simulation

To evaluate the effects of the proposed measures, using an artificial market may look suitable. However, such an artificial market simulation depends on the human behavior model being used, and since human reactions against currencies with negative interests, for example, are not well known yet, we are unsure if we can build a plausible human behavior model to evaluate our proposals. It would be easy to produce arbitrary effects. Furthermore, the law of supply and demand is an established economic theory. So rather, we will make basic design checks of our proposed measures through simple simulations.

6.1. Target and Reward Re-adjustments

Figure 5 shows a sample distribution of block intervals for different total hash rates (\(1 \times, 2 \times\) and \(0.8 \times\) of the reference value where \(\theta\) equals 10 minutes) to
check the validity of proposed thresholds for target and reward re-adjustments.

We assumed Poisson distribution of events. We generated 100 random counts of occurrences according to the distribution in 100 minutes, and plotted them on the graph through an evaluation of possibility density (frequency of occurrences). We have tried many iterations, and other iterations show basically the same shapes.

In the graph, 2\times of the reference hash rate produces blocks in rather short intervals. To make this well-longer than \( \theta_{min} \), the currency’s network protocol may need to be improved, as suggested in [6].

On the other hand, 0.8\times of the reference hash rate produces blocks in similar intervals to the reference condition. This is good in terms of detection of decreased \( M \) because it means that the detection may be possible before users begin to feel that block creations are getting delayed. But do not these detections happen too often? Actual data from Bitcoin blockchain shows that this event of the average interval reaching \( \frac{5}{4} \) of the reference (12.5 minutes) is rather rare (except during the recent congestions).

6.2. Reduction of Supply

Figure 6 shows a simulation result on the amount of coins in circulation with depreciation. In the simulation, we have run the total of 1,000 coinage eras each containing 2016 blocks (equals to 2,016,000 blocks). With reference
block interval of 10 minutes, 100 blocks (to detect changes in $\theta$) amount to about 17 hours, 2016 blocks (1 coinage era) amount to 2 weeks, and 100 coinage eras (time for 100% depreciation) amount to a little less than 4 years. But note that the graph is drawn in blocks, not in real time. In reality, the intervals between blocks may fluctuate largely. The reward for block creation starts at 12.5, and is adjusted through observed demand shocks injected artificially during the simulation.

A positive demand shock is injected at block 500,000, which is recovered around block 506,000, and a negative demand shock is injected at block 1,000,000, which is recovered around block 1,030,000.

Note that slight increase in the supply is caused by offsetting the doubling rule ($V = V \times 2$) with taking 80% rule ($V = V \times 0.8$) for three times (amounts to 0.512 of $V$ at the beginning of offsetting). In reality, supply is also adjusted by autonomous fluctuation of $\theta$.

It shows that the supply of coins remains fairly constant even after positive and negative demand shocks and their recoveries by the market price mechanism.
7. Discussion

7.1. Responsiveness

In order for the price stabilization to work, the number of miners $M$ needs to be quickly responding to demand changes. But the initial investment cost and sunk cost effects for miners may defer their entries and exits, although exiting miners have a choice of just turning (part of) their machines off instead of entirely leaving the business.

Recently, some new blockchain currencies have been started by hard forks (backward-incompatible changes of the protocols) from existing currencies. It is called a split of a blockchain.

Ethereum Classic[7], started in 2016, is probably the first of such instance, splitted from Ethereum due to a disagreement in the governance. Bitcoin Cash[8], started in 2017, is the first instance of splitting a new currency from Bitcoin.

Unless further changes are made on the proof of work algorithm, mining these currencies is compatible with the original blockchain currency. Therefore, miners may switch back and forth among compatible currencies, pursuing more profits. This switch can even be automated. With this competition among currencies, $M$ can be quickly responding to price changes according to demand shocks, making the proposed measures more effective.

7.2. Applicability to Structures other than UTXO

We described how to implement depreciation, or negative interests, on a UTXO structure in section 5.3. But there are blockchain currencies that do not depend on UTXO structures. Ethereum, for example, maintains the account states in each participating node, and transactions (encoded state transfers) only are stored in the blockchain.

With this account-state design approach, assuming the rule of 1% depreciation over a coinage era we described, 100 different sets of balances are required for an account to maintain a single currency, for storing the values without depreciation in the past 100 eras separately. These values are each negatively weighted as they are depreciated, upon calculating the effective balances.

7.3. Deployment

If we start a new blockchain currency with the proposed measures from its genesis block, it would have to start with virtually zero price level, and since the mechanism is intended to avoid speculations, the price level would remain near zero, not suitable to be used as a monetary medium to represent values of goods or services.

To avoid such a situation, we may want to utilize a split to employ the inertia of the original existing currency. If we start a new currency by splitting it from Bitcoin, for example, the new currency can start with a useful price level and enough attention, although how existing coins should be depreciated is a problem to consider.
7.4. Sustainability

With the proposed measures, the amount of coins in circulation is automatically maintained to be near constant, and there is no need for external measures to cap the supply of coins, such as the rule of halving rewards as found in Bitcoin. Rewards for block creations to miners can be perpetual, providing a possible solution to the problem of sustainability in concern.

This means that miners do not need to rely on fees, so we may as well want to abandon transaction fees altogether.

7.5. Effects of Depreciation

In order for the price stabilization to work, the created coins must actually be supplied into the market. In our proposal, because coins are depreciated, miners are incentivized to sell coins they created before they lose values. The supply is expected to be quick.

But this should be true for all users, not only for miners. In other words, depreciation should accelerate spending. The first author of this paper has made a detail study on the effects of depreciating (and amplifying) digital currencies in [9] before rise of blockchain currencies. Some of the outcomes of the work may still be applicable.

But a natural question would be, do people prefer currencies that depreciate over others that do not? Our answer may be non-intuitive, but yes.

In our proposal, transactions can be free of charge, as suggested in the previous section. Then depreciation can be a beneficial choice for users, because choices are between always paying transaction fees and possibly avoiding any kinds of it by spending before depreciation takes place. (Note that we are discussing digital currencies as media of exchange instead of investment products.)

7.6. Effects of Splitting

Finally, let us consider the case where a currency with proposed measures itself gets splitted, as it is a possibility for any blockchain currencies today.

If it happens, it creates a situation where $M$ decreases for both original and newly splitted currencies. Thus, both currencies would automatically react as if a negative demand shock occurred (which may be the case anyway, if the same set of budgets is used for purchasing both currencies). In case the new currency took half of the miners, the pace of block creation is slowed down, but eventually the average interval $\theta$ gets normal, and the reward $V$ is about halved for both currencies. If these two currencies compete well, the total coin amount in circulation is eventually halved for each currency, maintaining the total sum of the amounts of two currencies to be equal to the amount of the original currency coins in circulation before the split. When the process is complete, all coins copied to the new currency upon the split would have already been depreciated down to zero, and the two currencies are completely independent from one another in terms of the coins in circulation.

Therefore, in theory, the split would eventually result in two currencies with the maintained same level of prices as before and with the same amount in total
in circulation as before. But how the market in reality reacts against this would need further study.

8. Related Work

8.1. Improvements to Digital Currency Design

Improvements to the original design of Bitcoin have been proposed many times. Many of them have taken the forms of alternative coins (altcoins), instead of research papers.

Among these, one of the most well-known examples is Litecoin\[10\], from which many other altcoins forked their code. Litecoin has shown that with basically the same proof of work mechanism as Bitcoin (although cryptographic hash function in question is different), average block intervals can be as short as 2 minutes (Ethereum maintains average block intervals as short as 15 seconds, but with lots of other improved designs).

Bitcoin Cash was born by a split from Bitcoin, addressing the issue of improving the throughput by adjustable block sizes. Many other new currencies have followed the practice of splitting.

Sidechains\[11\] provide another forms of testing improvements to blockchains and their currencies.

To our best knowledge, none of these address measures against the negative demand shock (no means to collect coins in circulation to control supply of them).

8.2. Models of Economics

Economics of mining has also been modeled in \[12\], where the model is used for simulating the price clearing mechanism in the market using a virtual order book similar to that presented in \[13\].

Our model is far simpler, intended for analysis of the problems and devising solutions. However, in order to evaluate the effectiveness of our proposed measures in more detail, we may want to use the artificial market methods found in these work ourselves.

9. Conclusions

Continuing from our past work, this paper proposed minimal changes to the design of blockchain currencies so that their market prices are automatically stabilized, absorbing both positive and negative demand shocks of the currencies by autonomously controlling their supplies.

In addition to stabilization of prices, the proposed measures may have effects of making those currencies preferred means for payment by disincentivizing hoarding, and improving sustainability of the currency systems by making rewards to miners perpetual without need for transaction fees.
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