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Bitcoin and the PPP Puzzle

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This paper approaches the PPP puzzle by using the Bitcoin/US Dollar exchange rate. The use of the virtual currency as macroeconomic laboratory allows us to remove frictions that previously impeded the empirical demonstration of the law of one price. We show that price adjustments are still far from perfect due to information asymmetry between agents. Nevertheless, the real exchange rate is stationary and adjusts by 81% within one day. Finally, because of the different speed of information spread, good market arbitrage takes place in the Bitcoin economy but not in the US economy. Thus, we conclude that in a frictionless economy the PPP holds and the speed of arbitrage for the good market depends on the speed of information spread among agents.

JEL classification: F31

Keywords: Bitcoin, Purchase Power Parity, Silk Road

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Bitcoin and the PPP Puzzle

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Abstract

This paper approaches the PPP puzzle by using the Bitcoin/US Dollar exchange rate. The use of the virtual currency as macroeconomic laboratory allows us to remove frictions that previously impeded the empirical demonstration of the law of one price. We show that price adjustments are still far from perfect due to information asymmetry between agents. Nevertheless, the real exchange rate is stationary and adjusts by 81% within one day. Finally, because of the different speed of information spread, good market arbitrage takes place in the Bitcoin economy but not in the US economy. Thus, we conclude that in a frictionless economy the PPP holds and the speed of arbitrage for the good market depends on the speed of information spread among agents.

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1 Introduction

One of the main puzzles of modern macroeconomics is that Purchase Power Parity (PPP) cannot be unambiguously empirically shown (Rogoff 1996, Taylor and Taylor 2004). The underlying frictions impeding prices to converge are diverse: information asymmetry, tariff and nontariff trade barriers, transportation costs, nontraded components on goods, different taxation systems and non-convergent consumer behavior among others. So far, the empirical demonstration of the PPP theory has been a major challenge for economists since market imperfections cannot be removed. However, the Bitcoin economy emerged as a natural laboratory where most of these market imperfections are removed. We can now compare prices expressed in Bitcoin with those expressed in a fiat currency within the same country. The only imperfection left between the Bitcoin and the traditional economy is mainly due to information asymmetry.

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In the early moments of Bitcoin (BTC) its acceptance has been tightly linked to transactions of illegal goods, most notably through a platform called *Silk Road*.¹ Christin (2013) does a deep analysis of the platform and concludes that in the period between February and August 2012 almost 9% of all Bitcoin transactions (real and financial) took place in Silk Road and the half of them originated from the United States.² Within the platform, the relative majority of all transactions (c.a. 22,2%) involved cannabis and the pairwise correlation between the price of cannabis and the other four most sold products in Silk Road are above 90% and their market share add up to 40%.³ Therefore, in the context of the Bitcoin economy, where mainly illegal goods are sold, cannabis prices are taken as proxy for the economy price index. The PPP puzzle is then approached by comparing the daily BTC/US\$ exchange rate and the daily price change of cannabis in both the Bitcoin and the US economy during the 6-month period from February to August 2012.

Our analysis is unique as it eliminates most frictions that have impeded the empirical demonstration of the PPP in previous studies (see e.g., Rogoff 1996). First, the use of two economies within the same country allows us to remove tariff and nontariff trade barriers as well as different demand elasticity. Second, the study of black-market goods eliminates problems with different taxation systems. Third, the delivery costs for online shopping are calculated for every consumer separately meaning that prices are provided without postal charges. Fourth, both in the Bitcoin and in the US economy, the Information Communication Technology (ICT) allows consumers to verify and update online the market price of cannabis on a daily base. For those reasons, the remaining imperfections between the two economies are minimized to the different information set the buyers/sellers may have in one market with respect to the other one, and the different mechanisms according to which arbitrage may take place between the two economies. Thus, even though 6 months of data is seemingly too few for goods market to clear, it is enough time for agents supported by ICT to react.

To conclude, our study adds into the PPP debate in two fronts. First, we show that in a frictionless environment the PPP holds: the real exchange rate is stationary and adjusts by 81% within one day. Second, the inclusion of ICT in the price set mechanism leads to a significant increase in the speed of price adjustment between the two economies.

2 Data

Christin (2013) does a notable work in raising Silk Road information and provides in its online appendix the normalized price in BTC for all cannabis transactions in the platform between February and August 2012. Moreover, he provides the nominal exchange rate BTC/US\$. Because of technical problems raising the data, Christin's dataset has a few missing observations. Therefore, we conduct a series of temporal interpolations to fill the missing data in the dataset.⁴

Equally challenging is the data collection for cannabis prices in the US economy specially in a

¹Silk Road, also called the "eBay for drugs", was an online market for illegal products founded in February 2011 that operated as a tor hidden service, such that users were able to browse it anonymously and securely without potential traffic monitoring. On February 2013, the FBI shut down Silk Road.

²During our observation window most goods in Silk Road were denominated in Bitcoin (Christin 2013).

³After cannabis the most sold categories in Silk Road were prescriptions, benzos, books and hash; the price correlation coefficients to cannabis are respectively 0.908, 0.979, 0.906 and 0.989.

⁴Christin (2013) conducted a near-comprehensive crawl on Silk Road from February 3 until July 2012. The fastest crawl was completed in 3 hours, while the slowest took 30 hours.

daily frequency. Therefore, we rely on self reporting price data from the webpage priceofweed.com.⁵ In this site cannabis consumers may report the price they paid, where the transaction took place (city, state and country), the quantity they received and whether the quality was high, medium or low. We first aggregate linearly the daily prices for each quality and then we average the prices obtained for each quality. The result is a daily time series for the US cannabis market.

Table 1: Descriptive Statistics

	s_t	p_t^{US}	p_t^{BTC}
Mean	5.498	8.935	1.009
Standard Deviation	0.969	1.384	0.226
Skewness	1.681	2.141	-2.382
Kurtosis	5.668	11.919	11.916
Median	5.115	8.670	1.012
5% Percentile	4.580	7.283	0.977
95% Percentile	7.6	11.012	1.033

To summarize, our dataset is composed of a daily multivariate time series of cannabis price for both the US and the Bitcoin economy as well as the exchange rate between both economies as shown in Table 1.⁶

3 Empirics

The law of one price is the fundamental building-block of the PPP. Formally, it suggests that nominal exchange rate between two economies should equalize the price of goods in both economies:

$$s_t = p_t^* - p_t \quad (1)$$

where s_t is the nominal exchange rate (the foreign price of domestic currency) and p_t and p_t^* are the domestic and foreign price levels respectively, all expressed in logs. Therefore, real exchange rate, q_t , can be defined as deviations from the law of one price:

$$q_t = s_t + p_t - p_t^* \quad (2)$$

By using the US as home country and Bitcoin as the foreign one, we estimate (2) as:

$$s_t = \alpha + \beta_0 p_t^{BTC} + \beta_1 p_t^{US} + u_t \quad (3)$$

where s_t is the nominal exchange rate BTC/US\$, p_t^{BTC} is the dollar price of cannabis in the Bitcoin economy, p_t^{US} is the dollar price of cannabis in the United States and the residual u_t represents deviations from the real exchange rate. Thus, u_t needs to be stationary to conclude that PPP holds. In the present context, stationarity means that disruptions of the law of one price are mean reversal. Moreover, if cannabis was the only good in the Bitcoin economy and all arbitrage opportunities were indiscriminately exploited in both economies, the coefficients β_0 and β_1 would be expected to be exactly 1 and -1, respectively. Our estimation quantifies the market efficiency in both economies measured in terms of arbitrage opportunities based on the information set available to the agents.

⁵The data is provided by Husted (2013).

⁶Christin (2013) normalizes Silk Road prices with the first observation.

Our estimation methodology is OLS, where all variables are in log difference as the BTC/US\$ exchange rate is non stationary⁷. Formally,

$$s_t = \frac{0.002}{(0.002)} + \frac{0.353^{***}}{(0.081)} p_t^{BTC} + \frac{0.016}{(0.011)} p_t^{US} + u_t \quad (4)$$

$$R^2 = 0.093, F - stat = 9.73$$

Equation (4) is estimated with robust standard errors as homoskedacity may be rejected. Moreover, residuals are serial correlated.⁸ The coefficient for the BTC economy is highly significant and positive. This suggests that prices in the BTC economy adjust to price changes in the US economy. Even though the market for cannabis absorbs only 2% of the whole BTC economy, the estimated coefficient β_0 shows that a 1% change in cannabis price induces an 0.353% change in the nominal exchange rate BTC/US\$. The coefficient for the US economy is not significantly different from zero. This implies that arbitrage opportunities do not take place in the US economy. The different price dynamics observed in the two economies are likely to be explained by distinct risk aversions. Indeed, traffic of drugs is more risky if pushed through the traditional US street channels than through the anonymous peer-to-peer channels of the Bitcoin economy. Moreover, money laundering is less risky, faster and basically costless if executed via a decentralized money transfer system like Bitcoin than the traditional banking channel. Therefore, risk premium is likely to be higher in the US than in the Bitcoin economy. Moreover, price dynamics in the US economy are to a large extent a response to change in risk perception while in the Bitcoin economy it reflects marginal costs. To conclude, prices in the smaller and less risky Bitcoin economy adjust themselves to the prices in the bigger and more risky US economy. Price adjustments in the opposite direction are *not* registered.

The above results hold only if deviations from the real exchange rate, u_t , are stationary. The Dickey Fuller test statistic on the residual is $Z(t) = -10.684$ and the 1% critical value is -3.487 . Both results suggests that the real exchange rate reverses to its mean. In order to estimate the persistence of deviations on the real exchange rate we estimate the residual on its lags as follows:

$$u_t = \frac{0.190^{***}}{(0.076)} u_{t-1} + e_t \quad (5)$$

$$R^2 = 0.035, F - stat = 6.10$$

Equation (5) is an AR(1) representation of u_t and shows that 81% of deviations from PPP vanishes within one day. This result contrasts with previous findings, for instance Lothian and Taylor (1996), where only the 24% of Franc-Sterling price deviation vanishes within a year. The large difference embodies the sense of modern economics presented in this paper where the speed of information dissipation changed.

4 Conclusion

The present paper provides empirical evidence that by removing real economy imperfections, PPP holds. Real exchange rate is stationary and adjusts by 81% within one day. Moreover, ICT severely decreases the time required for the law of one price to hold. The Bitcoin economy adjusts itself to the US economy but not the opposite way round.

⁷The p-value of the Dickey-Fuller test for unit root on s_t is 0.996

⁸The p-value for the Breusch-Pagan heteroskedacity test is 0.004, the Durbin-Watson statistics for autocorrelation is 1.61.

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