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Economic Aspects of Bitcoin and other Decentralized Public-Ledger Currency Platforms

David S. Evans*

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Abstract

A number of internet-based digital currency platform based on decentralized public ledgers have started since the introduction of the blockchain concept by the founder of Bitcoin in 2008. An important element of these public ledger platforms is an incentive system that elicits efforts from a distributed global workforce to verify and record transactions on the public ledger and a governance system for the platform. The economic efficiency and possibly viability of a public ledger platform ultimately depend on the design of these incentive and governance systems. Even if a decentralized public ledger were a more efficient technology for conducting financial transactions, and for providing a platform for distributed innovation, deficiencies in its incentive and governance systems could make it overall inferior to alternatives, including existing systems. Current claims that public ledger platforms can conduct financial transactions more efficiently ignore the inefficiencies associated with the incentive and governance systems and the likely costs associated with regulation of these platforms and complementary service providers such as vaults, wallets, and exchanges. It is possible that public ledger platforms are more efficient than other alternative platforms for conducing financial transactions, but as of now the proposition is based on apples-to-oranges comparisons compounded with speculation. Competition will lead to better incentive and governance systems for public ledger platforms.

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This paper examines the economics of internet-based digital crypto-currency platforms that rely on a decentralized public ledger. I will refer to these platforms as "public ledger currency platforms." Their use of a decentralized public ledger, or blockchain, is their key distinguishing characteristic and the fundamental innovation for this new kind of currency.[1] Bitcoin was the first decentralized pubic ledger platform, is the best known, and is the largest by several measures as of this writing. The paper is organized as follows.

Part I describes the key attributes of public ledger currency platforms. It shows that the typical platform consists of a protocol for sending, receiving, and recording value securely using cryptographic methods; a container that carries value across the network; an incentive scheme for obtaining human and machine effort for performing functions required by the protocol; an open-source software licensing model; and a governance structure. The container is usually called a "coin" which suggests that it is money although it need not be.

Part II shows that it is improbable that a public ledger currency platform will establish its "coin" as a general-purpose currency. By "general purpose" I mean a currency that is used widely for exchange and not just among a niche group of users. The remainder of the paper then focuses on the role of public ledger currency platforms in providing financial services that do not depend on the container serving as a general-purpose currency. Most simply the container could carry general-purpose currencies such as the euro.

Part III considers the relationships between the protocol, the human and machine effort required by the protocol, and the incentive scheme established by the platform to elicit this effort. It shows that the "protocol" used by public ledger currency platforms is very different conceptually and economically from typical communication and information-technology "protocols". It then shows that the typical design of public ledger platforms makes it difficult for them to establish efficient incentives schemes for eliciting effort to work for the platform and price schedules for containers and transactions. As a result, public ledger platforms cannot operate efficiently given these common design choices.

Part IV discusses how public ledger currency platforms are governed. It shows that a major design choice involves determining the extent to which the platform follows an open source model and the degree to which the governance structure varies from community-based to dictatorial. It also considers the implication of these design choices for the efficiency of the platform. Overall, it shows that open source models that limit the ability of the platform to set input and output prices flexibly and in response to changes in market conditions make it difficult to operate an efficient, and perhaps even viable, public ledger platform.

Part V makes a tentative inquiry into how the public ledger currency ecosystem could evolve. It shows that public ledger currency platforms will tend to lead to the emergence of the same kinds of firms, with the same kinds of regulatory and consumer protection issues, as have traditionally existed in the financial services sector. It also shows that it is possible that the laborers for transaction processing will evolve into large enterprises, or collectives, and that these institutions will likely present regulatory issues as well.

Part VI examines the relationship between public ledger currency platforms and the existing financial services sector. It identifies the data and information we would need to determine whether decentralized public ledger currency platforms are necessarily a superior technology for delivering financial services. It shows that it is unclear, and unproved, whether the decentralized public ledger

[1] Unless otherwise noted whenever I use public ledger platform I mean a decentralized public ledger platform. It is possible to have a central agent verify and record transactions in a public ledger as well.

currency platforms are more efficient and more robust than either current payment platforms or alternatives that do not depend on an open-source public ledger model. To be clear, I am not claiming that these platforms could not be more efficient than existing financial services providers, only that there does not appear to be any sound basis for frequent assertions by their supporters they are superior.

Part VII, which concludes, poses questions and issues for further consideration.

I. Deconstructing and Defining Internet-Based Digital Currency Platforms

There are many ways to turn currency into digits and move it electronically. Most countries have electronic systems, such as the ACH system in the US or the Giro system in Germany, for moving money between bank accounts. Some countries have mobile money platforms, such as mPesa in Kenya, that enable people and businesses to move money between each other using their mobile phones without bank accounts. There are payment card systems such as MasterCard and Visa that mainly move money electronically between people and merchants. Further there are remittance systems such as Western Union that move money electronically in conjunction with agents that provide cash-in and cash-out services. Wallet providers such as PayPal leverage the assets of other payment networks to provide currency transfers between people and businesses in multiple countries. There have also been numerous Internet-based currencies particularly those involving games. Digital currency is therefore widespread and many decades old.

Many non-governmental currencies have appeared over time as well.[2] US banks sponsored currencies in the 19th Century. Merchants in various countries have issued their own currencies. One study reports that more than 2000 shopkeepers in Mexico City were issuing a metal token called the tlaco in 1766.[3] Various commodities ranging from gold to airtime minutes have been used as currency.[4] Some of these, such as airtime minutes, have been used as digital currency. These non-governmental sponsored currencies have generally not lasted as general-purpose currencies although some solve particular problems for particular transactors in particular places for some period of time.

So what is new and different about the public ledger currency platforms?

A. Features of Decentralized Public Ledger Platforms

Bitcoin lead the way in developing a different type of digital currency platform. These new platforms generally have the following features.

1. Internet-based

They rely on the Internet as the physical network for sending and receiving currency. That is different from most payment platforms, such as Visa, which typically rely on private secure communication networks.

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[2] Bruce Champ, "Private Money in Our Past, Present, and Future," Federal Reserve Bank of Cleveland, 2007. http://www.clevelandfed.org/research/commentary/2007/010107.cfm

[3] Eric Helleiner, *The Making of National Money. Territorial Currencies in Historical Perspective*. Cornell University Press, 2003.

[4] Andrew Zerzan, New Technologies, New Risks? Innovation and Countering the Financing of Terrorism, The World Bank, November, 2009.

2. Public Ledger Protocol

They have a protocol for sending, receiving and recording value. At this stage in their development the protocol is based on a public ledger that uses cryptographic methods to secure the values that are sent and received and provides a public record of transactions. The operation of the public ledger is decentralized. Individuals verify and record transactions. The valid public ledger is roughly speaking based on a consensus among these individuals. This public ledger is sometimes called the blockchain and is widely recognized as the key disruptive innovation.

3. Container for Value

There is container that is used to carry value on the public ledger. The container is used to send and receive value. The container is usually called a "coin" which suggests that it is intended to be a currency. It need not be. In principle it could contain a traditional currency such as a Yuan or a financial derivative.

4. Incentive Scheme for Labor Force

There is an incentive scheme for eliciting effort and the contribution of resources from people to conduct various record-keeping and verification activities for the public ledger. At this stage in the their development, the public-ledgers for digital currencies are intensive in labor and computer processing time. The incentive scheme provides a reward to people for providing labor, computing power, and other resources.

5. Open Source Licensing Model

There is a licensing model for enabling people to make changes to the software for the platform. Typically, public ledger currency platforms use one of the standard open-source licenses so that people can use the software underlying the public ledger and make changes to it.

6. Platform Governance System

There is a governance system for determining key operating principles for the platform, for adopting changes to the protocol and other features of the software, and for driving the evolution of the platform. Public ledger currency platforms typically use some variant of open source governance since they rely on a distributed network of "volunteers" to provide labor. The resulting governance systems run the same gamut that we have observed for open source—with a for-profit company managing the project, as is the case with Android; a benevolent dictator as is the case with Linux and many other successful large open source projects; or a consensus-driven management as is the case with many smaller open source projects.

B. Important Distinctions and the Danger of Analogies

Most public ledger currency platforms have all of the preceding attributes. The combination of these attributes makes these platforms different from traditional payment, currency, or software platforms. As a result one needs to be very careful about equating these public ledger currency platforms with existing platforms and using traditional concepts to describe them. Reasoning by analogy is particularly problematic. Let me highlight several key distinctions.

Public ledger platform sponsors typically refer to the container as a coin. That name suggests that the container is a currency. Some platform sponsors have expressed ambitions to create new general-purpose and, indeed, globally used currencies. It is possible that the container could become a currency if enough people wanted to use it as a medium of exchange. It is also possible that the container could be used to carry other currencies or financial assets on the public ledger as noted above.

In the end it is an empirical matter whether the coin becomes a general-purpose currency. Calling the container a coin causes confusion because, at least at the start of the platform, the container is not a currency, since it is not widely used, and because the public ledger platform could be viable even if the container did not evolve into being a general-purpose currency.[5] The next section argues that public-ledger platforms have features that make it improbable that their containers could evolve into general-purpose used currencies.

Another source of confusion concerns the "protocol" for public ledger platforms. Some commentators make the analogy between the public ledger protocols and other Internet-related such as HTTP.[6] There are indeed similarities. Public ledger protocols and Internet-related protocols both have network effects. As more people adopt each protocol the value of the protocol increases. There are more people to transact with in the case of the public ledger platform protocols and more people to interact with in the case of Internet communication protocols.

There is, however, a critical difference between these two types of protocols. A decentralized public ledger protocol insists that a network of third parties stand between A and B to verify that person A has the money to give person B and to record this transaction in the public ledger. In fact, the public ledger protocol cannot exist as a practical matter without an incentive scheme that induces a decentralized network of laborers to provide that effort. By contrast a typical communication protocol does not require any intermediary between the two parties. Parties A and B can communicate with the protocol without having to rely on any third parties. A communication protocol does not require a network of people to facilitate the bilateral communications or an incentive scheme to induce the effort of third parties. Establishing a decentralized public ledger protocol is more difficult than establishing an Internet protocol because it requires the participation of third parties and the adoption of an incentive scheme that induces the effort by enough third parties.

Finally, one needs to be careful in comparing public ledger currency platforms with successful open-source software models. The public ledger currency platforms may be based on an open-source license but they are fundamentally different from typical open-source projects.[7] The

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[5] By definition, a currency is a medium of exchange, a store of value, and a unit of account.

[6] Marc Andreessen emphasized this to in a series of Twitter exchanges with me and others. For his views generally, see Marc Andreessen, "Why Bitcoin Matters". DealB%k, The New York Times. January 21, 2014. Available at: http://dealbook.nytimes.com/2014/01/21/why-bitcoin-matters/

[7] Charles M. Schweik and Robert C. English, *Internet Success: A Study of Open-Source Software Commons* (Cambridge, MA: MIT Press, 2012)

pecuniary compensation of the open-source contributor is not a central design feature of open source projects and open source projects do not in practice typically have direct compensation schemes. Some open-source programmers work for companies that have decided to invest in an open source project. Some entrepreneurs develop for-profit companies that provide complementary services to the open-source project. But often programmers work for non-pecuniary reasons such as a shared interest in solving a problem or to show off their coding skills. Open source public ledger platforms attract programming contributions just as other open source projects do. However, the open-source public ledger platforms require another class of participants—the laborers who perform transaction processing—that require pecuniary compensation as an integral element of the protocol.

I mention these distinctions between public ledger platforms concepts and related concepts not to suggest that these distinctions are good or bad. The point is that one must be very specific about what public ledger platforms are and avoid reasoning using improper analogies.

II. The Container as a General-Purpose Currency

Each coin has a unique digital representation. Public-ledger currency platforms adopt rules concerning the production of coins. Typically, they create new coins, and thereby increase the supply of coins, by granting coins as rewards to people who supply services to the platform. As a result, the supply of coins is determined by two factors. First, it is determined by the amount of transactions that take place on the platform. The amount of activity on the platform determines the amount of effort required and therefore eligible for awards. Second, the supply is determined by the rules for awarding coins in return for supplying effort to validate these transactions.

Some of the public-ledger platforms have adopted rules that result in the supply of coins converging to a finite limit. The Bitcoin protocol, for example, sets the maximum number of coins at 21 million and has an algorithm that determines the rate of increase towards that long-run equilibrium.[8] Once that limit is reached laborers no longer receive any awards of coins for providing services. Their compensation, if any, would then be based entirely on transaction fees. Other platforms, such as Dogecoin, have adopted rules that allow for a steady increase in the maximum number of coins. The finite supply and constant-increase rules public ledger platform prevent the governance system for the platform from having any discretion over the supply of coins. Coin supply is hardwired into the protocol.

Coins are indestructible, are useful so long as the platform is, and are therefore long-lived assets. The value of a long-lived asset at any point in time reflects expectations about its future value. Given expectations, intertemporal arbitrage should result in a stable value for the asset that reflects its long-run value. Changes in expectations can change the value. If market participants expect that changes in demand or supply will reduce the value of the asset in the future they will bid the price of the asset down today. Likewise if market participants expect that changes in demand or supply will increase the value of the asset in the future they will bid the price of the asset up. These principles apply in practice to many familiar long-lived assets such as gold, diamonds, wine, and art.

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[8] "The block creation fee changes at every 210000 blocks. The block creation fee is a function of block height on the chain (genesis=0), and is calculated using 64 bit integer operations (in satoshis) as: (50 * 100000000) >> (height / 210000). The block creation fee started with 50 BTC, has fallen to 25 BTC at block 210000, will fall to 12.5 BTC at block 420000, and finally down to 0 satoshi with block 6930000. The block creation fee of all coinbase transactions will sum up to 2099999997690000 satoshis, practically 21million BTC." See https://en.bitcoin.it/wiki/Protocol_rules

They also apply to public ledger coins. The value of a coin depends on the expectations of market participants concerning its long-run value. Rational buyers would not pay $100 for a coin that would be worth $50 in the future and rational sellers would not take $100 for a coin that would be worth $200 in the future. If there were stable expectations over time the value of a coin would be stable over time. If expectations vary then the value will vary too, with increases when there is a change in expectation towards higher value and decreases when there is a change in expectations towards lower values.

The expected value depends on expectations concerning demand and supply of the asset over time. Since containers cannot be used for anything other than transactions the demand should depend entirely on the demand for the containers for conducting transactions on the platform. That may be difficult to predict. The supply depends on the stock of coins as well as the flow of new coins. In the long run the supply is fixed either at a finite level or by a deterministic increase rule. Until that long run is reached, however, the supply is correlated with transactions given the protocol and incentive scheme adopted by the typical public ledger platform. Like any asset, however, we would expect that market participants would engage in speculation over the future value of the asset.

We would expect that the market price of containers would be volatile in the early stages of platforms and become less volatile over time. Over time market participants would obtain more information about the likely demand and supply of containers as they get a better sense of the likely adoption of the platform and the utility of the platform for transactions. A platform that is more widely adopted by senders and receivers would have more transactions. A platform that can support more types of transaction—for example, conditional transactions and derivatives in addition to remittances—would also have more transactions.

Although we would expect that volatility would decline over time we would still expect the price of the containers to fluctuate. That would occur simply because expectations over demand could change for a myriad of reasons, some having to do with the platform, others having to do with competing platforms, and still others having to do with economic conditions that affect the volume of transactions that people and businesses want to engage in.

This volatility presents no particular problem for the ability of platforms to use coins as containers. In this case the coin is simply an input used for transactions on the platform. Senders need to buy a container—a satoshi, for example, which is the smallest unit of a bitcoin—to carry transactions on the public ledger.[9] The cost of that may affect their interest in using the platform for particular types of transactions. But, in the end, it is simply a cost of doing business and the input price would presumably settle to a level at which transactions were value-increasing for senders and receivers.

This volatility poses a much more serious barrier, however, to the adoption of the container—the so-called "coin"—as a general-purpose currency. Senders and receivers want to know the value of the funds they are sending or receiving. They therefore gravitate towards currencies that are stable and avoid currencies that are unstable.[10] Stable currencies also push out unstable currencies. People and businesses in countries with unstable currencies often use other stable currencies such as the dollar for trade. When countries go through extreme periods of currency

[9] The container would probably be the smallest divisible unit of the coin. In the case of Bitcoin, the smallest unit is a .00000001 of a bitcoin and is called a satoshi.

[10] For an early discussion of the importance of a stable currency that is particularly relevant to the current discussion over private crypto-currencies, see F. A. Hayek, *Denationalisation of Money: The Argument Refined,* Institute of International Affairs, 3rd edition, 1990. Available at http://mises.org/books/denationalisation.pdf

instability people and businesses tend to stop using the domestic currency almost entirely and use alternative currencies.

The importance of stability for currencies is seen in how central banks manage their national currencies. Most central banks manage the national money supply to achieve currency stability along with other macroeconomic objectives. Currency stability may give way to other priorities such as stimulating growth and reducing unemployment. Countries occasionally devalue their currencies as a result of trade imbalances or for other macroeconomic policy reasons. Nevertheless, central banks are judged in large part on their track record at achieving currency stability. They typically take this task seriously because the economic and political consequences of an unstable currency are too severe.

The importance of stability is one reason why there is virtually no support among central banks or economists for going back to the gold standard. For many years countries tied the value of their currency to gold by agreeing to redeem currency in gold. That resulted in periods of deflation and inflation that destabilized economies.[11] It also prevented the central bank from adjusting the money supply to deal with recessions or to counteract destabilizing periods of inflation or deflation. Virtually all economists, of all stripes and persuasions, oppose a return to the gold standard for these reasons.[12]

The empirical evidence shows that public-ledger currencies are in fact extremely volatile at this stage in their development. Column 2 of Table 1 shows the ratio between the intraday volatility (measured by the standard deviation of percentage intraday variation of the currency relative to the US dollar) of the euro and of three of the most popular public ledger currencies over the first 90 days on 2014. Bitcoin, the most stable of the three public ledger currencies is more than 18 times more volatile than the euro. The volatility has resulted in part from uncertainty over regulatory treatment of these currencies as well as market uncertainty over innovative financial services platforms.

It is possible that the degree of volatility will fall, as these issues get resolved. However, the volatility is high even during shorter periods of time in which there is little new information concerning the regulatory changes or the long-run viability of these currencies. Column 3 Table 2 shows similar ratios for month of January 2014 that preceded much of the negative events concerning Bitcoin. Bitcoin is still more than 15 times more volatile than the euro. Importantly, the data show a very high degree of volatility for bitcoin, which was five years into its growth phase as of early 2014.

[11] If the value of a currency is increasing—that is, there is deflation—currency owners have an incentive to hold it to realize the appreciation. During the American Civil War people ceased using metal coins as currency as their value increased. Deflation tends to slow down economies and central banks avoid it like the plague. A little bit of inflation—in which the value of the currency declines—is arguably a good thing. Rapid inflation, though, is a problem. Then receivers of funds can experience real costs if they cannot move the funds into an interest-bearing account that compensates them for the decline in the value of their funds.

[12] The University of Chicago did a pool of prominent economists and did not find a single support despite the fact that the economists polled were drawn from a wide spectrum. See http://www.igmchicago.org/igm-economic-experts-panel/poll-results?SurveyID=SV_cw1nNUYOXSAKwrq

Table 1. Ratio of Intraday Volatility between Cyrpto-Currencies and Euro (relative to the dollar between January and March 2014)

Cryptocurrency	January-March	January
Bitcoin / euro	18.44	15.79
Dogecoin / euro	63.90	92.40
Litecoin / euro	27.73	21.49

Source: Compilation with data from quandl.com, coinplorer.com, oanda.com

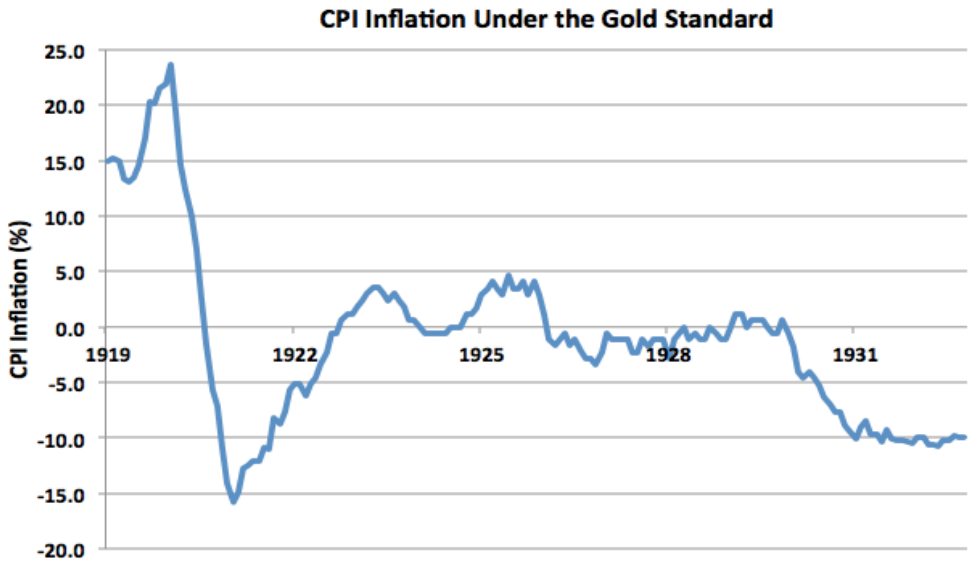
During the early years we would expect that public ledger coins would be volatile. But eventually much of the uncertainty will become resolved and market participants will have similar expectations on its future. One could argue that the asset value will become stable in the long run and can then be a currency.

Unfortunately, while it is possible that the value could become more stable in the long run it is still likely to be more volatile than the government-sponsored of most developed countries. That is because there is no central bank to intervene to make it stable. And the market value would likely fluctuate because of unanticipated changes in economic conditions, the development of competing currencies, and other issues involving the platform. If fact, one of the problems with gold, which was a physical currency with a fairly finite supply, was that its value fluctuated considerably when it was the standard. Figure 1 shows the fluctuation of prices under the gold standard.[13] Of course, gold had several millennia in which stabilize.

It is also possible that the market could provide solutions to volatility. For example, some bitcoin wallet providers such as Coinbase insure merchants against the volatility. Consumers buy coins for the wallets. When they pay a merchant that accepts bitcoins the wallet provider pays the merchant with a traditional currency. The logical extension would be to extend provide this same benefit to the consumer so they would not bear any currency risk either. The consumer could maintain a dollar balance in the wallet. When they want to pay a merchant the wallet provider could purchase bitcoins from an exchange so the consumer would not have to hold any.

Figure 1

[13] See Matthew O'Brien, "Why the Gold Standard is the World's Worst Economic Idea, in 2 Charts," *The Atlantic*, August 26, 2012, at http://www.theatlantic.com/business/archive/2012/08/why-the-gold-standard-is-the-worlds-worst-economic-idea-in-2-charts/261552/



This solution, in fact, demonstrates that the coin is not a medium of exchange. Consider the first case where the merchant was insured but the consumer was not. The merchant is not really accepting the coin for payment at all. They are accepting dollars or whatever traditional currency they have chosen to be paid in. The wallet provider is serving as an intermediary for senders who cannot find receivers willing to take the currency.

Consider the second case where the consumer and the merchant are both insured. In that case the transaction makes no sense. The consumer uses dollars to buy coins from the wallet provider for a transaction, the wallet provider buys coins from an exchange, then the wallet provider sells the coins back to the exchange since it needs to pay the merchant in dollars, then wallet provider pays the merchant in dollars, and the consumer gets their purchase. Of course the wallet provider could dispense with coins entirely and simply take dollars from the consumer and pay the merchant.

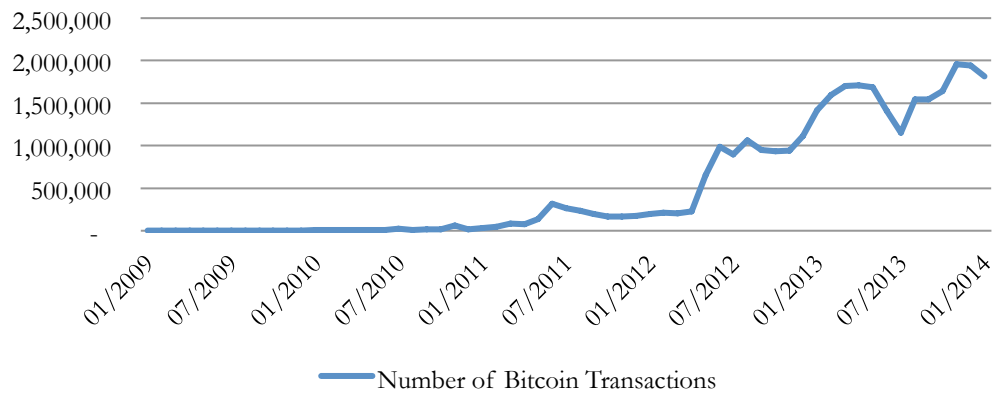
In the real world, of course, people could also use unstable currencies to transact in and hedge their transactions with various foreign exchange products. But unless they have some legal or regulatory obligation to do this they would simply standardize their transactions using a stable currency.

If in fact public ledger currencies were gaining widespread use one would have to dismiss these concerns over their stability. One could not argue with success. Although there is currently a great deal of press concerning bitcoin becoming widely used for commerce, the empirical evidence is less clear. We know from other platform businesses that successful platforms typically have "hockey-stick" growth path. There is slow growth until the platform reaches critical mass at which point growth accelerates rapidly. There is an inflection point at once critical mass is reached. Figure 2 shows the growth of bitcoin "transactions."

This chart overstates the use of bitcoins as a medium of exchange because these transactions include situations in which bitcoins are being bought and sold for speculative reasons. Even so, five years after the inception of the platform the chart does not show any evidence that bitcoin has the sort of hockey-stick growth that would be consistent with it being adopted as a form of payment.

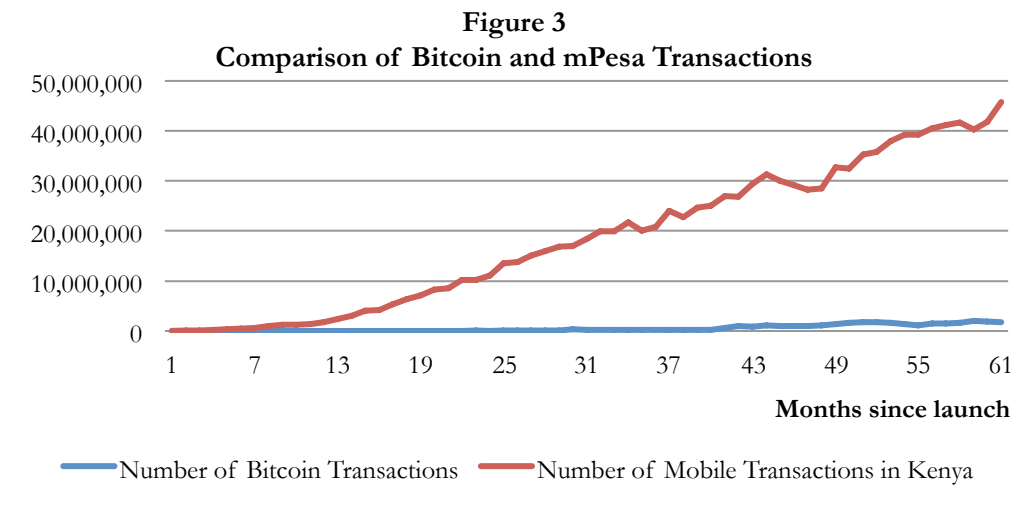
The apparent failure of Bitcoin to achieve accelerating growth is also seen by considering the growth of another person-to-person payment mechanism—mPesa—which was started around the same time as bitcoin. Figure 3 shows the growth of transactions for bitcoin and mPesa over their lifecycles. MPesa shows the typical hockey-stick growth, reaching an inflection point roughly 1 year after start, while bitcoin does not.

Figure 2
Number of Bitcoin Transaction



Source: Compilation with data from quandl.com

Figure 3
Comparison of Bitcoin and mPesa Transactions



Source: Compilation with data from quandl.com for Bitcoins and Central Bank of Kenya for mPesa

My conclusion is that it is highly improbable that public ledger coins, given the current protocols and governance systems, will evolve into general-purpose currencies. That is based on several findings. First, the protocols for supplying public ledger coins do not adjust supply with demand and therefore cannot provide stable values for the coins. Second, the theoretical explanations concerning why public ledger coins have unstable value are borne out by the empirical evidence concerning the volatility of bitcoin. Third, senders and receivers of funds will generally not adopt putative currencies that have unstable values. Moreover, senders will tend to hold rather than

use putative currencies if the currencies are increasing in value. Fourth, the importance of currency stability is borne out by the fact that central banks focus on maintaining currency stability and the fact that senders and receivers avoid unstable currencies. Fifth, five years after its inception there is no empirical evidence that would support claims that bitcoin is becoming a general-purpose currency; rather appears to be a niche currency and one that involves many transactions between speculators.

Public ledger currency platforms could nevertheless provide a more efficient alternative to existing payment and other financial services platforms. The "container", or coin, can carry traditional currencies and financial assets on the platform. In this case, the value of the container is not as a general-purpose currency but rather as an elementary input for the platform that facilitates the movement of financial assets on the public ledger. That container has an asset value and could be bought and sold in a market. Like any asset its value could be volatile and that would not necessarily interfere with the value of the container as an input into a financial services platform using the public ledger.

III. Protocols, Incentive Schemes, and Eliciting Effort to Operate the Public Ledger

The public ledger—or blockchain— is the fundamental innovation. It was first described in the white paper that proposed the Bitcoin peer-to-peer electronic cash system.[14] The public ledger requires protocols, effort required to implement the protocols, and the incentive system for eliciting that effort. This section focuses on the relationship between these components of the public ledger platform. The reader can consult many other sources for technical details.

The protocol provides a set of rules for using cryptographic techniques for sending and receiving transactions and using a distributed network to record and validate transactions. The process of recording and validating transactions on the public ledger requires effort by software programmers using computers. Protocols have different rules for confirming transactions. In the case of Bitcoin, transactions that take place at a given time are aggregated into a block, laborers independently solve algorithms to assess the validity of transactions in the block, and they broadcast valid blocks to all other laborers. Laborers determine whether a posted block is valid and, if it is, work on the subsequent block. The longest chain is taken as the valid version for the public ledger. The laborers are called "miners" in the case of Bitcoin because they make new bitcoins as a reward for their work. Different public ledger platforms may have different protocols for recording and validating transactions. But they all require laborers. (I argue later that the laborers would likely end up being mainly organized into enterprises.)

The laborers invest their own time, the cost of computer equipment, electricity, and perhaps other resources to perform these functions. This situation is very different from most open source projects. Programmers on open source projects often write software code that benefits themselves, or their employers, directly. They typically do not incur significant out-of-pocket costs.

The public ledger laborers, however, spend significant effort. They also incur significant costs in particular for computational resources. They are not contributing to a software project that will benefit themselves or their employers. Instead, they are providing a service services to individuals and businesses that are engaging in financial transactions.

[14] Satoshi Nakamoto, "Bitcoin: A Peer-to-Peer Electronic Cash System," 2008. Available at: https://bitcoin.org/bitcoin.pdf

There is no reason laborers would provide these critical services for free or to the extent needed for the platform. Recognizing this, public ledger currency platforms have implemented "incentive schemes" that are designed to elicit the supply of labor and other necessary resources. The Bitcoin white paper proposed to do this by giving bitcoins to laborers as rewards for their services in addition to possible bitcoin-based transaction fees.

This incentive system served a dual purpose. It injected new bitcoins into the system as it grew in addition to providing compensation for the effort expended. For Bitcoin the laborers are called "miners" because a byproduct of their efforts, during the growth phase, is the creation of new currency, just like people searching for gold. Most other public ledger currency platforms have adopted a similar approach. (Ripple, on the other hand, created a finite supply of containers and is awarding them like stock grants to motivate behavior.)

The relationship between the protocols, the incentive system and the supply of effort has not attracted much discussion. It is clearly central to the performance of the public ledger. The public ledger depends on the supply of labor and resources to function. The supply of labor depends on the incentives the platform provides to laborers. The incentives depend on the value of the coins provided as rewards as well as any transaction fees.

In the remainder of this section I examine the ability of the incentive system to elicit labor to manage the public ledger. It is useful to begin by considering how different types of public-ledger platforms would operate under centralized control.

Consider the situation in which a not-for profit entity (NPE) operates a public ledger in the public interest. Aside from using the blockchain technology the NPE in this example can do anything it wants. We will therefore call it an unconstrained NPE (UNPE). There's no obvious reason why it would choose to set a fixed supply of containers for the public ledger. Instead, it would determine the socially optimal number of containers for the public and set the socially optimal price to ration these containers across senders. It would also set socially optimal transaction fees taking into account the cost of resources needed to process these transactions on the public ledger. It would hire workers and other resources to operate the platform. Like any business it would vary its prices and wages over time in response to changes in demand and other market conditions.

The UNPE would also vary transaction fees and labor payments across countries. The demand for sending and receiving financial transactions varies across countries. For remittances people are willing to pay more for transferring money between the UK and Poland than between Chad and Nigeria. With a globally distributed workforce, the not-for profit entity would also pay different fees in different countries to minimize costs. There is no need to pay someone in Bolivia as much as someone in Norway.

Now let's assume that the NPE is required contractually to follow the typical public ledger protocol and incentive system. We will call this the constrained NPE (CNPE).

The CNPE would have to release coins following a mechanistic rule (possibly up to a finite limit) rather than varying the supply based on the demand for containers. As a result it would lose any control over the price of containers. The market would determine the price of coins.

Then, during the growth period, the CNPE would follow the protocol in awarding laborers with durable containers (coins) in return for their efforts in processing transactions on the public ledger in addition to transaction fees. However, since the CNPE does not have any control over the price of the coins it has no control over the value of the awards. This incentive system is similar to a company hiring workers on a piece rate but where the value of the piece rate is variable and outside of the control of the employer. It would be like a blueberry farmer saying you will be paid X per

bushel you pick but where the blueberry farmer has no control over the value of X and where the worker therefore does not know the value of the piece rate. The piece rate would also have to be the same worldwide. Moreover, as we saw above the price of the containers at any point in time reflects long-run expectations concerning the demand for transactions on the platform. The price of the containers at any point in time therefore does not even reflect current demand for using the platform. To take our blueberry example, the piece rate for picking blueberries does not necessarily even correspond to the current market demand for blueberries.

The transaction fee is the other possible lever for motivating the laborers. Whether the platform can set or adjust the transaction fee depends on the protocol the platform has adopted and the governance system. Bitcoin, for example, provides for voluntary transaction fees; the idea is that if senders offer a transaction fee, and a higher one, their transactions will receive a higher priority by the miners. Presumably a consensus would emerge. This mechanism for providing incentives is novel and there is no apparent reason why it would enable the revelation of efficient prices for laborers. Also, it is unclear whether the governance system for Bitcoin would enable the platform to establish mandatory transaction fees or to vary these fees based on the demand for effort.

The CNPE could not manage the public ledger platform efficiently under these constraints. It needs to manage a globally distributed workforce and the provision of resources to the platform. It also needs to decide on the optimal release of containers into the system. But it has few tools for performing either of these tasks. This would therefore appear to be a rather rickety structure for operating any sort of substantial remittance network or other financial services platform.

In fact, the approach towards managing the standard public ledger platform is so novel that we do not have any comparisons for assessing whether this approach could support an efficient or even viable platform in the long run. The public ledger platform model deviates significantly from open source models because the public ledger has to hire significant resources. Indeed, I do not know of any open source projects that manage markets that supply outputs and hire inputs in this manner. The public ledger platform also differs from proprietary models involving for-profit and not-for profit businesses because the platform protocol cedes almost all control over output and input prices to mechanistic rules that cannot adjust to market circumstances.

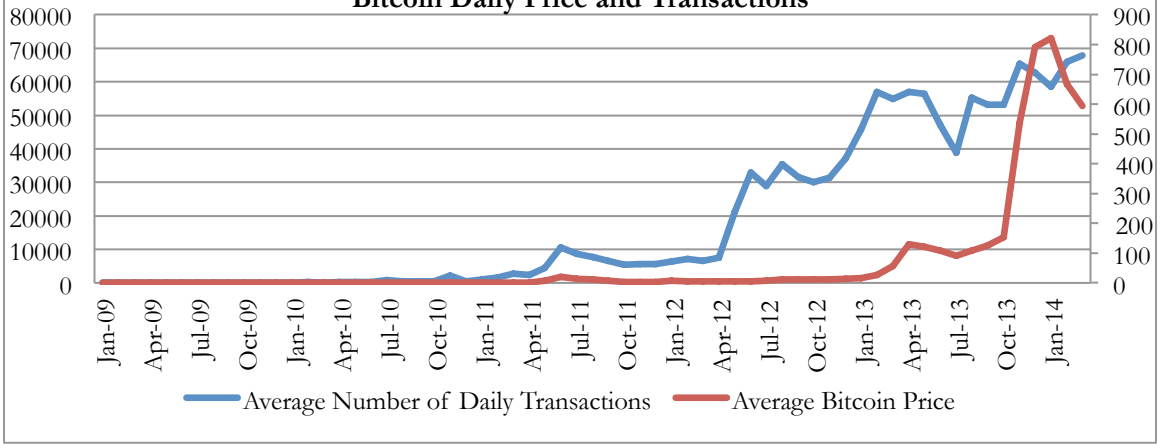
Bitcoin has operated for five years now and could provide some insights into how these platforms could operate in practice. It is, unfortunately, difficult to infer much about the long-run operation of public ledger platforms from the Bitcoin experience. There has been a rapid increase in the supply of resources to the Bitcoin platform in the last year. A whole industry of miners has developed. Manufacturers are producing increasingly powerful and expensive mining equipment.

This rapid increase in the supply of effort is, however, a predictable consequence of the rapid increase in the price of bitcoins that are provided as rewards to miners. The price increased from an average of $130.85 in April 2013 to $594.32 in March 2014. During that time the price was as low as $67.86 and as high as $1151.00[15]. This tremendous price fluctuation is obviously not the result of changes in the demand and supply of containers for transactions. Figure 4 shows the average monthly price of bitcoins and the average monthly number of transactions; as noted above the number of monthly transactions are likely dominated by exchanges between speculators who are holding bitcoin rather than using them for traditional transactions. The price fluctuation has been driven mainly by changes in beliefs concerning the expected future value of the containers as I argued above. While this process is eliciting more than enough effort to manage transactions at this

[15] quandl.com

point it does not tell us anything about how the platform would work in the longer run when the awards are less important, as they will be given the design of the protocol, and the novelty of mining has worn off.

Figure 4
Bitcoin Daily Price and Transactions



Source: Compilation with data from quandl.com

My conclusion is that the incentive system is central to the performance of any public ledger platform but that, as typically designed and given how the typical platform is governed, the incentive system does not enable the platform to manage the supply of effort to the platform efficiently. Further work is needed to model the interrelated market for containers, market for transactions, and market for effort.

Several other conclusions follow from the discussion above and will help motivate the remaining sections of the paper.

First, proponents of public ledger platforms often claim that they provide a peer-to-peer system for transferring financial assets that eliminates the need for intermediaries. That isn't quite right. The platform ***is*** the intermediary and uses an incentive scheme to hire resources to perform the functions of the intermediary. The fact that the intermediary may choose to use a globally distributed workforce is not a relevant detail. After all, remittance networks also use globally distributed third-party agents to perform many of the tasks of the network. The fact that the public ledger is decentralized—so there is not a bank or a government acting as the intermediary—may have interesting political or social value to some. But from the standpoint of considering economic efficiency there is still an intermediary, just a very different sort of one.

Second, nothing in the organization of public ledger platforms necessarily guarantees that these new intermediaries are more efficient at conducting financial services transactions than other alternative intermediaries. While the blockchain may provide an efficient technology for processing transactions, the limited control of the platform over input and output prices would likely result in it operating less efficiently than an entity that has control over input and output prices. It is ultimately an empirical question whether the public ledger platform is more efficient than other alternatives including existing platforms or new ones that do not rely on the public ledger.

Third, the evolution of public ledger platforms depends critically on the design of the governance system. In our discussion above we assumed that the platform was run by a non-profit entity interested in maximizing the social value of the platform. But the objectives of the governance

system depend on how it is designed. It could operate to maximize the value of the platform for transactions purposes or the value to miners or to some other interest group. The ability of the platform governance to achieve whatever objectives it has depends on the degree of control it has over prices. I turn to this next.

IV. Public Ledger Governance

In principle, a for-profit entity could operate a public ledger platform. It would use the blockchain technology, sell containers, and hire resources to operate the ledger. It would also own its intellectual property including software code and trademarks. As with the UNPE discussed above the for-profit entity could decide to rely on decentralized markets for some of its activities such as selling the containers or hiring resources. So far, however, public ledger platforms have mainly adopted some version of an open source model and it is this organizational form that I focus on.

A typical open source project solicits volunteers to help develop software code. The founders of the project usually develop some basic code to help solve a problem. They then solicit volunteers to help work on it. The software is released under an open-source license that enables people to use the open-source project code for free and to redistribute the code for free under the same license. Some licenses have a "copyleft" feature that requires anyone who redistributes the software code to make available any improvements they have made to the software under the same license. There is usually a lead developer and a core development team. This team and their designates incorporate proposed additions and changes made by participating developers into the core software although the rules for doing so varies according to the governance structure for the project.

Although open source projects share these features there is great heterogeneity in how projects operate in practice. In many case the open source project consists of a handful of developers who are in communication with each other and make decisions by consensus. In some cases there is a for-profit company, such as Google in the case of Android, behind the project. That company will typically fund the core development team. In other cases there is a very strong leader, such Linus Torvalds in the case of Linux, who maintains tight control over the project. Schweik and English have found, in fact, that large successful open source projects typically have a benevolent dictator who makes decisions.[16]

As is well known, one of the major problems for open source is that many different versions of the software evolve leading to forking and fragmentation of the code. That can happen even with more hierarchical models. For example, there are many different versions of Android and one of the major drawbacks of this software is that application developers would have to make modifications, perhaps significant, to their software to run on all these different versions.

To illustrate the possible governance models for public ledger platforms we consider three examples.

Bitcoin has adopted a loose governance model. There is a core developer group. There is also a foundation that provides financial support for core development. The core developer group solicits volunteers to contribute to development of the source code. The core developer group, mainly operating through the foundation, also encourages people to maintain servers to host a

[16] See, generally, Charles M. Schweik and Robert C. English, *Internet Success: A Study of Open-Source Software Commons* (Cambridge, MA: MIT Press, 2012)

distributed version of the public ledger and to engage in processing transactions. Anyone could modify details of the software code. Developers who propose changes to the software can let the development team know. If it is a simple noncontroversial change then they will adopt it. If not, the developer is supposed to post the change and it will be adopted if there is a broad consensus in the community that it should be.

As with most open source projects, it is possible that alternative versions of bitcoin could arise. In fact they have. Litecoin is a significant fork of bitcoin. It has a similar loose governance structure. Dogecoin, which has become the third most frequently used public ledger currency, is built off of the Litecoin code base. It also has a foundation and a core development team behind it similar to Bitcoin. One of the changes these public ledger platforms have made to the bitcoin software code concerns the generation of coins and the resulting incentive scheme for the laborers. However, they have continued to adopt largely mechanistic schemes for supplying coins and compensating laborers.

Ripple has taken a different approach. The public ledger platform software was developed by a for-profit company, which has secured private investment. It made the software open source, which enables it to benefit from open source development by volunteers but also makes the software available freely to everyone who has opens up the possibility of forking and fragmentation. Ripple, unlike Bitcoin, has given effectively stock grants on the containers which are called ripples. It uses these stock grants to motivate members of the community and to compensate the company. Ripple has a hierarchical governance model similar to Google's governance model over Android.

All of these platforms, however, also need to govern the laborers and other resources that operate the peer-to-peer network and public ledger. They need to motivate them and they may need to regulate them as we discuss in the next section. How they do that within a loose governance structure that has further given up key tools for guiding the platform is hard to envision.

My conclusion is that it is unclear whether the public ledger currency platforms will adopt governance systems that would enable them operate efficient, or even viable, financial services businesses. The few large open source software projects that have succeeded do not provide any evidence that the public ledger platforms will succeed too. As we saw above, the public ledger platforms are much more complicated than typical open project projects because they involve managing, and incenting, a potentially very large network of "laborers" to provide processing and of individuals to maintain servers for hosting the distributed public ledger platform. To my knowledge no one has tried using an open source governance framework to manage such a large and complicated economic enterprise.

The existing public ledger platforms could adopt more flexible and centralized governance systems. But attempting to do so could run into opposition from the community that supports these platforms including the laborers. New public ledger platforms could also arise that could rely at the outset on flexible and centralized governance systems. Whether they could secure the same amount of interest on the part of laborers and users is not clear. For example, Ripple has a more flexible and centralized governance structure than Bitcoin. But at least at this point there is no evidence that it is securing significant interest on the part of a global community of users and laborers; as expected, in fact, it is being criticized for deviating from the decentralized model of other open-source based public ledger platforms.

V. Industrial Organization of Public Ledger Platform Ecosystem

The public ledger platforms will likely reside at the center of an ecosystem in which two kinds of firms will develop. The first kind of firms would provide financial services to consumers and businesses based on the public ledger platform. I call this the "public ledger financial services market". The second kind of firms would operate the platform itself by providing processing and other services. I call this the "public ledger processing market."

Let me begin with the financial services market. The public ledger currency platforms would attract developers of applications that would use the platform to provide financial services. We would expect that there would be market opportunities for the same kinds of businesses that currently exist in financial services. That is what we have seen so far with Bitcoin. Companies have emerged that provide depository services (that is, places where people can securely keep their bitcoins), exchanges for buying and selling bitcoins, intermediaries that facilitate transactions between consumers and merchants, and cash-in/cash-out centers (these are currently unintended "ATM" type devices). We would also expect to see new forms of financial services firms emerge that rely on the fact that the containers can carry software code. A number of commentators have speculated that the containers would facilitate rules-based transactions.

We would expect that these businesses would raise the same prudential regulation and consumer protection issues as traditional financial services businesses. As these businesses mature, depository services will end up facing banking regulation, exchanges securities regulation, payment businesses consumer protection regulations, and all these businesses money transfer regulations. There is no apparent reason why public ledger platforms would lead to fewer regulatory or consumer-protection issues, or require fewer compliance resources, than non-public ledger based financial services firms.

A related point concerns the geographic reach of the firms that facilitate the provision of financial services. Financial services regulation is national (with a Brussels-driven overlay in the European Union). That tends to limit the geographic reach of financial services players in part because there are diseconomies in serving multiple geographies and in part because some countries impose barriers to entry. In fact, differences in national regulatory practices, which lead to differences in financial services practices, are the source of many of the inefficiencies in conducting cross-border payments transactions.

We are already seeing many of these regulatory developments with Bitcoin. Countries are looking into the regulation of various aspects of bitcoin transactions. That includes imposing money transfer regulations (KYC and AML regulations), regulations on the relationship between bitcoin exchanges and depository institutions, and exchange regulations. In some cases these regulations have made it impossible to operate—for example regulations by the People's Bank of China may effectively prevent bitcoin exchanges from operating in China.[17] In other cases these regulations have simply extended existing regulations to bitcoins—for example money transfer regulations in the United States.

Let me now turn to the public ledger processing market. Previously we referred to the participants in this market as "laborers." The public ledger platforms typically use open source terminology to refer to these laborers in the same way they refer to coders who participate in open source projects. The platform rules do not require that individuals rather than firms provide the processing services. It is difficult to predict the evolution of the processing market given the uncertainty over the incentives schemes. If public ledger platforms could establish predictable prices

[17] Xhang Yuzho and Li Xiaoxio, "PBOC Rule Means Bitcoin Websites in China Must Close, Expert Says," Caixin Online, March 27, 2014. http://english.caixin.com/2014-03-27/100657518.html .

for the services from processing there would be incentives for the emergence of large firms. Processing is intensive in computational capacity. With predictable prices entrepreneurs would make capital investments in computer capacity and realize scale economies, as is currently the case with payments processing generally. With unpredictable, or suboptimal, prices there would be less incentive to make sunk cost investments in forming firms and buying computer capacity. In that case we would expect processing to be conducted by underemployed laborers. During the growth period, however, the prices for processing are tied to the price for the containers. That could provide an incentive for enterprises, or other coalitions, to form for the purpose of manipulating the currency prices.

The Bitcoin experience provides some insights into the evolution of the processing market. Bitcoin transactions were initially processed by individuals using personal computers. As the price of bitcoins increased, and the computational difficulty of processing increased, two things major developments occurred. First, an equipment market emerged to provide more powerful computational capacity to miners. Second, mining pools emerged to diversify the risks of engaging in mining in which new bitcoins were awarded randomly. Reportedly, at one point one of the mining pools controlled more than 50 percent of the mining capacity.[18] That potentially gave the pool the ability to manipulate bitcoin prices as well as to engage in other bad behavior. The Bitcoin community discouraged the operation of such a large pool but it does not appear, other than moral suasion, it has any ability to prevent it.

The public ledger platform processing market would seem ripe for some forms of regulation. There are opportunities for laborers to cause negative externalities for the platform as the mining pool illustrates. That regulation could come either from the platform itself if its governance system were capable of that. Alternatively, as with the financial services side of the platform, it could come from the government.

VI. Comparison of Public Ledger Currency Platforms with Existing Financial Services Platforms

This section considers whether public ledger currency platforms could provide financial services products more efficiently, or lead to more rapid innovation, than alternative platforms that do not rely on a public ledger. It does not provide an answer but describes factors one would need to consider and data one would need to make such an assessment.

It is important to take several things into account in comparing public ledger and traditional platforms.

First, as always it is essential to compare like with like. Public ledger platforms are networks that enable the transfer of financial assets from a sender to a receiver. They should therefore be compared to financial services assets that provide the same functions. It may be that public ledger platforms could make it cheaper to provide ancillary functions but if so we need to say what those functions are and establish why public ledger platforms are better.

Consider remittances for example. One can compare the movement of public ledger currencies from the wallet providers for sender A to receiver B to the movement of traditional currencies from that traditional wallet (e.g. PayPal) of A to B after accounting for possible differences in services such as fraud protection. One cannot compare the movement of public ledger currents

[18] See http://www.coindesk.com/bitcoin-miners-ditch-ghash-io-pool-51-attack/

from the wallet providers for A and B to the movement of cash from a traditional remittance network that operates cash-in/cash-out agents in locations convenient to A and B.

For the purposes of operating a P2P money transfer network it is not obvious that the public ledger platforms are more efficient than traditional platforms. Traditional platforms such as Visa, ACH/Giro systems, PayPal, and similar national and global digital money systems are extremely efficient at transferring funds. They operate large, global, computerized networks with built-in redundancy. The actual cost of transferring funds from A to B is trivial. The prices that individuals and merchants pay are largely the result of other services that these platforms provide including security and fraud protection.

A number of countries have ACH-type systems that enable individuals to transfer money essentially for free given that they have a bank account. In the last few years, significant innovations have occurred to lower the cost and increase the convenience of these transfers. For example, Paym in the UK is enabling consumers to use their mobile phones to do P2P transfer just using mobile phone numbers; clearXchange in the US enables customers of participating banks to conveniently transfer funds; and mobile money schemes in a number of countries enable P2P money transfer on mobile devices.

There are of course many examples of frictions that result in inefficiencies in transferring money globally. But these frictions largely result from different national regulations of financial services together with the demand by governments, and the public, for strong laws concerning money laundering and terrorism.

PayPal provides a useful comparison for the public ledger platforms. It does not charge senders or receivers anything for transferring funds between accounts in the case in which both sender and receiver have PayPal accounts. For overseas transfers it charges the sender between 0.5 percent and 2 percent depending on the country for transactions that are fully funded from a bank account.

It is possible that public ledger platforms could provide these services more efficiently over a decentralized network using an incentive scheme to attract laborers. But that proposition is not obviously true and would need to be established. Any estimates of the relative efficiency of the public ledger platforms would need to address the operation of incentive and governance systems for these platforms, as these affect the cost and efficiency of these platforms. They would also need to address the cost of any regulations. There are other factors that would need to be considered as well, including the security of a networks under and not under central control given the assumption that both can benefit from advances in cryptographic technologies.

Unfortunately, discussions concerning the relative efficiency of public ledger platforms have been extremely superficial. They typically involve someone claiming that it costs significantly money to send funds using Western Union and costs little to send bitcoins. That is an apples and oranges comparison. The typical Western Union sending customer is going to an agent in a poor part of a city, where it is costly for agents to operate, going through KYC checks, and handing in cash. The typical Western Union receiving customer is going to an agent in a remote part of a country and going through KYC checks there as well. Western Union is operating a network of physical agents for cash in and cash out. The cost of the computerized network for transferring money from the receiving agent to the sending agent is trivial. The cost lies in the agent network and the regulations. It is true that bitcoins are more efficient for an upper middle class entrepreneur in the US to send bitcoins to his middle class developer in Belarus who can then use the bitcoins to buy some things

online. That use case, though, is not particularly relevant to most of the billions of people on the planet.

Second, the financial services products supported by public ledger platforms are almost certainly going to be subject to the same sorts of regulations as other financial services products. There is nothing about public ledger platforms that makes the governmental and public demand for regulation and consumer protection lower for financial services businesses based on the public ledger rather than traditional platforms.

The depository institutions and exchanges for public ledger platforms are already encountering many of the same issues that lead to regulation for similar institutions for traditional financial services products. And we are already hearing demands—including from the supporters of public ledger platforms—for government regulation. One needs to factor in the costs of complying with these regulations including operational and market inefficiencies that such regulations result in.

As a starting point I would expect that the regulatory costs for public ledger currency platforms will be as high as for platforms that are not based on public ledgers. There may be a variety of ways of evading strict bank regulations that would reduce costs. But that could be accomplished with other platforms that are not operated by banks (such as PayPal) and would not seem to require the blockchain.

Third, one has to make conjectures on how the incentive schemes and governance structures for public ledger platforms will evolve before making any comparisons between the efficiency of public ledger platforms and alternatives. Those schemes and structures, as we have seen above, have critical implications for whether the efficiency and viability of public ledger platforms. It is not at all obvious how most of the public ledger currency platforms could manage a large public ledger platform requiring significant resources from laborers and other actors especially when the platforms limit the ability of the platforms to control input and output prices. And as I mentioned earlier these public ledger platforms are very different from large successful open source projects such as Android and Linux since those open source projects do not require the incentive schemes for the provision of significant amounts of labor and resources to running the platform.

We are unfortunately wading into a sea of uncertainty when it comes to how the incentive schemes and governance structures will evolve, and their implications for the operational and economic efficiency of these public ledger platforms. We simply do not know at this point. It is certainly adventurous to embrace mechanistic rules and open source governance structures in the place of using the price mechanism and for-profit enterprises for what aspires to be a large complex industry.

This discussion has, however, ignored the possibility that the public ledger platforms could enable new financial services products that rely on the ability to write applications for the platform generally and the containers in particular.

Developers write applications that work with the open public ledger platform. It is possible that as we have seen with mobile phones it will be possible to accelerate financial services innovation by pushing innovation out to the edge into the hands of a distributed network of entrepreneur-developers. In addition, it is possible to use the public ledger platform for transactions that are based on software-enabled contracts. It is possible for the container to carry software code that includes rules concerning the transaction. Many supporters of the public ledger platforms see many opportunities in developing innovations that rely on the ability to program the containers.

In principle, one could do this with any open platform and a number of Internet-based financial services platforms including PayPal have created APIs and are encouraging a developer

community. However, most financial services platforms tend to be closed for security reasons and there has not been great enthusiasm generally for developing open platforms. Nevertheless, it is just as possible to encourage application development on a centralized proprietary platform such as the iPhone as on a decentralized open source platform such as Android. Indeed, Android is typically a second choice for developers because of the cost of developing applications for multiple incompatible versions of Android (as well as many different hardware configurations).

VII. Open Questions and Issues

Public ledger currency platforms are complex organizations. We have much to learn about how they will evolve over time. This paper has just made some preliminary observations that will hopefully kick off a discussion. The following questions and issues require further consideration.

- What is the optimal governance structure for these platforms and is it possible for them to adopt this governance structure given their origin as loosely governed open source projects?
- How can these platforms provide efficient incentives for demanders of transactions and suppliers of platform services given that they have adopted protocols that limit their ability to establish prices to either demanders or suppliers?
- Can these platforms develop governance structures and incentive schemes that would enable them to offer stable currencies by mimicking the limited discretion approaches that many successful and sophisticated central banks adopt?
- How much more efficient are public ledger currency platforms than proprietary closed financial services platforms in providing similar services?
- Once one accounts for operational and economic inefficiencies resulting from the governance systems used by public ledger currency platforms, and the imposition of regulation on financial service providers that rely on the public ledger currency platforms, are the public ledger currency platforms more efficient than proprietary closed financial services platforms?
- Does the ability to write applications (including rules-based transactions) for the open public ledger software platform more than compensate for any deficiencies these platforms have in other dimensions?
- Is it possible to achieve the benefits of distributed application development from proprietary centralized but open platforms without incurring the costs and inefficiencies that may result from relying on the decentralized public ledger model?

Analyzing these questions requires careful analysis and evidence. None have immediate and unambiguous answers. That said it is not at all obvious that public ledger currency platforms provide efficient or viable vehicles for developing financial services products.

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