

The Price of a Digital Currency

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Abstract

This paper introduces a pricing relation for digital currencies as the globally-traded assets in frictionless markets. Using the pricing relation, the paper finds that Bitcoin, unlike the other globally traded assets such as commodities and currencies, is not priced globally. It also documents Bitcoin price discrepancies for various pairs of denominated currencies namely the U.S. dollar, euro, British pound, and Canadian dollar. The price discrepancies reach a peak at 27%, which is almost three times more than the maximum Bitcoin price disparity in the US dollar documented in [Yermack \(2014\)](#). Finally, the paper studies the theoretical price and volatility of cryptocurrencies with zero fundamental values and finds that they have much lower price volatility. And therefore it is much easier to regulate, use, and hold them.

Keywords: Bitcoin; Pricing; Volatility; Zero Fundamental Value.

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1 Introduction

A major innovation in the financial technology (FinTech), such as blockchain, has great potential to impact the world economy. For example, the foreign exchange market is the largest market by an average trading turnover of \$5 trillion per day,¹ and cryptographic digital currencies (cryptocurrencies) equipped with blockchain have potential to change this market through direct international peer-to-peer electronic payments and forgoing the conventional currency trading channels of financial institutions. And those changes will increase customers' welfare while reduce significantly banks' revenues from currency trading fees and governments' revenues from currency trading taxes.

However, Bitcoin trading turnover is only around 0.001 percent of the total foreign exchange trading turnover.² And to a much higher turnover, Bitcoin and other digital currencies face two major challenges; Firstly, their prices are too volatile and secondly there is still a lack of government regulations at domestic and international levels. These two challenges are connected and very complex. In fact, the lack of regulations may increase digital currency price volatilities, and high price volatilities make their regulation more complex. To highlight their complexity, we should consider that even pricing and regulating extant fiat currencies are difficult and complex. Thus, pricing and regulating digital currencies, which are equipped with young technologies and have many unknown aspects, are indeed more complex.

To shed some light on the digital currency pricing, this paper introduces a simple pricing relation for globally-traded digital currencies in frictionless markets. In fact, the pricing relation is an extended version of the triangular arbitrage relation, which suggests that there is no price discrepancy among any three exchange rates in a frictionless market. Therefore, a competitive digital currency should be exchangeable with any competitive fiat currency without a pricing discrepancy too. As a result, we are able to study the price of digital currencies from a global perspective and not necessarily from the perspective of a U.S. representative agent. In particular, the relation suggests that the appreciation rate of a fiat currency w.r.t. a digital currency equals to a multiplier of the average appreciation rate of the denominated fiat currency w.r.t. a basket of the other fiat currencies minus the average appreciation rate of the digital currency w.r.t. a basket of all fiat currencies. The later is the value changes of a digital currency from a global perspective.

By implementing the pricing relation to data, the paper presents some evidences that Bitcoin is not priced globally unlike the other globally traded assets such as commodities and fiat currencies. In other words, Bitcoin is mainly priced in the U.S. dollar and

¹Trading in foreign exchange markets averaged \$5.1 trillion per day in April 2016 [BIS \(2017\)](#).

²Considering Bitcoins' trading of an average \$50 million per day, its market share is about 0.001percent (\approx \$50M/\$5T). For more statistics of Bitcoins' trading see [Böhme, Christin, Edelman, and Moore \(2015\)](#).

that the other denominated-currency prices of Bitcoin are calculated through bilateral exchange rates with respect to the U.S. dollar. In addition, the paper also documents Bitcoin price discrepancies for various pairs of denominated currencies such as British pound, Canadian dollar, euro, and the U.S. dollar. The price discrepancies reach a peak at 27%, which is almost three times more than the maximum Bitcoin price disparity in the US dollar documented in [Yermack \(2014\)](#).

More importantly, the suggested pricing relation helps to study the price and volatility of digital currencies with a zero fundamental value (see [Cheah and Fry \(2015\)](#) and [Athey, Parashkevov, Sarukkai, and Xia \(2016\)](#)). In particular, the the pricing relation suggests that the price of a digital currency with a zero fundamental value should not change w.r.t. a basket of all fiat currencies. The intuition is that when a fiat currency appreciates relative to the other fiat currencies, it should appreciate relative to a globally traded digital currencies too. However, there is no fundamental value such as a claim on a commodity or some lawful money to strengthen or weaken the digital currency relative to the fiat currencies. Thus the price of a digital currency may change relative of a fiat currency but does not change w.r.t. all fiat currencies on average. Consequently, the price of a digital currency with a zero fundamental value should be closely related to the price of fiat currencies, and its volatility should be even slightly lower than the volatility of each fiat currency. And therefore regulating, using, and holding a digital currency with a zero fundamental value is much easier than the extant cryptocurrencies.

When the price of a digital currency does not vary relative to a basket of fiat currencies, the digital currency performs as a medium of exchange, a store of value, and a unit of account. These characteristics of a fiat currency should hold for a “real” digital currency, as suggested in [Yermack \(2014\)](#). In addition, ensuring users about the value of a digital currency disentangles them from predicting the return and volatility of digital currency price fluctuations, which is a very important concern of digital currency users that the extant cryptocurrencies (like Bitcoin) do not address.

When the price of a digital currency varies relative to a basket of fiat currencies, it generates a volatility that brings extra costs to the digital currency users. Because, users may need to spend time and resources to predict the digital currency price and volatility, which are hard exercises even for fiat currencies. In addition users may bear extra regulation costs (risks), due to the lack or complexity of regulations. Consequently, as the legitimate core competency of digital currencies is providing regular functions of fiat currencies with less transaction costs, such as less transaction time and less transaction fees,³ the higher volatility of a digital currency may affect its core competency. In

³A digital currency may be used in illegal trading, money laundering, and tax evasion ([Böhme, Christin, Edelman, and Moore \(2015\)](#)). In addition, this paper does not consider digital currency options to donate to organization like Wikileaks or to conduct business anonymously, for more details see

other words, the higher utilization costs of a volatile digital currency may offset its lower transaction costs.

Finally, the paper studies an economy with zero-fundamental-value digital currencies and various participants, including digital currency issuers, market makers, users, and speculators.

2 Digital Currencies

Digital currencies allow for instantaneous domestic and international transactions and transfer-of-ownership. And they can be used for a direct peer-to-peer electronic payment to prevent transaction time and fees of going through a financial intermediary. However, such transaction may be subject to a double-spending problem. [Nakamoto \(2008\)](#) proposes cryptography as a solution to prevent double-spending.⁴ [Barber, Boyen, Shi, and Uzun \(2012\)](#) study weaknesses and strengths of the cryptography and ways to either improve or build on cryptocurrencies like Bitcoin.⁵

[Catalini and Gans \(2016\)](#) study in detail the impact of blockchain and cryptocurrencies in reducing the time and cost of transaction and identify two major reductions in the verification cost and the networking cost. [Böhme, Christin, Edelman, and Moore \(2015\)](#) find that updating the blockchain entails an undesirable delay that makes Bitcoin less competitive for domestic transactions. However, [Tasca \(2015\)](#) and [He *et al.* \(2016\)](#) among many others suggest that digital currencies are very competitive for international transactions.

Although both market participants and financial regulators agree on the time and cost advantage of digital currencies ([Khapko and Zoican \(2017\)](#), [Luther \(2015\)](#)) suggests that monetary stability and government supports play a major role in the competitiveness of digital currencies. And [Evans \(2014\)](#) finds that deficiencies in the incentives and government regulations can make digital currencies inferior.

[Yermack \(2014\)](#) raises the importance of Bitcoin's price volatility and its current functionality that does not fit to those of a real currency, which are endorsed in a later study of [Ali, Barrdear, Clews, and Southgate \(2014\)](#).⁶ In particular, [Yermack \(2014\)](#)

[Grinberg \(2011\)](#).

⁴Cryptography turns hashing transaction into an ongoing chain of hash-based proof-of-work, forming a record that cannot be changed without redoing the proof-of-work, so called blockchain.

⁵[Grinberg \(2011\)](#) suggests that potential users should be aware of various risks of a young and developing digital currency like bitcoin. Since then, several papers studies various aspect of Bitcoins, for example [Moore and Christin \(2013\)](#) reports a 45% risk of ceased operation of Bitcoin exchanges, [Harvey \(2015\)](#) reviews the Bitcoin technology, [Athey, Catalini, and Tucker \(2017\)](#) studies privacy aspects of Bitcoin through an experiment, and [Yermack \(2017\)](#) studies the impacts of blockchain on corporate governance.

⁶For more information about Bitcoin price and volatility see [Kristoufek \(2015\)](#), [Hencic and Gouriéroux](#)

finds that Bitcoin's price is much more volatile than extant fiat currencies, and that it prevents them to perform properly as a medium of exchange, a store of value, and a unit of account.

Dwyer (2015) finds that Bitcoin's complexity is a disadvantage, as it requires blind faith in anonymous people's expertise. While domestic regulations of digital currencies are complex, He *et al.* (2016) argue that their international regulations are even harder and more complex. This complexity is not surprising, considering that even the price modeling and international regulations of extant fiat currencies are very complex.

In sum, developments of the blockchain technology as well as the supporting legal and security issues have materialized a basement for the realization of digital currencies, which can reduce cost and time of daily international payments. However, cryptocurrency users and financial regulators still share a great concern about cryptocurrency price volatility as well as international regulations. This paper investigates cryptocurrency price dynamics from an international perspective and finds that the price of a cryptocurrency with a zero fundamental value is closely related to the price of fiat currencies and its volatility level is even slightly lower than those of extant fiat currencies. And therefore, the international regulation of a zero-fundamental-value cryptocurrency is much easier though avoiding the higher complexity raised from very high volatility and unruly price movements of extant cryptocurrencies.

3 Bitcoin Mispricing

In this section, I test Bitcoin mispricing from an international perspective. In particular, I test price discrepancies among several sets of three exchange rates of Bitcoin and fiat currencies, and I compare price discrepancies of Bitcoin with the U.S. dollar price disparities of Bitcoin.

A simple rule, which is known as the law of one price, implies that a currency should be traded at the same rate in various exchanges in the absence of frictions. Yermack (2014) documents a disparity of around 7% between the high and low quotes of Bitcoin in five exchanges with the highest trading volume quoted U.S. dollar prices for one bitcoin.

Another simple rule in the foreign exchange markets is that a pricing discrepancy among any three exchange rates generates an arbitrage opportunity which is usually exploited quickly by algorithmic traders in a competitive market. In other words, when an exchange rate between two currencies (e.g., USD/EUR) is not aligned with their

(2015), Donier and Bouchaud (2015), Kaminski and Gloor (2014), Ciaian, Rajcaniova, and Kancs (2015). And for more information about Bitcoin price modelling see Athey, Parashkevov, Sarukkai, and Xia (2016) and Bolt and van Oordt (2016)

implicit exchange rate through a third currency (e.g., USD/GBP times GBP/USD), a trader equipped with a machine recognizes it quickly, and uses a triangular arbitrage strategy of exchanging the three rates simultaneously (e.g., USD/GBP, GBP/USD, and USD/EUR) to lock in a zero-risk profit. Therefore, exchange rates adjust quickly and a profitable triangular arbitrage is very rare in a competitive exchange market.

Meanwhile, Figure 1 presents evidences of price discrepancies for Bitcoin trading at Bitcoin exchange markets. In particular, Figure 1 shows the percentage differences between the implicit exchange rate of bitcoins denominated in USD, EUR, CAD, and GBP traded at the three largest Bitcoin exchange markets, namely the Coinbase (GDAX), Kraken, and Localbtc (LocalBitcoins) and the observed fiat currency exchange rates.⁷ For example the left graph for Localbtc is the changes in the USD price of one unit of Bitcoin (traded at the Localbtc) relative to its EUR price (traded at the Localbtc) divided by the changes in the USD/EUR exchange rate. As can be seen, the implicit rates deviate dramatically up to 27% from the observed rates. The maximum price discrepancies is more than three times higher than the maximum price disparity documented in [Yermack \(2014\)](#). The deviations have been higher at the introduction of the markets and then they decrease and approach to zero for EURUSD ratio of bitcoins traded at the Kraken and Coinbase and GBPUSD ratio of bitcoins traded at the Coinbase. However, the deviations are still high at the Localbtc, which has lower trading turnover than the Kraken and Coinbase.

In the next section, I study price changes of Bitcoin as a globally-traded asset.

4 Price of a Globally-Traded Asset and its Denominated Currency

The global value of globally traded assets, like currencies, commodities, and cryptocurrencies, is better investigated from a global perspective. For example, Australian dollar may slightly appreciates w.r.t. Canadian dollar, while its global value may highly depreciates (w.r.t. to a basket of fiat currencies) at the same time. In other words, to investigate the global value of a currency, it is better to study its average appreciation rate of relative to a basket of other currencies rather than its bilateral rates. For more information about the relation between global and bilateral appreciation rates of currencies, see [Aloosh and Bekaert \(2017\)](#).

From the same perspective, as prices of global assets are often given in the U.S. dollar and the appreciation rate of the U.S. dollar affects the appreciation rate of asset prices, any asset that is priced globally, like commodities, currencies, and cryptocurrencies, is

⁷Bitcoins in the UK British pound at the Localbtc, in the UK British pound at the Coinbase, and in Canadian dollar at Kraken are not available.

better to be investigated from a global perspective. For example, when the global value of the U.S. dollar increases (decreases), we expect the U.S. dollar price of commodities to decrease (increase).

Table 1 reports summary statistics of the price changes of several commodities, currencies, and bitcoins w.r.t. the U.S. dollar. In Panels II and III, when the U.S. dollar appreciates (depreciates) by more than 0.5% on average, commodity and foreign currency prices depreciate (appreciate) by around 0.3% to 0.8% (0.1% to 0.9%) on average. This is consistent with our expectation given earlier. However, Bitcoin prices appreciate by around 0.0% to 2.1% when the U.S. dollar appreciates by 0.5% on average in the left side of Panel IV. And bitcoins prices at Localbtc depreciates by 0.6% and bitcoins prices at Coinbase and Karken appreciates by 0.5% and 0.1% respectively in the right side of Panel IV, when the U.S. dollar appreciates by 0.5% on average. Thus, there are some inconsistencies in Bitcoin price movements and Bitcoin does not seem to be a globally priced asset.

Furthermore, I investigate correlations between the global value changes of the U.S. dollar and the U.S. dollar price changes of commodities, currencies, and cryptocurrencies in Table 2. As can be seen in Panels I and II, the price changes of commodities and currencies are negatively correlated with the price changes of the U.S. dollar, when either it appreciates or depreciates more than 0.5%. This is consistent with our expectation. However, the correlations between Bitcoin price changes (traded at the Coinbase and Karken) and the U.S. dollar price changes are close to zero. And Bitcoin price changes (traded at the Localbtc) are slightly positively correlated with the U.S. dollar price changes, when the U.S. dollar depreciates by more than 0.5%. Therefore the U.S. dollar price changes of Bitcoin are not persistently negatively correlated the global value changes of the U.S. dollar.

In sum, in contrast to commodities and fiat currencies, Bitcoin does not show the price dynamic of a globally priced asset. To investigate further the Bitcoin prices from a global perspective, I present a pricing relation for the globally traded assets in frictionless markets. In particular, I extend the triangular arbitrage relation to separate the underlying asset (such as Bitcoin) value changes from their denominated currency value changes.

5 A Global Pricing

Assume an agent that uses a domestic fiat currency H and a digital currency D, and that she can exchange D and H, as follows:

$$\Delta s_{D,t+1}^H = s_{D,t+1}^H - s_{D,t}^H \quad (1)$$

where, $s_{D,t+1}^H$ is the log exchange rate of a digital currency D per unit domestic fiat currency H at time t, and $\Delta s_{D,t+1}^H$ is the change in the log exchange rate of currency H w.r.t. currency D from time t to time t+1. In the absence of triangular arbitrage, we have;

$$s_{D,t+1}^H = s_{i,t+1}^H - s_{i,t+1}^D, \quad \forall i \quad (2)$$

thus,

$$\Delta s_{D,t+1}^H = \Delta s_{i,t+1}^H - \Delta s_{i,t+1}^D, \quad \forall i \quad (3)$$

where, $i (\neq H)$ is a foreign fiat currency in the market. Equation 2 suggests that the direct exchange rate for currencies D and H equals to their indirect exchange rate through exchanging currency i. In other words, in the absence of a triangular arbitrage opportunity, there is no discrepancy among any three exchange rates, as in Equation 2. When Equation 2 holds at any point of time after t, we get a similar relation among exchange rate changes of any three exchange rates, as in Equation 3.

For an economy with N fiat currency, Equation 3 holds for N-1 foreign currency 'i's ($\neq H$). And by averaging across N-1 equations, we get;

$$\Delta s_{D,t+1}^H = \frac{1}{N-1} \sum_{i \neq H}^{N-1} (\Delta s_{t+1}^H - \Delta s_{t+1}^D), \quad (4)$$

or,

$$\Delta s_{D,t+1}^H = \frac{1}{N-1} \sum_{i \neq H}^{N-1} (\Delta s_{t+1}^H) - \frac{1}{N-1} \sum_{i \neq H}^{N-1} (\Delta s_{t+1}^D), \quad (5)$$

where, N is the number of available fiat currencies (including H). Equation 4 suggests that the direct exchange rate for currencies D and H equals to the average indirect exchange rate through exchanging for N-1 foreign fiat currencies, 'i's ($\neq H$). In other words, Equation 4 suggests that the appreciation rate of fiat currency H w.r.t. digital currency D equals to average appreciation rate of H minus average appreciation rate of D w.r.t. N-1 different fiat currency 'i's.

By the same token, Equation 5 suggests that the appreciation rate of H w.r.t. D equals to the average appreciation rate of H w.r.t. a basket of N-1 fiat currencies minus

average appreciation rate of D w.r.t. a basket of N-1 fiat currencies. In the second term of the right hand side of Equation 5, $\frac{1}{N-1} \sum_{i \neq H}^{N-1} (\Delta s_{t+1}^D)$, the fiat currency H is not included in the basket of fiat currencies. Therefore, to provide an equation with a general term for the appreciation rate of the digital currency D w.r.t. a basket of all fiat currencies (including H), we can subtract $\frac{1}{N-1} \Delta s_{H,t+1}^D$ from both sides of Equation 5, as follows;

$$\Delta s_{D,t+1}^H - \frac{1}{N-1} \Delta s_{H,t+1}^D = \frac{1}{N-1} \sum_{i \neq H}^{N-1} (\Delta s_{t+1}^H) - \frac{1}{N-1} \sum_{i \neq H}^{N-1} (\Delta s_{t+1}^D) - \frac{1}{N-1} \Delta s_{H,t+1}^D, \quad (6)$$

$$\Delta s_{D,t+1}^H + \frac{1}{N-1} \Delta s_{D,t+1}^H = \frac{1}{N-1} \sum_{i \neq H}^{N-1} (\Delta s_{t+1}^H) - \frac{1}{N-1} \sum_i^N (\Delta s_{t+1}^D), \quad (7)$$

$$\frac{N}{N-1} \Delta s_{D,t+1}^H = \frac{1}{N-1} \sum_{i \neq H}^{N-1} (\Delta s_{t+1}^H) - \frac{N}{N-1} \frac{1}{N} \sum_i^N (\Delta s_{t+1}^D), \quad (8)$$

$$\Delta s_{D,t+1}^H = \frac{N-1}{N} \left[\frac{1}{N-1} \sum_{i \neq H}^{N-1} (\Delta s_{t+1}^H) \right] - \left[\frac{1}{N} \sum_i^N (\Delta s_{t+1}^D) \right], \quad (9)$$

$$\Delta s_{D,t+1}^H = \frac{N-1}{N} CB_{t+1}^H - CB_{t+1}^D. \quad (10)$$

CB_{t+1}^H is the log value changes of currency H relative to a basket of N-1 fiat currencies (excluding H) and CB_{t+1}^D is the log value changes of currency H relative to a basket of N fiat currencies (including H). Equation 10 enables us to use the same global appreciation rate of D, CB_{t+1}^D , for evaluating the bilateral appreciation rate of any fiat currency H w.r.t. D.

In other words, Equation 10 expresses bilateral value changes of H w.r.t. D as a function of global value changes of currency H as well as global value changes of currency D. Consequently, by modeling the average log changes in the value of currency D w.r.t. a basket of fiat currencies, CB_{t+1}^D , we would be able to explain the dynamics of any bilateral rates of fiat currencies w.r.t. D.

Although the pricing relation in Equation 10 is developed to study Bitcoin prices, it is very useful to study the price of any globally traded asset. In fact, the model is independent from the underlying global asset, and it assumes only that there is no pricing discrepancy in frictionless markets. Next section provides an implication of Equation 10.

5.1 The Global Value of Bitcoin

Using Equation 10, Table 3 reports the mean and standard deviation of the U.S. dollar value changes w.r.t. a basket of G10 currencies (USD), the U.S. dollar value changes

of Bitcoin ($\mathbb{B}_{Coinbase}^{USD}$), and the global value changes of Bitcoin ($\mathbb{B}_{Coinbase}^{Global}$). As can be seen, the U.S. dollar is appreciated 8% on average, and the U.S. dollar and global value of Bitcoin is appreciated 36% and 44%, respectively. However, the standard deviation of $\mathbb{B}_{Coinbase}^{Global}$ and $\mathbb{B}_{Coinbase}^{USD}$ (64% and 63% respectively) are around 7 times more than the standard deviation of USD. This extremely high volatility is much higher than most of economic factors and makes Bitcoin regulations very hard at the international level.

Figure 2 plots the observed U.S. dollar value of Bitcoin (the blue line) and its global value (the red line). As the global value of U.S. dollar is appreciated in the sample period from January 2014 to April 2017, the global value of Bitcoin is higher than the U.S. dollar value of Bitcoin. This makes Bitcoin looks even more overpriced to those who believe that Bitcoin has been overpriced. For example, the global value of Bitcoin is around 18.9% more than the U.S. dollar value of Bitcoin (1246.38\$) in April 2017.

In the next section, we explore compare some properties of $\mathbb{B}_{Coinbase}^{Global}$ with the fiat currencies such as the U.S. dollar, euro, British pound, and Canadian dollar, and three commodities, namely oil, gold, and sugar.

6 Correlations

To emphasize Bitcoin mispricing from an international perspective, Figure 2 shows the 66-day rolling (with overlap) correlations between Bitcoin prices in the U.S. dollar, Canadian dollar, British pound, and Euro traded on Coinbase (GDAX), Kraken, and Localbtc (LocalBitcoins). For example, the top left graph presents the 66-day correlation between the U.S. dollar and euro price changes of Bitcoin traded on the Coinbase. As can be seen, the correlation is increasing from around 85% in July 2015 to 98% in April 2017. This confirms that Bitcoin mispricing is reducing for the trades on Coinbase, which is also consistent with Figure 1.

Meanwhile, the correlation between the U.S. dollar and euro price changes of Bitcoin is a function of variances and covariances of the U.S. dollar and euro too. Therefore, I test whether low correlations between the two different denominated prices of Bitcoin is related to the value changes of the denominated currencies. In particular, I test whether the correlations between denominated-neutral prices of Bitcoin is 100%.

The top left graph of Figure 2 also shows the 66-day rolling correlations between the global prices of Bitcoin (the red lines). As can be seen, the correlation between denominated-neutral global prices of Bitcoin (the red line) covaries closely with the correlation between observed prices of Bitcoin (the blue line) on Coinbase. More importantly, the global price correlation is lower than 100%. Therefore, Bitcoin is not priced globally and it may be due to the fact that Bitcoin prices are very volatile.

We get a similar conclusion from the top right graph of Figure 2. The 66-day rolling correlations between Bitcoin the observed Bitcoin price changes in the U.S. dollar and British pound on Coinbase is increasing from around 76% in July 2015 to 97% in April 2017. And the global price correlation is lower than 100%, increasing from around 76% in July 2015 to 98% in April 2017.

The middle two graphs in Figure 2 present correlations between Bitcoins traded on Kraken. As can be seen, the correlation between the observed U.S. dollar and euro price changes of Bitcoins on the Kraken are less than those on Coinbase, and the correlation between the observed U.S. dollar and Canadian dollar price changes of Bitcoins on the Kraken is even decreasing at the end of period.

The bottom two graphs present correlations between Bitcoins traded on Localbtc, where its trading turnover is much lower than the Coinbase and Kraken. The correlations of Bitcoins traded in the U.S. dollar, euro, and Canadian dollar are very low in Localbtc. This is also consistent with higher Bitcoin price discrepancies on Localbtc in Figure 1.

To summarize, Bitcoin prices correlations have been increasing on Coinbase and Kraken, which might be due to the fact that the Bitcoin are quoted more competitively and therefore there are less Bitcoin mispricing in those exchanges. In addition, all graphs shows that the correlations between the global value changes of Bitcoin (the red lines) covary closely with the observed price correlations of Bitcoin (the blue lines), and they are indeed lower than 100%. This suggest that Bitcoin is not a globally priced asset.

To emphasize the difference between a global and a single currency perspective for the correlations among globally priced assets, Table 4 reports correlations among three commodities as well as three fiat currencies from a U.S. dollar perspective as well as from a global perspective. In the left side of Panel I, the correlations among the observed U.S. dollar price changes of oil, sugar and gold vary from 5% to 10%. In the right side of Panel I, the correlations among the global value changes of oil, sugar and gold vary from -2% to 8%. In particular, oil and gold seems to be slightly positively correlated from the U.S. dollar perspective, while they are indeed slightly negatively correlated from a global perspective.

Similarly, in the left bottom of Panel I, the correlations among CAD, EUR, and GBP vary from 41% to 53%, while their correlations vary from -37% to 0% in the right bottom of Panel I. In particular, CAD and EUR seem to be +41% correlated from the U.S. dollar perspective, but they are actually negatively correlated from a global perspective. And GBP and EUR seem to be +53% correlated from the U.S. dollar perspective, but they are actually not correlated at all from a global perspective.

In Panel II, the correlations among Bitcoin prices vary from one denominated fiat currencies to another one traded at various exchange markets, but the global value corre-

lations in the right panels are similar to the observed price correlations in the left panels. This highlights the difference between Bitcoin and the other globally priced assets such as commodities and fiat currencies.

Table 5 reports the correlation between Bitcoin and USD, EUR, CAD, and GBP from a single perspective and a global perspective. The left panel reports correlations between the observed U.S. dollar, euro, Canadian dollar, and British pound value changes of Bitcoin and the appreciation rates of the U.S. dollar, euro, Canadian dollar, and British pound value changes w.r.t. a basket of G10 currencies. For example, the third row of the second column shows that the correlation between the U.S. dollar price changes of Bitcoin traded on Coinbase ($\mathbb{B}_{Coinbase}^{USD}$) and the U.S. dollar appreciation rates w.r.t to a basket of G10 currencies (USD) is 8%. In the three left panels, the observed price changes of Bitcoin are positively correlated with five out of nine appreciation rates of denominated currencies (the bold numbers); in particular, the observed U.S. dollar prices of Bitcoin (\mathbb{B}^{USD}) are positively correlated with the USD in all three exchanges. This is the opposite of our expectation for a globally priced asset. In addition, the observed euro price changes of Bitcoin (\mathbb{B}^{EUR}) are positively correlated with the EUR in two out of three exchanges. This might be due to the fact that Bitcoin is mainly traded and priced in the U.S. dollar and euro.

The right three parts of Panel I report correlations between global value changes of Bitcoin and USD, EUR, CAD, and GBP a global perspective. For example, the third row of the sixth column shows that correlation between the global value changes of Bitcoin traded on Coinbase and the USD is 27%. As can be seen, the global value changes of Bitcoin exhibit similar correlations with fiat currencies in each column except for those associated to the denominated currencies and those in the bottom panel (Bitcoins traded on Localbtc). In addition, there are less similarities among correlations between global value changes of Bitocins and USD. This might be due to the fact that Bitcoin is priced mainly in the U.S. dollar.

In the next section, I use Equations 11 and 12 to study the expected price dynamics of digital currencies.

7 A Digital Currency with a Zero Fundamental Value

In contrast to fiat and commodity currencies, a digital currency with a zero fundamental value is not tied to any economic value or governmental supports. Therefore, its price should be constant relative to a basket of fiat currencies. In other words, the price of a digital currency D with a zero fundamental value should not change relative to a basket

of fiat currencies;⁸

$$CB_{t+1}^D = 0. \quad (11)$$

Equation 11 provides interesting outcomes. Under this equation, the price changes of digital currencies with zero fundamental values are closely related to price changes of fiat currencies. In particular, by replacing Equation 11 in Equation 10, the appreciation rate of a fiat currency H w.r.t. a digital currency D (with a zero fundamental value) equals to:

$$\Delta s_{D,t+1}^H = \frac{N-1}{N} CB_{t+1}^H. \quad (12)$$

As a result, the appreciation rate of a fiat currency H w.r.t. a digital currency D equals to a constant multiplier of the appreciation rate of H w.r.t. a basket of fiat currencies. For example, when the value of currency H appreciates by 0.50% relative to a basket of 9 foreign fiat currencies, the agent should be able to buy 0.45% ($= \frac{9}{10} \times 0.50\%$) more of the digital currency D.

Equation 12 suggests that the volatility of a zero-fundamental-value digital currency is even lower than the volatility of a fiat currency ($\sigma(\Delta s_{D,t+1}^H) < \sigma(CB_{t+1}^H)$ as $\frac{N-1}{N} < 1$). In addition, the price of a digital currency with a zero fundamental value as in Equation 12 does not depend on supply of the digital currency, its competitor digital currencies, or investor sentiment. Consequently, regulating, holding and using such a digital currency is much easier. This is very important to regulators, as the prices of extant cryptocurrencies are highly volatile and unruly.

In addition, as a digital currency with a zero fundamental value has a low volatility, it serves reliably as a store of value, as a unit of account in commercial markets, and a medium of exchange. In the next section, we study an economy with a zero-fundamental-value digital currency.

7.1 Market Conditions for a Digital Currency with a Zero Fundamental Value

In this section, we explore details of a market for a digital currency that follows the price condition suggested in Equation 12. In particular, we study its market rate quotes, bid-ask spread, market making, speculating, users' exchange risk, and an economy with several of such digital currency in next sections.

⁸While its price may change relative to an individual fiat currency. The intuition is that when a fiat currency appreciates w.r.t. the other fiat currencies, it should appreciate w.r.t. a globally traded digital currency too.

7.1.1 A Zero-Fundamental-Value Digital Currency Quote

Assuming that the real time bid and ask rate of fiat currencies is given, and that the digital currency issuer quotes a mid-price appreciation rate to determine the price of a zero-fundamental-value digital currency, as follows;

$$CB_{t+1}^{H,mid} = \sum_{i \neq H}^N \left[\left(\frac{s_{i,t+1}^{H,bid} + s_{i,t+1}^{H,ask}}{2} \right) - \left(\frac{s_{i,t}^{H,bid} + s_{i,t}^{H,ask}}{2} \right) \right], \quad (13)$$

thus,

$$s_{D,t+1}^H = s_{D,t}^H + \frac{N-1}{N} CB_{t+1}^{H,mid}. \quad (14)$$

The issuer matches buying and selling orders of users at the quoted price of a zero-fundamental-value digital currency. Consequently, if there are trading costs for a digital currency, users will buy and sell at slightly different prices, as follows;

bid rate:

$$s_{D,t+1}^{H,bid} = s_{D,t}^H + \frac{N-1}{N} CB_{t+1}^{H,mid} - f_{D,t+1}^{H,bid}. \quad (15)$$

ask rate:

$$s_{D,t+1}^{H,ask} = s_{D,t}^H + \frac{N-1}{N} CB_{t+1}^{H,mid} + f_{D,t+1}^{H,ask}. \quad (16)$$

where $0 \leq f_{D,t+1}^{H,bid}$ is a selling cost and $0 \leq f_{D,t+1}^{H,ask}$ is a buying cost for a zero-fundamental-value digital currency.

7.1.2 Bid-Ask Spreads

Assume that a user with a domestic fiat currency H buys (sells) a product from (to) a foreign company, and that she has two choices to pay (receive) its price in a foreign fiat currency K; Firstly, a direct exchange of the domestic and foreign fiat currencies (H-K) in a fiat currency exchange market, and secondly using a digital currency for an indirect exchange of the domestic and foreign fiat currency (H-D and D-K) in a digital currency exchange market. The difference between the two choices is that her payment is subject to one bid-ask spread in the first choice and it is subject to two bid-ask spreads in the second choice. To preserve better deals in a digital currency market than their equivalence in a fiat currencies market, she should get:

$$f_{D,t+1}^{H,ask} \leq \min \left\{ \frac{f_{i,t+1}^{H,ask}}{2} \right\} \quad \& \quad f_{D,t+1}^{H,bid} \leq \min \left\{ \frac{f_{i,t+1}^{H,bid}}{2} \right\} \quad \forall i. \quad (17)$$

Equation 17 suggests that bid-ask spread of exchanging H for D should be less than or equal to the half of the minimum bid-ask spread of exchanging H for any other fiat

currency.⁹ The intuition is that she pays only one transaction cost to exchange currencies H and K, while she pays two transaction costs in the digital currency market for an equivalent exchange of currencies H and K. For example, assume that she should pay the price of a product in currency K. Through indirect exchanges for digital currency D, she gets:

$$s_{D,t+1}^{K,ask} - s_{H,t+1}^{D,ask} = s_{D,t+1}^{K,mid} + f_{D,t+1}^{K,ask} - \left(s_{H,t+1}^{D,mid} - f_{H,t+1}^{D,ask} \right), \quad (18)$$

$$s_{D,t+1}^{K,ask} - s_{H,t+1}^{D,ask} = s_{H,t+1}^{K,mid} + \left(f_{D,t+1}^{K,ask} + f_{H,t+1}^{D,ask} \right), \quad (19)$$

assuming that $f_{D,t+1}^{H,ask} = f_{H,t+1}^{D,bid}$, we get:¹⁰

$$s_{D,t+1}^{K,ask} - s_{H,t+1}^{D,ask} = s_{H,t+1}^{K,mid} + \left(f_{D,t+1}^{K,ask} + f_{D,t+1}^{H,bid} \right), \quad (20)$$

By substituting Equation 17 in Equation 20, we get:

$$s_{D,t+1}^{K,ask} - s_{H,t+1}^{D,ask} \leq s_{H,t+1}^{K,mid} + \frac{f_{H,t+1}^{K,ask} + f_{K,t+1}^{H,bid}}{2}, \quad (21)$$

assuming that $f_{H,t+1}^{K,ask} = f_{K,t+1}^{H,ask} = f_{H,t+1}^{K,bid} = f_{K,t+1}^{H,bid}$, we get:

$$s_{D,t+1}^{K,ask} - s_{H,t+1}^{D,ask} \leq s_{H,t+1}^{K,mid} + f_{H,t+1}^{K,ask}, \quad (22)$$

$$s_{D,t+1}^{K,ask} - s_{H,t+1}^{D,ask} \leq s_{H,t+1}^{K,ask}, \quad (23)$$

Therefore, as transaction costs are at least twice lower in the digital currency market, Equation 17 ensures that she is better off transacting through a digital currency, D. In other words, if the two parties exchange their fiat currencies directly in the fiat currency market, they either pay more or receive less money, as they should pay higher transaction fees.

⁹When the user exchange K for D, the equation would be:

$$f_{D,t+1}^{K,ask} \leq \min \left\{ \frac{f_{i,t+1}^{K,ask}}{2} \right\} \quad \& \quad f_{D,t+1}^{K,bid} \leq \min \left\{ \frac{f_{i,t+1}^{K,bid}}{2} \right\} \quad \forall i.$$

¹⁰The accurate equation is $f_{D,t+1}^{H,ask} = \frac{1}{s_{H,t+1}^{D,mid}} f_{H,t+1}^{D,bid}$. However to simplify the notations we assume that $f_{D,t+1}^{H,ask} = f_{H,t+1}^{D,bid}$ for the same amount of trading. For example, assume that the transaction cost of exchanging 1.0H for 0.5K is 0.001H, and then we assume that the transaction cost of 0.5K for 1.0H is 0.001H, which is equivalent to a transaction cost of 0.002H to exchange 1.0K for 2.0H.

7.1.3 Market Making

When the market liquidity decreases and the bid-ask spread widen ($0 \ll f_{D,t+1}^{H,bid} \ \& \ f_{D,t+1}^{H,ask}$), a market maker provides liquidity for a profit that equals to his quoted bid-ask spread per unit of transactions. Therefore, the market maker's return per one unit of the digital currency (that he buys and sells) is, as follows:

Market maker's profit =

$$\left(s_{D,t}^H + \frac{N-1}{N} CB_{t+1}^{H,mid} + f_{t+1}^{MM,ask} \right) - \left(s_{D,t}^H + \frac{N-1}{N} CB_{t+1}^{H,mid} - f_{t+1}^{MM,bid} \right), \quad (24)$$

where, $f_{t+1}^{MM,bid} \leq f_{D,t+1}^{H,ask} \ \& \ f_{t+1}^{MM,ask} \leq f_{D,t+1}^{H,bid}$, thus: Market maker's profit=

$$f_{t+1}^{MM,bid} + f_{t+1}^{MM,ask} \leq f_{D,t+1}^{H,ask} + f_{D,t+1}^{H,bid}, \quad (25)$$

Equation 25 shows that a market maker can make a profit smaller than the bid-ask spread.

7.1.4 Speculating

When domestic fiat currency H appreciates relative to digital currency D at time t, speculators buy currency D and hold it until time T, when the H depreciates. Then, they sell their currency D to make a profit, as follows: Speculator's Return

$$= s_{D,T+1}^{H,bid} - s_{D,t+1}^{H,bid} - r(T-t), \quad (26)$$

$$= s_{D,T}^H + \frac{N-1}{N} CB_{T+1}^{H,mid} - f_{D,T+1}^{H,bid} - s_{D,t}^H - \frac{N-1}{N} CB_{t+1}^{H,mid} - f_{D,t+1}^{H,ask} - r(T-t), \quad (27)$$

$$= \left(\frac{N-1}{N} \sum_{i=t}^T CB_{i+1}^{H,mid} \right) - \left(f_{D,t+1}^{H,ask} + f_{D,T+1}^{H,bid} \right) - r(T-t), \quad (28)$$

where, r is the continuously compounding interest rate.

7.1.5 Digital Currency Users

Individuals and companies, who buy or sell products and services in foreign currencies, are increasingly interested in digital currencies. They also interested in evaluating the exchange rate risk of using and holding digital currencies.

On the one hand, costumers prefer a consistent price than a volatile one. On the other

hand, companies also prefer less volatile cash flows to reduce their cost of financing. If costumers and companies hold a pile of digital currencies that are more volatile than fiat currencies, they are exposed to more exchange rate risk. Consequently, they would be better off not holding the digital currency and only use it when they make or receive a payment.

In particular, when the digital currency price changes relative to a basket of fiat currencies;

$$\sigma^2 (\Delta s_{D,t+1}^H) = \left(\frac{N-1}{N} \right)^2 \sigma^2 (CB_{t+1}^H) + \sigma^2 (CB_{t+1}^D) - 2 \frac{N-1}{N} \text{cov} (CB_{t+1}^H, CB_{t+1}^D), \quad (29)$$

where, $CB_{t+1}^D \neq 0$ is the log changes in the value of a digital currency D w.r.t. a basket of fiat currencies. This equation suggests that when the covariance between currency D and H fluctuations is very small, even a tiny volatility in the price of currency D w.r.t. fiat currencies, $\sigma (CB_{t+1}^D)$, increases the volatility of exchange rate between fiat currency H and digital currency D, $\sigma (\Delta s_{D,t+1}^H)$. Unfortunately, extant digital currencies have very high volatilities and a low covariance with the fiat currencies. This increases significantly the exchange rate risk of users.

Furthermore, dollar currencies, e.g., U.S. dollar, Canadian dollar, and Australian dollar, are negatively correlated with European currencies, e.g., Euro, Swiss franc, Norwegian krona, and Swedish krona.¹¹ For example, the correlation between Australian dollar currency basket and Euro is -0.46. Therefore, it is almost impossible to introduce a digital currency with a positive correlation with all of fiat currencies. As a consequence, any digital currency with a volatile price w.r.t. a basket of fiat currencies ($\sigma^2 (CB_{t+1}^D) > 0$) increases exchange rate risks for some users. While, the a zero-fundamental-value digital currency, which does not vary w.r.t. a basket of fiat currencies as in Equation 11, does not increase exchange rate risks of users. Furthermore, although a digital currency with volatile price w.r.t. fiat currencies might be useful for hedging purposes, it will increase exchange rate risk for individuals and companies that use several fiat currencies that are positively correlated with the digital currency.

7.1.6 An Economy with Several Zero-Fundamental-Value Digital Currencies

Political and economic factors among many others may lead to a global economy with multiple zero-fundamental-value digital currencies, where one digital currency is used in a region and another digital currency used in another region. As suggested in this paper, the price of a zero-fundamental-value digital currency is constant relative to a basket of

¹¹For more information about correlation between currency-basket factors, see [Aloosh and Bekaert \(2017\)](#).

fiat currencies. Therefore, the price of zero-fundamental-value digital currencies will be constant relative to each other, as follows:

Following Equation 1, we have: $s_{D,t+1}^H = s_{D,t}^H + \Delta s_{D,t+1}^H$, and $s_{D',t+1}^H = s_{D',t}^H + \Delta s_{D',t+1}^H$ where, D and D' are two different digital currencies and H are their exchange rates w.r.t. a fiat currency H respectively. And, according to Equation 11, we have: $\Delta s_{D,t+1}^H = \Delta s_{D',t+1}^H = \frac{N-1}{N}CB_{t+1}^H$. Thus, we get;

$$s_{D,t+1}^H - s_{D',t+1}^H = s_{D,t}^H - s_{D',t}^H = s_D^{D'} \quad (30)$$

This equation suggests that the difference between the log exchange rates of two zero-fundamental-value digital currencies w.r.t. a fiat currency is constant through time. In other words, under the suggested price condition in Equation 11, the exchange rate of the two zero-fundamental-value digital currencies, $s_D^{D'}$, is constant through time.

8 Conclusions

To shed some light on Bitcoin pricing, this paper introduces a pricing relation for digital currencies as globally-traded assets in frictionless markets. The pricing relation is an extended version of triangular arbitrage relation and helps to separate the global value changes of the denominated currency from the global value changes of the underlying assets.

Using the pricing relation, the paper finds that Bitcoin, unlike the other globally traded assets such as commodities and currencies, is not priced globally. In particular, Bitcoin price changes exhibit different correlations compared to those of commodities and fiat currencies. For example, the correlations between Bitcoin price changes and its denominated currency value changes is not persistently negative.

In addition, the paper documents Bitcoin price discrepancies for various pairs of denominated currencies namely the U.S. dollar, euro, British pound, and Canadian dollar traded on the Coinbase (GDAX), Kraken, and Localbtc (LocalBitcoins). The price discrepancies reach a peak at 27%, which is almost three times more than the maximum Bitcoin price disparity in the US dollar documented in [Yermack \(2014\)](#).

Finally, the paper studies the theoretical price and volatility of digital currencies with zero fundamental values and finds that they have much lower price volatility. And therefore it is much easier to regulate, use, and hold them. This is important to regulators, investors, and users because the extant cryptocurrencies exhibit very high volatilities, which make their pricing and international regulation very complex.

References

- Ali, Robleh, John Barrdear, Roger Clews, and James Southgate. The Economics of Digital Currencies. Bank of England Quarterly Bulletin 2014, 54(3), 276–286.
- Aloosh, Arash, and Geert Bekaert. Currency Factors. Columbia Business School Research Paper No. 17-88, 2017.
- Athey, Susan, Christian Catalini, and Catherine E. Tucker. The Digital Privacy Paradox: Small Money, Small Costs, Small Talk. MIT Sloan Research Paper No. 5196-17, 2017.
- Athey, Susan, Ivo Parashkevov, Vishnu Sarukkai, and Jing Xia. Bitcoin Pricing, Adoption, and Usage: Theory and Evidence. Stanford University Graduate School of Business Research Paper No. 16-42, 2016.
- Barber, Simon, Xavier Boyen, Elaine Shi, and Ersin Uzun. Bitter to Better—How to Make Bitcoin a Better Currency. Financial Cryptography and Data Security 2012, vol. 7397 of Lecture Notes in Computer Science, pp. 399–414.
- Barrdear, John, and Michael Kumhof. The Macroeconomics of Central Bank Issued Digital Currencies, BoE Staff Working Paper 605, 2016.
- Ben-Sasson, Eli, Alessandro Chiesa, Christina Garman, Matthew Green, Ian Miers, Eran Tromer, and Madars Virza. Zerocash: Decentralized Anonymous Payments from Bitcoin. Proceedings of the 2014 IEEE Symposium on Security and Privacy, May 18–21, 2014.
- BIS statistics, Triennial Central Bank Survey of foreign exchange and OTC derivatives markets in 2016. Last access on May 10th, 2017. Available at <http://www.bis.org/publ/rpfx16.htm>
- Bolt, Wilko, and Maarten R.C. van Oordt. On the Value of Virtual Currencies. Bank of Canada Working Paper No. 2016-42, 2016.
- Böhme, Rainer, Nicolas Christin, Benjamin Edelman, and Tyler Moore. Bitcoin: Economics, Technology, and Governance. Journal of Economic Perspectives 2015. 29 (2): 213–238
- Catalini, Christian, and Joshua S. Gans. Some Simple Economics of the Blockchain. MIT Sloan Research Paper No. 5191-16, 2016.

- Cheah, Eng-Tuk, and John Fry. Speculative bubbles in Bitcoin markets? An empirical investigation into the fundamental value of Bitcoin. *Economics Letters* 2015, 130, 32 – 36.
- Ciaian, Pavel, Miroslava Rajcaniova, and d’Artis Kancs. The economics of bitcoin price formation. *Applied Economics*, pages 1–17, 2015.
- Donier, Jonathan, and Jean-Philippe Bouchaud. Why do markets crash? bitcoin data offers unprecedented insights. *PloS one*, 10(10):e0139356, 2015.
- Dwyer, Gerald P. The economics of Bitcoin and similar private digital currencies, *Journal of Financial Stability* 2015, (17), 81-91,
- Evans, David S. Economic aspects of bitcoin and other decentralized public-ledger currency platforms, Discussion Paper, No. 685 University of Chicago Coase-Sandor Institute for Law & Economics Research Paper, 2014.
- Grinberg, Reuben. Bitcoin: An Innovative Alternative Digital Currency. *Hastings Science & Technology Law Journal* 2011, Vol. 4, p.160.
- Harvey, Campbell R. Cryptofinance, Working paper Fuqua School of Business 2015.
- He, Dong, Karl Habermeier, Ross Leckow, Vikram Haksar, Yasmin Almeida, Mikari Kashima, Nadim Kyriakos-Saad, Hiroko Oura, Tahsin Saadi Sedik, Natalia Stetsenko, and Concepcion Verdugo-Yepes. *Virtual Currencies and Beyond: Initial Considerations* (No. 16/3). International Monetary Fund, 2016.
- Hencic, Andrew, and Christian Gouriéroux. Noncausal Autoregressive Model in Application to Bitcoin/USD Exchange Rates. *Econometrics of Risk* 2015, 17-40
- Kaminski, Jermain, and Peter Gloor. Nowcasting the bitcoin market with twitter signals. arXiv preprint arXiv:1406.7577, 2014.
- Khapko, Mariana and Marius A. Zoican. ‘Smart’ Settlement. Rotman School of Management Working Paper No. 2881331, (2017).
- Kristoufek, Ladislav. What are the main drivers of the bitcoin price? evidence from wavelet coherence analysis. *PloS one*, 10(4):e0123923, 2015.
- Lee, Larissa. New Kids on the Blockchain: How Bitcoin’s Technology Could Reinvent the Stock Market, *Hastings Business Law Journal* 2016, 12, 81-132.
- Luther, William J. Cryptocurrencies, network effects, and switching costs. *Contemporary Economic Policy* 2015. 34 (3): 553–571.

- Malinova, Katya and Andreas Park. Market Design with Blockchain Technology, unpublished manuscript, 2016. <https://ssrn.com/abstract=2785626>
- Moore, Tyler, and Nicolas Christin. Beware the middleman: Empirical analysis of bitcoin exchange risk. In International Conference on Financial Cryptography and Data Security 2013, pages 25–33.
- Nakamoto, Satoshi. Bitcoin: A Peer-to-Peer Electronic Cash System. unpublished manuscript, 2008.
- Peters, Gareth William, Ariane Chapelle, and Efstathios Panayi. Opening discussion on banking sector risk exposures and vulnerabilities from virtual currencies: An operational risk perspective. *Journal of Banking Regulation*, 2016, 17, 239-272
- Peters, Gareth W, Efstathios Panayi, and Ariane Chapelle. Trends in crypto-currencies and blockchain technologies: A monetary theory and regulation perspective. arXiv preprint arXiv:1508.04364, 2015.
- Tasca, Paolo. Digital Currencies: Principles, Trends, Opportunities, and Risks (2015). Available at SSRN: <https://ssrn.com/abstract=2657598>
- Yermack, David. Corporate Governance and Blockchains. *Review of Finance* 2017. 21 (1): 7-31.
- Yermack, David. Is Bitcoin a Real Currency? An economic appraisal, NBER Working Paper No. 19747, 2014.

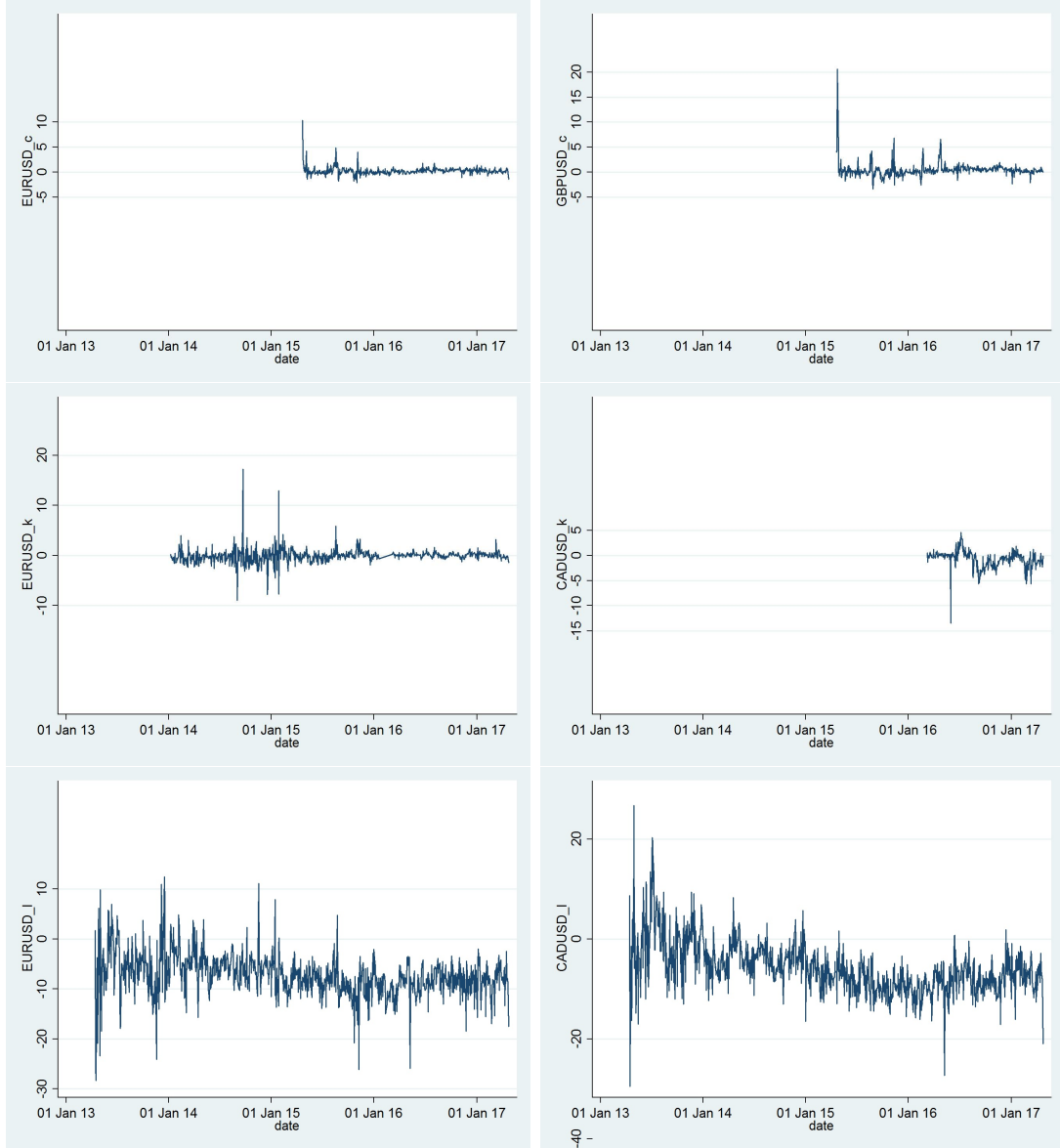


Figure 1: Percentage Differences between Observed and Implicit Exchange Rates.

Figure 1 reports percentage differences between EUR-USD, CAD-USD, and GBP-USD exchange rates and their implicit rates for Bitcoins exchanged with the U.S. dollar, Euro, Candaina dollar, and British pound on Coinbase, Kraken, and Localbtc. For example, in the top left graph, the implicit EUR-USD log exchange rate at the Coinbase is $\mathbb{B}_{Coinbase,t}^{USD,t} - \mathbb{B}_{Coinbase,t}^{EUR}$, and the proportional difference between observed EUR-USD log exchange rate ($s_{EUR,t}^{USD}$) and its implicit rate is $\left(\frac{\mathbb{B}_{Coinbase,t}^{USD} - \mathbb{B}_{Coinbase,t}^{EUR}}{s_{EUR,t}^{USD}} \times 100 \right)$.



Figure 2: The U.S. Dollar and the Global Value of Bitcoin

The figure plots the observed U.S. dollar price of Bitcoin on Coinbase (the blue line) and the global value changes of Bitcoin w.r.t. the G10 currencies as in Equation refeq:10 (the red Line). As the U.S. dollar is appreciated w.r.t. a basket of G10 currencies, the global value of Bitcoin (BitcoinGP) is higher than its U.S. dollar price of Bitcoin (BitcoinUSD).

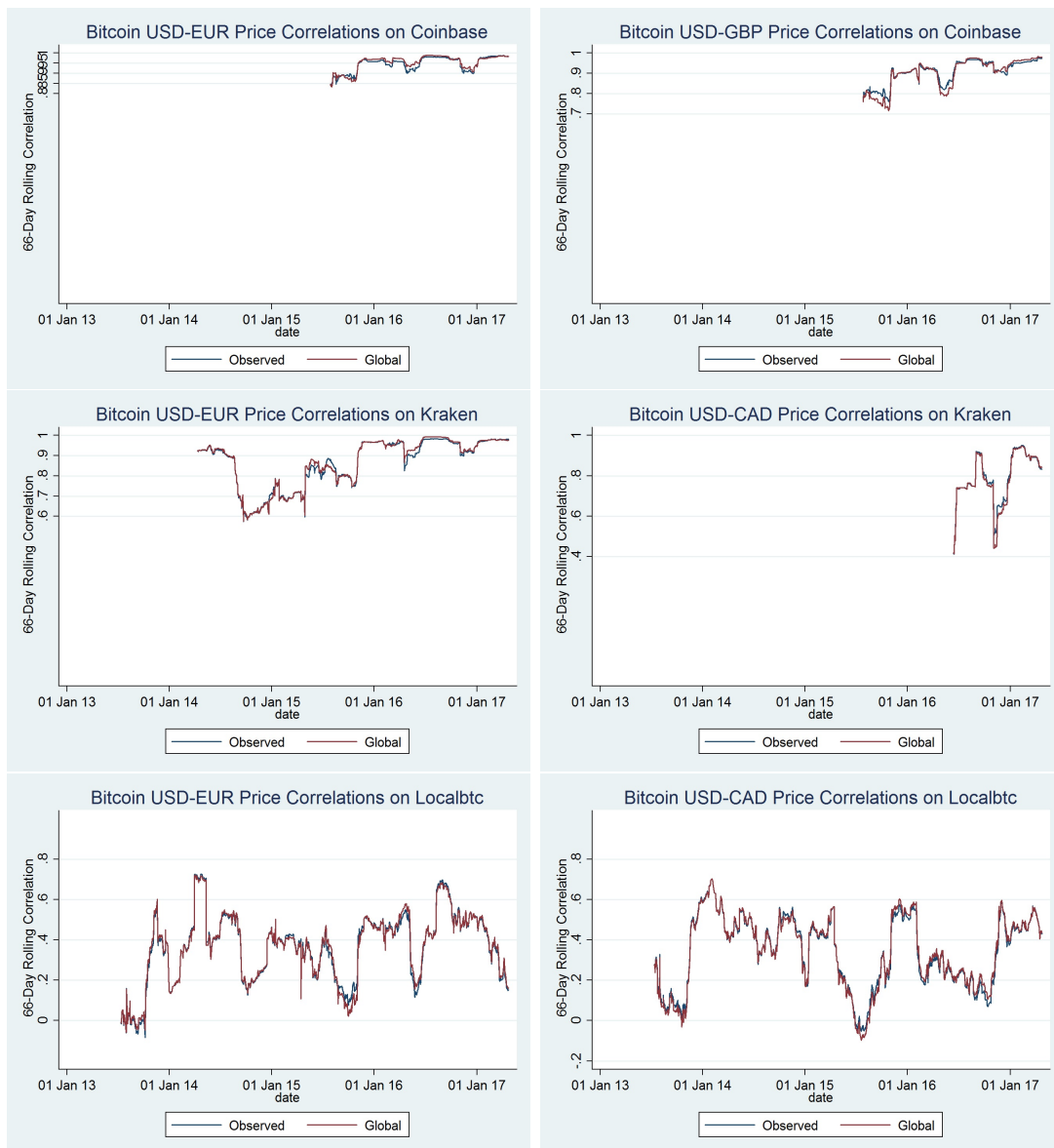


Figure 3: **66-Day Price Correlation of Bitcoin across Exchanges**

The figure plots quarterly (66-day) rolling with overlap correlations among Bitcoin prices denominated in the U.S. dollar, Euro, and Canadian dollar across the Coinbase, Kraken, and Localbtc. Each graph plots correlations for their observed price changes (the blue line) as well as their global (denominated-neutral) value changes (the red line).

Table 1: Descriptive Statistics

	USD>0.005			USD<-0.005		
Mean	0.008			-0.008		
S.D.	0.003			0.003		
	Oil	Sugar	Gold	Oil	Sugar	Gold
Mean	-0.006	-0.003	-0.007	0.005	0.001	0.009
S.D.	0.023	0.018	0.012	0.025	0.018	0.011
	CAD	EUR	GBP	CAD	EUR	GBP
Mean	-0.006	-0.008	-0.007	0.006	0.008	0.007
S.D.	0.005	0.005	0.009	0.005	0.005	0.006
	Coinbase	Kraken	Localbtc	Coinbase	Kraken	Localbtc
Mean	0.003	0.000	0.020	0.005	0.001	-0.006
S.D.	0.025	0.029	0.049	0.038	0.037	0.039

The table reports daily means and standard deviations (S.D.), when the U.S. dollar depreciates or appreciates more than 0.5% w.r.t. a basket of G10 currencies in the left and right panels, respectively. The top panel reports descriptive statistics for the U.S. dollar basket factor. In addition, the table reports descriptive statistics of commodities, namely oil, sugar, and gold, and fiat currencies, namely Canadian dollar, euro, and British pound. The bottom panel reports mean and standard deviation for the U.S. dollar prices of Bitcoin quoted on the Coinbase, Kraken, and Localbtc.

Table 2: Correlation between the U.S. Dollar Price Changes of Globally-Traded Assets and The U.S. Dollar Value Changes w.r.t. the G10 Currencies

USD>0.005			USD<-0.005		
Oil	Sugar	Gold	Oil	Sugar	Gold
-0.09	-0.04	-0.30	-0.12	-0.27	-0.21
CAD	EUR	GBP	CAD	EUR	GBP
-0.49	-0.56	-0.54	-0.63	-0.53	-0.51
$\mathbb{B}_{Coinbase}$	\mathbb{B}_{Kraken}	$\mathbb{B}_{Localbtc}$	$\mathbb{B}_{Coinbase}$	\mathbb{B}_{Kraken}	$\mathbb{B}_{Localbtc}$
0.00	-0.03	-0.11	-0.01	-0.01	0.03

The table reports daily correlations, when the U.S. dollar depreciates or appreciates more than 0.5% w.r.t. a basket of G10 currencies in the left and right panels, respectively. The top panel reports correlations between the U.S. dollar basket factor and commodities, namely oil, sugar, and gold. The middle panel reports reports correlations between the U.S. dollar basket factor and fiat currencies, namely Canadian dollar, Euro, and British pound. And the bottom panel reports correlations between the U.S. dollar basket factor and Bitcoin exchanged for the U.S. dollar at the Coinbase, Kraken, and Localbtc. The sample period is from 01/14/2015 to 04/24/2017.

Table 3: Descriptive Statistics

	USD	$\mathbb{B}_{Coinbase}^{USD}$	$\mathbb{B}_{Coinbase}^{Global}$
Mean	0.08	0.36	0.44
S.D.	0.09	0.63	0.64

The table reports daily means and standard deviations (S.D.) for the U.S. dollar value changes w.r.t. a basket of G10 currencies (USD), the observed U.S. dollar value of Bitcoin traded on Coinbase ($\mathbb{B}_{Coinbase}^{USD}$), and the global value of Bitcoin w.r.t. a basket of G10 currencies ($\mathbb{B}_{Coinbase}^{Global}$) as in Equation 10.

Table 4: Correlations among Commodities, Fiat Currencies, and Bitcoin

	Single Perspective			Global Perspective		
	Panel I					
	Oil	Sugar	Gold	Oil	Sugar	Gold
Oil	1.00			1.00		
Sugar	0.10	1.00		0.09	1.00	
Gold	0.05	0.08	1.00	-0.02	0.03	1.00
	CAD	EUR	GBP	CAD	EUR	GBP
CAD	1.00			1.00		
EUR	0.41	1.00		-0.37	1.00	
GBP	0.44	0.53	1.00	-0.01	0.00	1.00
	Panel II					
	$\mathbb{B}_{Coinbase}^{USD}$	$\mathbb{B}_{Coinbase}^{EUR}$	$\mathbb{B}_{Coinbase}^{GBP}$	$\mathbb{B}_{Coinbase}^{Global}$	$\mathbb{B}_{Coinbase}^{Global}$	$\mathbb{B}_{Coinbase}^{Global}$
$\mathbb{B}_{Coinbase}^{USD}$	1.00			1.00		
$\mathbb{B}_{Coinbase}^{EUR}$	0.98	1.00		0.98	1.00	
$\mathbb{B}_{Coinbase}^{GBP}$	0.95	0.96	1.00	0.96	0.96	1.00
	$\mathbb{B}_{Kraken}^{USD}$	$\mathbb{B}_{Kraken}^{EUR}$	$\mathbb{B}_{Kraken}^{CAD}$	$\mathbb{B}_{Kraken}^{Global}$	$\mathbb{B}_{Kraken}^{Global}$	$\mathbb{B}_{Kraken}^{Global}$
$\mathbb{B}_{Kraken}^{USD}$	1.00			1.00		
$\mathbb{B}_{Kraken}^{EUR}$	0.97	1.00		0.98	1.00	
$\mathbb{B}_{Kraken}^{CAD}$	0.81	0.81	1.00	0.81	0.81	1.00
	$\mathbb{B}_{Localbtc}^{USD}$	$\mathbb{B}_{Localbtc}^{EUR}$	$\mathbb{B}_{Localbtc}^{CAD}$	$\mathbb{B}_{Localbtc}^{Global}$	$\mathbb{B}_{Localbtc}^{Global}$	$\mathbb{B}_{Localbtc}^{Global}$
$\mathbb{B}_{Localbtc}^{USD}$	1.00			1.00		
$\mathbb{B}_{Localbtc}^{EUR}$	0.39	1.00		0.40	1.00	
$\mathbb{B}_{Localbtc}^{CAD}$	0.33	0.13	1.00	0.35	0.13	1.00

The table reports daily correlations among commodities, fiat currencies, and Bitcoin from a single currency perspective and a G10 currency (global) perspective in the left and right panels, respectively. Panel I reports correlations among oil, sugar, and gold as well as the euro, Canadian dollar, and British pound. Panel II reports correlations among Bitcoin prices in as well as the U.S. dollar, euro, Canadian dollar, and British pound exchanged on the Coinbase, Kraken, and Localbtc. The sample period is from 04/12/2013 to 04/24/2017.

Table 5: Correlations of Commodities and Fiat Currencies

	Single Perspective				Global Perspective			
	USD	EUR	CAD	GBP	USD	EUR	CAD	GBP
$\mathbb{B}_{Coinbase}^{USD}$	0.08	0.06	-0.01	-0.20	0.27	0.05	-0.01	-0.24
$\mathbb{B}_{Coinbase}^{EUR}$	0.19	0.02	0.01	-0.25	0.19	0.12	-0.03	-0.25
$\mathbb{B}_{Coinbase}^{GBP}$	0.21	0.06	0.01	-0.36	0.15	0.06	-0.01	-0.12
$\mathbb{B}_{Kraken}^{USD}$	0.08	0.06	-0.01	-0.20	0.26	0.05	-0.01	-0.24
$\mathbb{B}_{Kraken}^{EUR}$	0.20	0.02	0.01	-0.24	0.19	0.12	-0.03	-0.24
$\mathbb{B}_{Kraken}^{CAD}$	0.14	0.10	-0.07	-0.22	0.14	0.05	0.05	-0.23
$\mathbb{B}_{Localbtc}^{USD}$	0.03	0.03	0.05	-0.03	0.13	0.02	0.05	-0.06
$\mathbb{B}_{Localbtc}^{EUR}$	0.07	-0.04	0.04	0.00	0.07	0.03	0.01	0.00
$\mathbb{B}_{Localbtc}^{CAD}$	0.10	0.09	-0.07	-0.04	0.10	0.05	0.03	-0.05

The table presents correlations between the observed Bitcoin prices and the denominated-currency appreciations with respect to a basket of G10 currencies in the left panels, and correlations among Bitcoin global values and the denominated-currency appreciations with respect to a basket of G10 currencies in the right panels. The top, middle and bottom panels report correlations for Bitcoin traded on Coinbase, Kraken, and Localbtc, respectively. The sample period is limited to the availability of Bitcoin prices in the Canadian dollar at the Kraken, which is from 03/10/2016 to 04/24/2017.

For example, the U.S. dollar basket factor (USD) and the global value of Bitcoin quote in the U.S. dollar on Coinbase as follows:

$$USD_t = \frac{1}{9} \sum_{i \in G10} (\Delta s_t^{USD}) \quad \& \quad \mathbb{B}_{Coinbase,t}^{Global,USD} = \frac{9}{10} USD_t - \mathbb{B}_{Coinbase,t}^{USD}$$