Bitcoin and Portfolio Diversification:

Evidence from Portfolios of U.S., European and Chinese Assets

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This research explores the effects of adding bitcoin to an optimal portfolio (naïve, long-only, unconstrained and semi-constrained) by relying on a mean-CVaR approach. We explore bitcoin's role in portfolios of U.S., European and Chinese assets. We back-test to compare the performance of portfolios with and without bitcoin for each scenario. The results show that by adding bitcoin, the portfolio performance improves; but this depends more on the increase in returns than in the reduction of volatility. In addition, the overall benefit is mainly the result of the high returns obtained in 2013 with marginal advantage thereafter. We conclude that bitcoin may have a role in portfolio diversification even if our analysis confirms its speculative characteristics.

Keywords: Bitcoin, Cryptocurrencies, Portfolio Diversification, Portfolio Strategies

JEL classification: G11

Introduction

The Bardi Family used to be a very powerful and rich in the fourteenth century. Their activities covered trading as well as banking (they ran one among the largest banks of the late middle age) and, together with the Peruzzi family, were among those that financed King Edward's III war efforts against France. When in 1345 when England went bankrupt and was unable to repay them, they were forced out of business. In that very same year, three members of the Bardi family (namely Rubecchio, his uncle Aghinolfo and his cousin Sozzo), having lost almost their entire wealth decided to change their core activities: from bankers to forgers. The suspicious smoke and hammering sounds that could be easily heard when walking around their property, immediately attracted the attention of the local authorities. Because of their lack of expertise as forgers, they were caught at the very beginning of their new enterprise and on 15th October 1345, the local authority started the proceeding against them (Cipolla 1994). Interestingly enough, the major driver for their very clumsy attempt as forgers was the lack of liquidity and the re-valuation of silver and gold that characterised the years between 1333 and 1348 when the explosion of the Black Death completely reshaped the social and economic fabric around Europe.

Nowadays the link between metal and value of the currency (metallism) is not relevant anymore and even if forging is an illegal activity that has its followers, the maladroit game attempted by the Bardi would not be possible. Institutions (i.e. the central banks and commercial banks) can expand money and debase it via quantitative easing and lending activity. The result is that the majority of dollars, euros or pounds aren't printed but are created by private banks when they make loans (de Soto 1995). However, the scepticism about the role of any central authority over the political and economic lives of individuals is pushing financial technology further and is among the reasons for the launch of cryptocurrencies. In this realm, bitcoin plays a central role as the first cryptocurrency ever mined – the first ever article on cryptocurrency was published by the Financial Times on 6th June 2011 (Allowey 2011).

Bitcoin is characterised by being managed and maintained via a decentralised global network of nodes operating in a globally distributed environment, where the supply is strictly controlled and fully transparent to all participants (Narayanan et al. 2017). In addition, bitcoin operates collaboratively without the need of financial intermediaries (Böhme et al. 2015; Narayanan et al. 2017). In other words, no central authority controls it. It is backed by the energy required to mine it through the concept of cryptographic proof-of-work (Vigna and Casey 2015). A link to metallism is the fact that production of Bitcoin (mining) calls for the solution of mathematical problems the difficulty of which increases with time according to an internal algorithm that controls the supply.

Such a process demands considerable computing power (i.e. electric energy) and real-money investments in specialised hardware (Narayanan et al. 2017; O'Dwyer and Malone 2014). Nakamoto (2008) (bitcoin founder) argues that fiat currencies do not perform properly as a medium of exchange because of high transaction costs and the exclusion of a large part of the world population from the banking system. He also argues that fiat currencies do not function well as stores of value either, due to the presence of excess inflation. Bitcoin addresses these issues by making its supply pre-determined, constant, decreasing, and ultimately finite and thus deflationary. In addition, it aims to be an excellent store or value in the long run (Nakamoto 2008). The last point raises a key question: if bitcoin is an excellent store of value, should it be included in a portfolio of assets?

Truthfully, ever since the seminal work by Markowitz (1952, 1976), finance stresses the importance of portfolio diversification and a lot of analysis explores the optimal mix of assets that allows for the maximisation of the return by minimising the risk (i.e. the volatility). Historically the focus was on shares (e.g. Treynor and Black 1973), bonds (e.g. Barnes and Burnie 1990), and derivatives (e.g. Galai and Geske 1984). More recently, research explored the link between portfolio diversification and other aspects such as taxes (e.g. Stein et al. 2000) and leverage (e.g. Ruban and Melas 2011). Closer to our research are the works that focus on the role of currencies in portfolio diversification (e.g. Makin 1978; Pojarliev and Levich 2011). Lately the increasing presence of cryptocurrencies has started to attract some interest among academics who wish to assess bitcoin as an asset to include in portfolio diversification. Sadly, to the best of our knowledge very little has been published so far, all of which based on portfolios of U.S. assets, (Brière et al. 2015; Carrick 2016; Wu and Pandey 2014) suggesting the need for additional research in this area.

This study, by following the approach of Brière et al. (2015), explores the effect of bitcoin on the overall risk-return ratio of a portfolio of well diversified assets by examining three different groups of assets, i.e. including bitcoin in a portfolio in the U.S, Europe and China. Our aim is to explore the role of bitcoin in portfolio diversification and explore whether it has different role in different asset groups. We construct four different portfolio frameworks, namely naïve portfolio, the long-only portfolio, the unconstrained portfolio and the semi-constrained portfolio (Eisl et al. 2015). We also add a fifth portfolio (unconstrained portfolio where bitcoin cannot be shortened) since, at present, it is not easy to take short positions on bitcoin – regulated markets only launched derivatives on bitcoin allowing for a proper short strategies in late 2017 (Meyer 2017). In the case of long-only, unconstrained and semi-constrained portfolios (with and without shortening), the weights are calculated using the mean-CVaR optimisation process (Eisl et al. 2015).

Our analysis suggests that bitcoin as an additional asset class in our portfolios tends to generate benefits in terms of increased returns and reduction of the risk/return. In the time window considered (2013-2016), bitcoin generates higher returns but also and higher volatility and, in the case of naïve and long portfolios both with and without rebalancing, the Sharpe ratio improves. The results are mixed in the case of unconstrained and semi-constrained portfolios. In addition, we discovered a marked difference of the role of bitcoin prior to December 2013 and the subsequent period until the end of 2016. During the early period, the effects of inclusion are significantly positive in all the portfolios. After December 2013, the inclusion reveals mixed effect in terms of return.

This manuscript is structured as follows: next section explores previous research on bitcoin and portfolio diversification. Section 3 discusses the methodology and illustrates the variables used. Section 4 presents the descriptive statistics while section 5 reviews the separate results in the case of the U.S., European and Chines assets. Section 6 discusses the results commenting on similarities and differences. Section 7 concludes.

2. Portfolio Diversification and Bitcoin

To most ordinary people bitcoin remains a mystery: an intangible, and difficult-to-understand currency with little or no use in the real economy (Garcia et al. 2014). Nakamoto (2008) in his whitepaper describes bitcoin as a peer-to-peer cash system. Bitcoin system's main concern lies with verifying whether the sender owns the funds they intend to spend, as well as preventing double-spending, which has for years been the main obstacle to the development of a viable peer-to-peer payment system (Böhme et al. 2015; Nakamoto 2008; Narayanan et al. 2017). Anyone wishing to spend, signs the request to send some bitcoin to another address using the private key of the address they wish to send from, which is then broadcast to the network of nodes for processing. Nodes can confirm ownership by using the public key of the sending address to check whether the request is genuine. Genuine requests are collected into blocks and added to the blockchain a public ledger consisting of a distributed database maintained by a network of nodes. Every node holds an exact copy of the database containing all historical transactions, which can only be updated with mutual consensus (Böhme et al. 2015; Nakamoto 2008; Narayanan et al. 2017). Once a record of transaction is added to it, it becomes nearly impossible to change or compromise (Böhme et al. 2015; Narayanan et al. 2017).

The idea behind the decentralisation of verification is to remove the 'middle man' from the equation, thus not only eliminating the risk of any one party tampering with the proof of agreement but also making the overall economy more efficient (Timmerman and Thomas 2017). The lack of a governance structure other than its underlying software has several implications for the functioning of the system: there is no obligation to verify a user's identity; there is no prohibition on sales of particular items; payments are irreversible (Böhme et al. 2015). This aspect does in fact raise issues linked to the use of bitcoin as payment for illicit transactions and money laundering (Hope 2017; McLannahan 2017). However, the role that cryptocurrencies are taking is so relevant that governments are starting to investigate ways to deal with these illicit transactions (Seddon 2017; Terazono 2017).

Unlike fiat currencies where the money supply can be expanded to meet the increasing demand via the fractional reserve system or by direct monetary policies such as quantitative easing (de Soto 1995), bitcoin's total supply and the rate of supply is pre-determined, non-elastic and fully transparent (Nakamoto 2008). By design, the supply is capped to 21 million units of bitcoin divisible down to eight decimal places and smallest unit ("Satoshi") represents the base unit of all arithmetic calculations. New bitcoin is created via an activity called mining, and nodes that engage in mining are called miners (Narayanan et al. 2017). Since the rate of supply is pre-determined and continually decreasing - a process governed by an internal algorithm - bitcoin is inherently deflationary and the laws of supply and demand as well as the market consensus among its adopters play significant part in its price formation (Ciaian et al. 2015; Kristoufek 2015). As of January 2017, around 16.1 million bitcoins have been mined, roughly 80% of the total. The remainder will be mined at a much slower rate. This slowing down in the supply adds to deflationary pressures and will eventually shift the miner's incentives from block-rewards to transaction fees. Additional deflationary pressure is exerted by 'destruction'; the system records the transfer of bitcoin from one wallet to another, but it does not manage or keep records of wallets: if bitcoin are sent to non-existing wallets, effectively making them un-spendable, bitcoin are destroyed (Böhme et al. 2015; Nakamoto 2008). Once the money supply is completely exhausted and all the bitcoins have been mined, the demand would have to be met by further deflation, or further subdivisions of the currency.

Kristoufek (2015) find that the supply side does affect the price, although the relationship is not significant. Polasik et al. (2015) using a variety of methodologies, show that the demand factors affect the price formation significantly more than the supply side. In Keynesian economics, the demand for money is driven by three determinants: the precautionary demand, transaction demand, speculative demand and. These in turn are driven by motives such as the need to save for a rainy day, holding money for daily transactions and the need for taking advantage of investment opportunities (Keynes 1936).

Is bitcoin suitable to store of value? Bitcoin's 60 days average volatility over the six-year period (till early 2017) shows a steady decline but it remains much higher than that of gold, averaging about 1.5% and the traditional G10 currencies between 0.5% and 1%. Furthermore, bitcoin's return distribution exhibits stronger non-normal characteristics and heavier tails, suggesting that it is yet to reach investment-grade maturity (Osterrieder and Lorenz 2017). Bouri et al. (2016) suggest that bitcoin's distinctive volatility is due to the small size of the market and the trading volume even if Harvey (2017) has found no correlation between volatility and the market capitalisation prior to 2014. However, since January 2015, the price dynamics do appear to enter a new period of steady decline in volatility as a result of increasing market capitalisation even if the events in second half of 2017 suggest a reverse in that trend. Academic consensus is that the price dynamics are still evolving, and many earlier proposed models break down as time passes (Bouri et al. 2016). However, given the highly volatile nature of bitcoin that makes it unsuitable to store of value, its demand cannot solely be driven by the precautionary demand.

This evidence leaves two alternative determinants of bitcoin demand and price volatility: transaction demand (derived from trade transactions) and speculative demand (derived partly from exchange transactions).

Bitcoin transaction data is used by Kristoufek (2015) to show that an increase in trade volume is correlated with bitcoin price, consistent with the theoretical expectations of the quantity theory of money, further supported by Ciaian et al. (2015) and Wang et al. (2016). Thus, bitcoin appreciates in the long run if it is used more for transacting, challenging the earlier studies that have argued that its price is driven purely by the expectations of future exchange rate, or pure speculation (Cheah and Fry 2015). In fact, the comparison of exchange-traded volume of bitcoin to total transaction volume within the bitcoin network suggests that most users (by volume) treat their bitcoin investments as speculative assets rather than as means of payment (Glaser et al. 2014). Bouri et al. (2016) and Kristoufek (2015) find bitcoin is not effective as a safe haven since its hedging properties vary between time horizons. More importantly, since 2013 it has not been a good hedge nor a safe haven for major world stock indices, bonds, and currency indices. Specifically, even if some research suggests bitcoin has not reached the investment grade status (Cheah and Fry 2015; Urquhart 2016) more recent research suggest that it is in fact mature (Nadarajah and Chu 2017) and thus can be included in a portfolio of well differentiated assets. Bitcoin might therefore offer diversification benefits and thus, a related question emerges: is bitcoin an asset that could be included in an optimal portfolio? Oddly, there is very limited research that tries to answer to this question.

The effects of adding bitcoin to optimal portfolios have been studied by Brière et al. (2015). They show that adding it to an already diversified portfolio of U.S. assets improves its Sharpe Ratio (Sharpe 1963). In addition, an optimal mix of bitcoin and U.S. equities can reduce the overall risk of a portfolio (Bouri et al. 2016). Similarly, Eisl et al. (2015) show that including bitcoin in an already diversified portfolio of U.S. assets increases both the expected return and the risk of the portfolios. They go on suggesting a possible allocation of bitcoin in such portfolio to maximise the Sharpe Ratio. Bitcoin also increases the efficiency of portfolios when tested against other measures, such as the Omega Ratio (Wu and Pandey 2014) devised by Keating and Shadwick (2002) and other variations of the Sharpe ratio where VaR and CVaR replace the standard deviation as a measure of risk (Eisl et al. 2015).

However, bitcoin's financial characteristics, such as volatility, have evolved considerably since the "crash" of 2013, when some of its earlier properties as a safe haven completely disappeared (Kristoufek 2015). This implies that bitcoin's qualities as a diversifier might also have been affected since previous works have been published (Bouri et al. 2016). More importantly, the quoted empirical studies adopt the perspective of a U.S. investor, where portfolio optimisations mainly incorporate U.S. assets listed in the U.S. financial markets, with very limited exposure to non U.S. assets. Incidentally, in these alternative markets bitcoin trading activity and the adoption rates are very high. In fact, historical data[1] from *data.ity.org* shows that the proportion of bitcoin bought and sold, for instance, in China has steadily grown over the years and as of September 2017 comprises of ~99% of all bitcoin exchange transactions globally, whereas USD transactions have remained relatively stagnant in comparison, comprising less than 1% of global exchange volume. Consequently, events happening in the wider Chinese economy directly affect the CNY bitcoin market which in turn can have a significant impact on the USD market (Kristoufek 2015). A similar situation can be quoted for the European markets and assets.

The lack of research on the role of bitcoin in portfolio diversification of European and Chinese assets as well as the very limited research on U.S. is too important to be dismissed.

3. Methodology and Data

The nature of this research is primarily explorative. It employs a variation of the established Modern Portfolio Theory (Markowitz 1952, 1976) to estimate parameters and draw conclusions from historical data. The analysis will focus on the effects of adding bitcoin to an already diversified portfolio, or more precisely the effects that it might have on the risk-reward ratio of such a portfolio. The analysis requires the building of efficient frontiers of portfolios where bitcoin is present and comparing it to portfolios where *ceteris paribus*, bitcoin is not present. The efficient frontier comprises of all the possible portfolios which can be constructed from a given pool of assets where the return is maximised given the desired risk. We use terms ‘optimal’ and ’well-diversified’ interchangeably throughout this work to refer to such portfolios. We follow Eisl et al. (2015) by constructing portfolios in different optimisation contexts, described in more detail below. We then repeat the process but with an asset pool that contains bitcoin. These are subsequently compared to see if adding bitcoin has any effect on portfolio weights and the portfolio risk-return ratio in respect

[1] Accessed on 12/09/2017

of the optimisation procedure used.

Scenario 1: Naïve (equal weights) Portfolio ($w_i = \frac{1}{N} \quad \forall \; i$)

The naïve portfolio is constructed so that all assets are allocated equally irrespective of potential effects on the risk-return ratio. In their landmark study, DeMiguel et al. (2007) have shown that a portfolio where asset allocation is calculated using the mean-variance optimisation procedure, performs no better than an equal weight portfolio consisting of the same pool of assets in terms of Sharpe Ratio (Sharpe 1963, 1964). It would therefore be interesting to see what kind of effect bitcoin might have in this scenario and if such an effect is any different from the one observed in other scenarios. Since no part of the sample data is used to estimate optimal weights, the out-of-sample period equals the entire 60-month sample period.

Scenario 2: Long-Only Portfolio ($w_i \in \mathbb{R}^+ : \sum w_i = 1$)

This optimisation process allows no shorting and effectively limits the individual weights to 100%. This framework represents a more feasible option for investors given the context, and the asset weights should also be more stable when re-balancing. Since the first 12 months are used to determine portfolio weights, the explored sample period is 12 months shorter than the total sample period.

Scenario 3: Unconstrained Portfolio ($w_i \in \mathbb{R}$)

Under the unconstrained scenario, no restrictions are placed on asset weights. Shorting and leveraging are both allowed and in theory it should yield the highest risk-return ratio of all. This type of optimisation is expected to result in extreme long or short positions which might not be implementable in the real world, due to large initial weights in either direction (short or long) and subsequent shifts in weights during re-balancing. Its main purpose however, is test theoretical limits of any advantages bitcoin might add to well-diversified portfolios. Also in this case, the first 12 months of the sample data are used to construct the portfolio weights; hence the explored period is 12 months shorter than the total sample period.

Scenario 4: Semi-constrained Portfolio ($w_i \in \mathbb{R} : -1 \leq w_i \leq 1 : \sum w_i = 1$)

Here, the optimisation process seeks to maximise the risk-return ratio of a portfolio without placing any weight-related constraints on assets without allowing leveraging, as such it should yield a better risk-return ratio than other scenarios except for the unconstrained portfolio.

Scenario 5: Semi-constrained Portfolio with No Shortening on bitcoin ($w_{i \neq btc} \in \mathbb{R}, w_{btc} \in \mathbb{R}^+$)

Though hypothetically it is possible to short bitcoin, there is limited evidence at present and it is linked to financial products that are typically over the counter. Thus, we estimate a portfolio where all the assets but bitcoin can be shortened. The results of this strategy might therefore be rendered purely theoretical should the optimisation procedure demand that bitcoin is shortened.

3.1 The Mean-CVaR approach

For all scenarios except naïve, we adopt a variation of Markowitz's Modern Portfolio Theory (Markowitz 1952) as basis for constructing efficient portfolios, where an efficient portfolio is defined as the one that achieves maximum expected return for a desired level of risk. Under the original model, the expected return is simply the weighted average of constituent asset returns and the risk, which is measured by the portfolio variance σ_p^2, and is a function of the correlations $\rho_{ij}$of constituent assets, for all asset pairs (i, j) (Markowitz 1952). The main disadvantage with the mean-variance approach is that it oversimplifies the risk-preferences of investors. Variance is a symmetric measure that incorporates both, the upside and the downside volatility, whereas in the real-world, assuming investors are rational, only the downside component is undesirable.

An alternative risk measure proposed in literature is the Value-at-risk (VaR). It is an asymmetric measure that is expressed as a minimum loss value (or percentage) for a given probability and time horizon. VaR's main limitation is that it only estimates the minimum potential loss, and does not quantify the amount this threshold could be exceeded by potentially underestimating the tail risk. The Conditional Value at Risk (CVaR), or as it is also more commonly known, the Expected shortfall (ES) addresses this problem by calculating the expected return (average loss) beyond the VaR threshold (Alexander and Baptista 2004) and it has been previously used to portfolio optimisation (e.g. Silvapulle and Granger 2001; Topaloglou et al. 2002). Acerbi and Tasche (2002) have shown that CVaR/ES offers a number of advantages over VaR, without giving up any of its original attractions. CVaR/ES is often described as a coherent measure of risk, because it satisfies a set of four desirable properties, namely: Monotonicity, Translation invariance, Homogeneity and Sub-additivity (Artzner et al. 1999) whereas Variance and VaR do not.

We adopt the Conditional Value at Risk (CVaR) as the measure of portfolio risk which we calculate for each asset at the $\alpha = 5\%$ confidence level.

$$CVaR_p^2 = \sum_i \sum_j w_i w_j CVaR_i CVaR_j \rho_{ik} \qquad (1)$$

From which, portfolio risk is derived:

$$CVaR_p = \sqrt{CVaR_p^2} \qquad (2)$$

The optimisation procedure for non-naïve scenarios will therefore seek optimal asset weights that maximise the risk-return ratio, provided that the listed constrains for each scenario are met as prescribed.

$$\max\left(\frac{E(R_p)}{CVaR_p}\right) \qquad (3)$$

Calculating portfolio risk using this approach requires that we know the CVaR of individual assets used in the optimisation process. There are various methods for calculating the CVaR, the most common being the variance-covariance, stochastic and empirical methods. Skewed distributions make the historical/empirical approach the preferred method for the purpose of our research (note that bitcoin returns exhibit a pronounced positive skew). The main advantage of this method is that it does not make assumptions of normality, since the distribution is inferred from historical data. The downside of this strategy of course assumes that future distributions maintain the same skew over time. Using the 12 month in-sample daily data and for each asset, we calculate monthly moving averages (MA) of daily returns, resulting in 261 data points. CVaR is then calculated as the simple mean of all the observations on and below the Value-at-Risk (VaR) threshold at the $\alpha = 5\%$ confidence interval, or the 5th percentile of the calculated monthly moving average returns:

$$CVaR = \frac{1}{N}\sum_{i=1}^{N} MA \; : \; MA \leq VaR \tag{4}$$

3.2 Evaluating robustness

We divide back-testing in two parts. The first part assesses whether the initial weights w_i calculated during the optimisation process are robust over the entire sample investment period without any rebalancing. The second part examines the performance of portfolios over the entire sample period but with semi-annual weight rebalancing. For non-naïve scenarios where the initial 12-month sample period is used to calculate the initial weights, the investment period is 48-months long, whereas for the equally-weighted scenario, the full 60 month sample is used for backtesting: we calculate the monthly rolling excess portfolio returns and monthly rolling CVaR, and then apply 3-month smoothing. Using these data, we derive and observe monthly risk-reward (RR) performance of all eight portfolios over the investment period using a simple risk-reward ratio formula:

$$\mathrm{RR}_m = \frac{R_m}{CVaR_m} \tag{5}$$

Finally, we take the average Risk-reward ratios of all portfolios without bitcoin and compare them to their respective equivalents with bitcoin. We repeat the entire process again but with six-monthly rebalancing using the same methods used to calculate the initial weights. The results will be deemed robust if the mean of the estimated bitcoin weights over the investment period is not significantly different from the initial weights, with regard to the optimisation procedure used.

3.3 Data

3.2.1 The Bitcoin Price Index

We construct the bitcoin USD Price Index (BTCUSD), EUR Price Index (EURBTC) and bitcoin CNY Price Index (BTCCNY) using data from *data.bitcoinity.org*, which in turn derives its data from the publicly available raw blockchain[2] data. Historical data for bitcoin starts on 18th July 2010, however, the early period of bitcoin's trade is characterised by very low trading volumes and liquidity which does not significantly improve until 2012. Thus, we choose February 2012 as the start date of the sample period ending on 31st January 2017, covering 60 months of daily returns data.

3.2.2 Other asset classes

To allow for creation of a well-diversified portfolio, we sample a broad range of assets available to US, Europe and Chinese investors consisting of equities, fixed income, commodities, real estate, cash equivalents, currencies, and alternative investments. Each of these asset-classes is represented by a liquid investible index, most of which are denominated in the local RMB, EUR or USD currency.

Table 1, shows a detailed overview of assets which will be used in the optimisation process.

TABLE 1 HERE

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4 Descriptive statistics

The tables 2A, 2B and 2C below show the descriptive statistics of the excess monthly returns[3] of assets included in the portfolios used in the optimisation process in the case of the U.S., European

[2] The blockchain is the distributed public ledger of all the historical bitcoin transactions.

[3] The returns used in the analysis are net risk free rate. This explains the differences between values in US and China markets of the same asset class (e.g. bitcoin)

and Chinese assets.

TABLE 2A

TABLE 2B

TABLE 2C

In line with the previous studies by Eisl et al. (2015) and Wu and Pandey (2014), bitcoin exhibits large kurtosis and is positively skewed, albeit to a much lesser extent than previously reported (Figure 1A, 1B and 1C)

FIGURE 1A

FIGURE 1B

FIGURE 1C

The correlation coefficients are reported in Table 3A, 3B and 3C.

TABLE 3A

TABLE 3B

TABLE 3C

As far as the U.S. assets are concerned, bitcoin presents significant correlations with the largest part of the other indexes. Interestingly, it shows a quite high and significant correlation with the Standard and Poor index (positive) while the highest negative (and significant) correlation is with gold. This is in contrast with earlier works by Eisl et al. (2015) and Wu and Pandey (2014) that do not report significant correlations with any of the U.S. assets indices. The difference can be ascribed to a different time window.

In the case of the European assets, bitcoin shows a relatively high and significant correlation with the hedge fund index (HFRX) and small but statistically significant positive correlations to all the European assets' indices except for the S&P Pan-Europe Developed Sovereign Bond Index, Dow Jones Europe Select Real Estate Securities Index and S&P EURO Futures Index Spot.

In the case of the Chinese assets, bitcoin shows small but statistically significant correlations to all the Chinese assets' indices except for the China Mid-Cap, Small-Cap equity indices and the Guggenheim China Real Estate ETF (TAO). The results are in line with the U.S. and European correlations. A significant negative correlation exists between bitcoin and the Chinese government bill index (billcn), and a somewhat weaker but still significant negative correlation with the China Sovereign bond (condcn) and corporate bond (corpcn) indices, suggesting that bitcoin could be used by some investors in China as a safe haven during certain events that affect the prices of these assets.

5 Analysis

In this section, we examine the bitcoin portfolios linked to the different areas: first we explore the role of bitcoin in the case of portfolios of U.S. assets, then the case of the European ones and finally the case of Chinese assets. The last part of the analysis compares the results exploring similarities and differences in the use of bitcoin in the three areas.

5.1 U.S. Assets and Bitcoin

The initial weights of the optimisation process (not reported here) show unconstrained and the semi-constrained portfolios with a relative small weight of bitcoin relative to other assets. When applying semi-annual rebalancing (Table 4) to a long-only portfolio, the weight of bitcoin shows a progressive decline averaging at 5.47% for the duration of the investment period. The unconstrained portfolio suggests huge adjustments during the period (from -16.76% to +16.21%) while both the semi-constrained/bitcoin long-only portfolios present an average of 2.88% but with values between .01% to 8.19%. An additional note is needed: as far as the semi-constrained portfolio is concerned, no shortening emerges in the optimisation process. Thus, the weights of bitcoin in the semi-constrained and semi-constrained (no shorting on bitcoin) are the same.

TABLE 4

In order to have a clearer idea of the performance of a portfolio with bitcoin, we run back-testing: first without any rebalancing, and then with semi-annual rebalancing using the same optimisation technique used to calculate the initial weights (Table 5).

TABLE 5

In portfolios where no semi-annual rebalancing is applied, the results indicate that adding bitcoin to portfolio of U.S. assets is beneficial in all the cases (higher return and better Sharpe ratio). However, this is not the case for the semi-constrained portfolio where the average Sharpe ratio goes down from .82 to .42 where in the case of naïve and long-only portfolios there is an increase in the return that overcome the increase in the C-VaR while in the case of the unconstrained the improved Sharpe ratio depends on the reduction in the C-VaR.

When semi-annual rebalancing is applied, the results show the positive effect on the risk/return ratio on all the portfolios except the semi-constrained one that worsens (from .63 to .56). Also in this case the monthly return of all the portfolios except the semi-constrained one increase as well as the risk (C-VaR), but the improvement of the return compensates for the increased volatility of the portfolio.

We also explore how often the portfolio with bitcoin over-performs the portfolio without bitcoin. In the case of the naïve balancing, the portfolio with bitcoin over-performs that one without bitcoin in 65.77% of the observations while in the case of long-only and unconstrained portfolios the percentage decrease to 54.83% and 37.23% respectively. In the case of the constrained portfolio, bitcoin over-performs in 54.29% of the observations. The results suggest that the benefit bitcoin generates relies on high returns in relatively few days that compensate for poor returns in a relatively high number of days. This point is further supported by the detailed analysis of the returns that shows a marked difference between the role of bitcoin prior to December 2013 and the subsequent period until the end of 2016 (Table 6).

TABLE 6

The benefit generated by bitcoin in terms of returns is mainly due to the large difference in

2013 when the effects of inclusion are significantly positive in naïve and long-only scenarios (4.12% and 6.29% average daily return with respect 0.57% and 0.10% average return of the portfolio without bitcoin). During that year a portfolio with bitcoin was superior to a portfolio without bitcoin in 100% of naïve and long portfolio and 87% in the case of the semi-constrained. The result partially supports the earlier findings (Eisl et al. 2015) that suggest that bitcoin improves the risk-reward ratio in all scenarios if added to an optimal portfolio of western assets. A divergence can be observed in the period after December 2013 where the inclusion reveals no relevant effect in terms of the return ratio in any scenario: the portfolio with bitcoin over-performed very marginally the portfolio without bitcoin (up to .69% on average) and, in some occasions, they underperformed (e.g. -3.43% in unconstrained portfolio in 2015). The weaker performance is also supported by the number of days a portfolio with bitcoin over-performed a portfolio without bitcoin: in the case of long-only bitcoin portfolio over-performed only in 8%. In terms of risk (volatility of the portfolio) the results suggest that inclusion of bitcoin increases it in all the portfolios in 2013 and 2016 while it reduces portfolios' volatility in 2014. The results for 2015 are less clear since in 2015 bitcoin reduces C-VaR only in naïve and semi-constrained ones. In term of risk-reward, the results are very interesting: bitcoin inclusion improves the Sharpe ratio in the case of the naïve portfolio while in the case of the long-only and semi-constrained portfolios it improves only in two years. Bitcoin inclusion is even less beneficial in the case of the unconstrained portfolio where the Sharpe ratio improves only in the first year.

5.2 European Assets

In the initial optimisation process, only the long-only portfolio results in significant amounts of bitcoin: in the unconstrained and the semi-constrained portfolios the weight of bitcoin relative to other assets is relatively small, and remains small with semi-annual rebalancing. When applying semi-annual rebalancing to long-only and unconstrained portfolios the weight of bitcoin faces large changes (between 0% and 56.31% in the case of long-only and between -10.18% and 104.97% in the case of unconstrained). In the semi-constrained portfolio bitcoin paints an overall minor yet stable role.

TABLE 7

Also in the case of the European Market, the back-testing has been implemented twice (without any rebalancing and then with semi-annual rebalancing). The results are reported in Table 8

TABLE 8

As far as the “without rebalancing” approach is concerned, the results indicate that adding bitcoin to a portfolio of European assets is beneficial in all the cases. The unconstrained portfolio enjoys an increase in the average return of almost 10 times while C-VaR increases less than three times. The portfolio that benefits most in terms of risk return ratio is the long-only with a Sharpe ratio that increases from .02 to .53. Also in the case of semi-annual rebalancing there is a positive effect on the risk return ratio on all the portfolios and this is mainly due to the higher performance that characterises all the portfolios. In fact, the risk (C-VaR) decreases only in the case of the semi-constrained portfolio.

The yearly analysis shows that in the case of the naïve portfolios, the one containing bitcoin over-performs one without in 61.97% of the observations. In the case of long-only and unconstrained the percentage decreases to 49.88% and 48.70% respectively while in the case of the constrained portfolio, the bitcoin over-performs less frequently.

TABLE 9

The benefit generated by bitcoin is consistent in different portfolios in different years: the inclusion of bitcoin in 2013 increases the performance in all the portfolios (between 2.68% and 40.23%) and the same applies in the case of 2014 even if the benefit is less marked (between .68% ad 8.01%). A divergence can be observed in the period after December 2013 where the inclusion reveals limited effect in terms of the return in any scenario: the portfolio with bitcoin over-performs very marginally. The weaker performance is also supported by the number of days portfolio with bitcoin over-performed a portfolio without it.

When we turn our attention to risk, bitcoin inclusion increases portfolio volatility in naïve portfolio for all the years except 2016. In the case of other portfolios, bitcoin tends to decrease C-VaR (e.g. in the case of long-only portfolio C-VaR with bitcoin is lower in all years but 2014 and in the case of semi-constrained portfolio volatility increases in the two most recent years). In term of risk-reward, bitcoin inclusion improves the Sharpe ratio in the case of the naïve portfolio while in the case of the long-only portfolios the ratio improves in three years (2014-16). Bitcoin inclusion is less beneficial in the case of the unconstrained and semi-constrained portfolios where the Sharpe ratio improves only in the second year while in the case of semi-constrained (no shorting) Sharpe ratio improves marginally also in 2016. Our empirical evidence partially supports earlier findings (Eisl et al. 2015) that suggest that bitcoin improves the return in all scenarios if added to an optimal portfolio of western assets.

5.3 Chinese Assets

The initial optimisation process suggests including a significant proportion of bitcoin only in the long-only portfolio. The unconstrained and the semi-constrained portfolios have a proportion of bitcoin that is relatively small. When applying semi-annual rebalancing (table 10) to a long-only portfolio, the weight of bitcoin is reduced to a relatively minor proportion while in the case of the unconstrained one it ranges between -3.04% and 75.05%.

TABLE 10

Turning our attention to the performance of the portfolio with Chinese assets, in the case of no rebalancing, the results (Table 11) indicate that adding bitcoin to a portfolio increases the return in all the cases even if in terms of the Sharpe ratio the unconstrained portfolio worsens (from .14 to .06). The naïve portfolio enjoys an increase in the average return of almost 4 times while C-VaR increases only very marginally. The case of the long-only portfolio the improvement of the risk return ratio (from .21 to .58) is entirely due to the dramatic increase in the returns since the portfolio volatility of this portfolio faces also a relevant increase in the C-VaR.

TABLE 11

When semi-annual rebalancing is applied, the results show a positive effect on the risk return ratio on all the portfolios, except the semi constrained one that remains unchanged at .51. The monthly return of all the portfolios except the semi-constrained one improve. At the same time the risk (C-VaR) increases but the improvement of the return overcome the increased volatility of the portfolios.

In terms of comparative performance when balancing is applied, the portfolio with bitcoin over-performs that one without bitcoin in 60.55% of the observations while the long only and unconstrained the percentage decreases to 55.09% and 35.90% respectively. In the case of the semi-constrained portfolio, the bitcoin over-performs in 47.75% of the observations. The result suggests that the benefits bitcoin can generate depend on higher returns in between a quarter and two thirds of the observations.

Turning attention to the yearly performance (table 12), the analysis suggests that the benefits generated by bitcoin in terms of returns are mainly due to the 2013 performance. In line with evidence from portfolios with European and U.S. assets, during this year, the effects of inclusion are significantly positive in naïve and long-only scenarios (3.54% and 14.96% average daily return with respect .45% and -.13% average return of the portfolio without bitcoin).

TABLE 12

A divergence can be observed in the period after December 2013 where the inclusion reveals limited effect in terms of the risk-reward ratio in any scenario: the portfolio with bitcoin over-performs marginally and in a good number of cases, it underperforms.

The results in terms volatility of the portfolio suggest that bitcoin inclusion decreases portfolio volatility in all the portfolios in 2013 while in the following years the result is more variegated: in 2014 naïve and long-only portfolio do not benefit from bitcoin inclusion while in 2015 this is the case for naïve and unconstrained portfolio. Finally, in 2016, only the semi-constrained portfolio enjoys a reduction in its volatility for all the years.

In terms of risk-reward, bitcoin inclusion improves the Sharpe ratio of naïve portfolios in three out of the four years under consideration, while in the case of the long-only and un-constrained portfolios, the ratio improves only in 2014 and 2016. Bitcoin inclusion is less beneficial in the case of the semi-constrained portfolios where the Sharpe ratio improves only in the first year. Also, in this case, our empirical evidence provides partial supports the earlier findings (Eisl et al. 2015) which suggest that bitcoin improves the return in all scenarios if added to an optimal portfolio of western assets even if they are less supportive than in the case of U.S. and European assets.

6. Discussion

The results in terms of performance are quite consistent among the three contexts under investigation. More in detail, in the case of the long portfolios, the results are always consistent. In the case of naïve portfolio there is only one case (Chinese portfolio in 2015) where the result is different with respect the other two contexts. A lower level or consistency emerges in the case of unconstrained portfolios (Chinese portfolios generate a different result with respect U.S and European ones in three cases while the U.S. portfolios generate a different result with respect European and Chinese ones in one case) and in the case of semi-constrained portfolios (U.S. portfolios generate a different result with respect Chinese and European ones in two cases while the European portfolios generate a different result with respect U.S. and Chinese ones in one case). In terms of risk (C-VaR), the results are very consistent among the three contexts. The only investment strategy that presents different results among the three contexts is the semi-constrained portfolio. Finally, a marginally greater level of heterogeneity in terms of results can be found in the case of the Sharpe ratio where in 8 cases out of 60 different scenarios the results are not consistent among all the three contexts. Thus, we can conclude that there are no major differences in the inclusion of bitcoin in the portfolios of U.S., European of Chinese assets.

Interestingly, our evidence suggests that bitcoin plays a relevant role in portfolio diversification: it is consistent in generating benefits linked to the increase in the returns (in 43 cases out of 60, bitcoin increases the return of the portfolio). At the same time, it has a reduced role in decreasing the volatility (in 33 cases out of 60, bitcoin reduces the volatility). More in detail, the inclusion of bitcoin consistently generates benefits in the portfolios' performance in naïve and long portfolios both with and without rebalancing. The results are mixed in the case of unconstrained and semi-constrained portfolios. The joint effect of improved return and change in volatility can be appreciated by looking at the risk return ratio: it improves consistently in the case of naïve portfolios while the results are mixed in the case of other investment strategies. The results suggest that bitcoin's benefit is mainly related to the increase in portfolio returns and only marginally to the reduction in C-VaR. Our evidence also suggests that the portfolios with European assets are, on average, those that benefit most by bitcoin inclusion, followed by the portfolio of Chinese assets and then by that one containing U.S. assets.

An additional interesting aspect to explore is the evolution of the role of bitcoin through time: there is a marked difference between the role of bitcoin prior to December 2013 and the subsequent period until the end of 2016. During this early period, the effects of inclusion are significantly positive in all the portfolios with higher average return between .56% (unconstrained China) to +40.23% (unconstrained Europe), the only case where the portfolio with bitcoin underperforms is the portfolio of unconstrained Chinese assets (-.50%). However, the picture changes at the beginning of 2014: during the following three years, the maximum benefit by the inclusion of bitcoin was +8.01% (unconstrained portfolio with European assets – 2014) and the greater adverse effect was -3.43% (unconstrained portfolio with U.S. assets – 2015). In addition, the portfolio with bitcoin underperformed that without in 15 out of 45 cases. Thus, we can conclude that the benefit linked to bitcoin's inclusion is linked to a quite specific period (2013). This is not a surprise: bitcoin showed a marked increase in its value during 2013.

All in all, by adding bitcoin to a portfolio that contains either U.S. or European or Chinese assets improves the portfolio performance but this depends more on the increase in the returns than in the reduction of the volatility. In addition, the overall benefit in the time window considered in the analysis is mainly the result of the high return obtained in 2013 since the benefits of bitcoin in the following years are not systematic and definitely reduced when compared with 2013. The results are partially in line with the previous findings and tend to suggest the current speculative nature of bitcoin as an asset class.

In fact, an important caveat must be stressed: the portfolio allocation suggested by our analysis cannot necessarily be implemented. The major problem is linked to the fact that the bitcoin market is not very liquid in the sense that buying and selling large amounts of bitcoin can be problematic: currently there is a limited number of websites where bitcoin can be traded; occasionally they struggle to satisfy investor requests; it is not rare to find quite big differences in the exchange rate applied by different website (suggesting good possibilities for arbitrage but the low liquidity of the market). This can adversely affect the possibility to implement the semi-annual adjustments when they imply a large reduction/increase in the amount of bitcoin to include in the portfolio: the investor may struggle to buy the amount of bitcoin that they want to add to their portfolios; similarly, they can discover that by selling the bitcoin the price can drop dramatically.

7. Conclusions

Bitcoin is arguably one of the most important financial innovations in recent times. It has drawn an increasing number of critics and supporters in equal measure, yet its rise has been exceptional since its inception in the early 2009 when one bitcoin sold for less than a $0.01 and continued to climb the highs of 18,000USD by the fourth quarter of 2017. There is now a rising body of academic literature attempting to explain various value drivers that have contributed to this, such as the genuine transaction demand, speculation, and the in-build deflationary characteristics of bitcoin. There's also a growing body of literature attempting to analyse its other financial characteristics, such as the particularly high volatility, correlations with other more traditional assets and any potential roles that it could play in the financial and investment markets. However, the research remains quite scarce and draws conclusions from the U.S. perspective. There is no previous research that covers the role of bitcoin in portfolios of Europe and Chinese assets.

Our results show some common themes between the inclusion of bitcoin in a portfolio of U.S., European and Chinese assets: it generates benefits in terms of improvement of the risk return ratio of the portfolio. This benefit is linked to the increase in the returns that compensate for the increase in the risk of the portfolio. Interestingly, the positive effect of adding bitcoin to a portfolio is mainly linked to the period before the end of 2013, with marginal benefits thereafter. This finding applies to naïve and long portfolios. Where unleveraged shorting is allowed, effects on the risk-reward ratio are marginal throughout the sample period, even with semi-annual rebalancing. In the scenario where, in addition to shorting, leveraging is possible, bitcoin's effect is marginally positive when rebalancing is applied. However, such rebalancing requires significant shifts in weights which might not be possible in practice. The reason behind the relevant role played by bitcoin is linked to the volatility that characterises bitcoin in 2013 and the huge increase in its value. In fact, after February 2014 bitcoin presents quite a high volatility but with a reduced increase in its value.

A more surprising outcome of this research relates to the (under)performance of the portfolios where shorting is present compared to the long-only portfolios and especially the naïve portfolio. DeMiguel et al. (2007) show that naïve portfolios often perform better than optimised portfolios in general, yet this does not entirely explain why the optimised long-only portfolio performed well. We suggested that this might be due to infrequent semi-annual re-balancing used. Optimisations with shorting react to bitcoin's high volatility, producing negative weights during short-to-medium-term downturns but fail to capture the long-term upward trend.

This research opens to further areas of investigation. A first aspect that asks for additional investigation is a detailed analysis of the events at the end of 2013 beginning 2014 that affected the performance of the inclusion of Bitcoin. This is an interesting area since a clearer understanding of the role played by bitcoin's high volatility and its increase in value can allow for a better management of bitcoin as an asset. Secondly, this is the first research to investigate the role of bitcoin in China and Europe and one of the few that explore the role in U.S. In actual fact, we do not find any major difference in the role of bitcoin in the contexts under investigation. However, it can be interesting to explore bitcoin's role in portfolios containing less liquid assets (such as bonds and shares listed in minor markets). Thirdly, at the beginning of 2017 bitcoin represented the bulk of the total market capitalisation of all tradeable cryptocurrencies. By September 2017, this proportion has fallen[4] to under 50% (60bn/130bn), mainly due to the more rapid expansion of alternative

[4] Source: https://coinmarketcap.com/ (accessed 23 September 2017)

cryptocurrencies. This has given rise to a variety of theoretical crypto-indices such as the CRIX[5] and the WorldCoinIndex[6]. Future research should seek to explore the effects of such indices on optimal portfolios for a more comprehensive analysis. A final area of analysis is to explore the role of high increase in value and the very high volatility of bitcoin in 2017: our result suggests that till 2016 the benefit of including bitcoin was mainly due to the improved returns that compensate for the increase in C-VaR. Considering the stellar increase in bitcoin value as well as very high volatility, does this hold true in 2017?

Notwithstanding the limitations, our study indicates that bitcoin is an emerging relevant asset class and it might play a more relevant role in portfolio diversification strategies in U.S., Europe and China than has heretofore been acknowledged.

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Table 1 – *Asset Classes Included in the Analysis*

	Name	Mnemonic	Asset Class
United States	BTC-USD-Index	btcusd	Cryptocurrency
	S&P U.S. TREASURY BILL INDEX	billus	Money Market
	S&P U.S. TREASURY BOND INDEX	condus	Fixed-income
	DOW JONES EQUAL WEIGHTS U.S. ISSUED CORPORATE BONDS	corpus	Fixed-income
	S&P WCI GOLD (ER)	gold	Gold ETF
	S&P 100	sp100	Equity (large cap)
	S&P 500	sp500	Equity (mid cap)
	S&P 600	spsml	Equity (small cap)
	S&P WCI	wcig	Commodities
	DOW JONES U.S. REAL EASTATE INDEX	resus	Real Estate
	Global hedge fund index	hfrx	Alternative
	Dow Jones FXCM Dollar Index	usdollar	Currency
Europe	BTC	btceur	Cryptocurrency
	S&P Pan-Europe Developed Sovereign Bond Index	condeu	Fixed-income
	S&P Eurozone Investment Grade Corporate Bond Index	corpeu	Fixed-income
	S&P WCI GOLD (ER)	gold	Gold ETF
	S&P EUROPE 350	sp350eu	Equity
	S&P WCI Europe	wcie	Commodities
	Dow Jones Europe Select Real Estate Securities Index	reseu	Real Estate
	Global hedge fund index	hfrx	Alternative
	S&P EURO Futures Index Spot	speuf	Currency
China	BTC-CNY-Index	btccny	Cryptocurrency
	S&P CHINA GOVERNMENT BILL INDEX	billcn	Money Market
	S&P CHINA SOVEREIGN BOND INDEX	condcn	Fixed-income
	S&P CHINA CORPORATE BOND INDEX	corpcn	Fixed-income
	S&P WCI GOLD (ER)	gold	Gold ETF
	S&P CHINA A 100 INDEX (RMB)	spc100	Equity (large cap)
	S&P CHINA A 200 INDEX (RMB)	spc200	Equity (mid cap)
	S&P CHINA A SMALLCAP INDEX (RMB)	spcsml	Equity (small cap)
	S&P WCI ASIA	wcia	Commodities
	Guggenheim China Real Estate ETF (TAO)	tao	Real Estate
	Global hedge fund index	hfrx	Alternative
	USDCNY Exchange rate (holding USD as investment)	usdcny	Currency

Table 2A Descriptive Statistics U.S. Assets

	Descriptive Statistics of excess monthly returns											
	btcusd	billus	condus	corpus	gold	sp100	sp500	spsml	wcig	resus	hfrx	usdollar
Min	-55.99%	-0.05%	-2.67%	-5.12%	-14.49%	-12.32%	-11.64%	-12.21%	-20.40%	-16.48%	-4.17%	-3.93%
Max	208.31%	0.07%	2.31%	3.86%	12.19%	11.77%	10.55%	17.56%	19.26%	13.34%	2.71%	3.90%
Mean	12.84%	0.00%	0.08%	0.35%	-0.35%	1.25%	1.10%	1.28%	-0.84%	0.58%	0.14%	0.34%
Median	6.51%	-0.01%	0.10%	0.43%	-0.22%	1.58%	1.30%	1.43%	-0.40%	1.03%	0.31%	0.27%
Skewness	2.38	1.11	-0.33	-0.55	-0.06	-0.58	-0.50	0.03	-0.22	-0.45	-0.84	0.06
Kurtosis	7.99	1.76	1.09	1.04	0.05	1.25	1.07	0.68	0.26	0.52	0.91	-0.45
St.Dev.	34.90%	0.02%	0.76%	1.34%	4.54%	3.07%	3.05%	4.14%	6.79%	4.05%	1.12%	1.34%
VaR	24.63%	0.02%	1.16%	2.28%	7.81%	4.53%	4.44%	5.45%	13.17%	6.86%	2.04%	1.71%
C-VaR	32.90%	0.03%	1.70%	3.01%	9.91%	6.49%	6.49%	7.60%	16.29%	8.74%	2.76%	2.24%
Sharpe (C-VaR)	0.39	0.00	0.04	0.11	-0.04	0.19	0.17	0.17	-0.05	0.07	0.05	0.15

Table 2B Descriptive Statistics European Assets

	Descriptive Statistics								
	btceur	condeu	corpeu	gold	sp350eu	wcie	reseu	hfrx	speuf
Min	-54.15%	-3.99%	-2.83%	-14.88%	-16.18%	-23.55%	-18.11%	-4.57%	-8.71%
Max	190.69%	2.66%	1.46%	11.79%	11.83%	20.47%	12.02%	2.32%	7.14%
Mean	12.76%	0.00%	-0.07%	-0.75%	0.51%	-1.24%	0.19%	-0.26%	-0.67%
Median	6.43%	0.18%	0.07%	-0.62%	0.69%	-0.66%	0.52%	-0.08%	-0.59%
Skewness	2.22	-0.85	-0.83	-0.06	-0.51	-0.25	-0.39	-0.84	-0.27
Kurtosis	7.02	0.90	0.67	0.05	0.85	0.38	0.11	0.91	0.58
St.Dev.	33.82%	1.13%	0.66%	4.54%	3.98%	7.33%	4.74%	1.12%	2.31%
VaR	22.90%	2.28%	1.40%	8.21%	6.85%	14.94%	7.99%	2.43%	4.43%
C-VaR	32.93%	2.94%	1.75%	10.31%	9.32%	18.22%	10.50%	3.15%	6.00%
Sharpe (C-VaR)	0.39	0.00	-0.04	-0.07	0.05	-0.07	0.02	-0.08	-0.11

Table 2C Descriptive Statistics Chinese Assets

	Descriptive Statistics of excess monthly returns											
	btccny	billcn	condcn	corpcn	gold	spc100	spc200	spcsml	wcia	tao	hfrx	usdcny
Min	-56.21%	-1.79%	-3.47%	-2.13%	-14.70%	-33.33%	-47.12%	-53.94%	-11.89%	-22.39%	-4.39%	-1.84%
Max	208.10%	1.74%	3.19%	2.95%	11.97%	33.12%	28.94%	35.67%	13.65%	18.02%	2.50%	3.02%
Mean	12.63%	0.00%	0.09%	0.20%	-0.57%	0.61%	0.61%	1.01%	-0.73%	0.61%	-0.08%	-0.07%
Median	6.29%	-0.03%	0.12%	0.22%	-0.44%	0.57%	1.25%	1.32%	-0.91%	1.22%	0.10%	-0.23%
Skewness	2.38	-0.17	-0.32	-0.06	-0.06	0.31	-0.97	-0.93	0.31	-0.46	-0.84	1.01
Kurtosis	7.99	6.26	1.01	1.24	0.05	2.86	3.54	4.50	0.25	0.54	0.91	1.08
St.Dev.	34.90%	0.32%	0.88%	0.73%	4.54%	7.77%	9.00%	9.90%	4.07%	6.44%	1.12%	0.83%
VaR	24.85%	0.34%	1.40%	1.15%	8.03%	11.59%	15.40%	15.52%	7.36%	9.67%	2.25%	1.18%
C-VaR	33.11%	0.73%	1.99%	1.52%	10.13%	17.59%	24.61%	26.72%	8.50%	14.75%	2.97%	1.34%
Sharpe (C-VaR)	0.38	0.00	0.04	0.13	-0.06	0.03	0.02	0.04	-0.09	0.04	-0.03	-0.05

Figure 1A U.S. Assets Distributions of Excess Returns

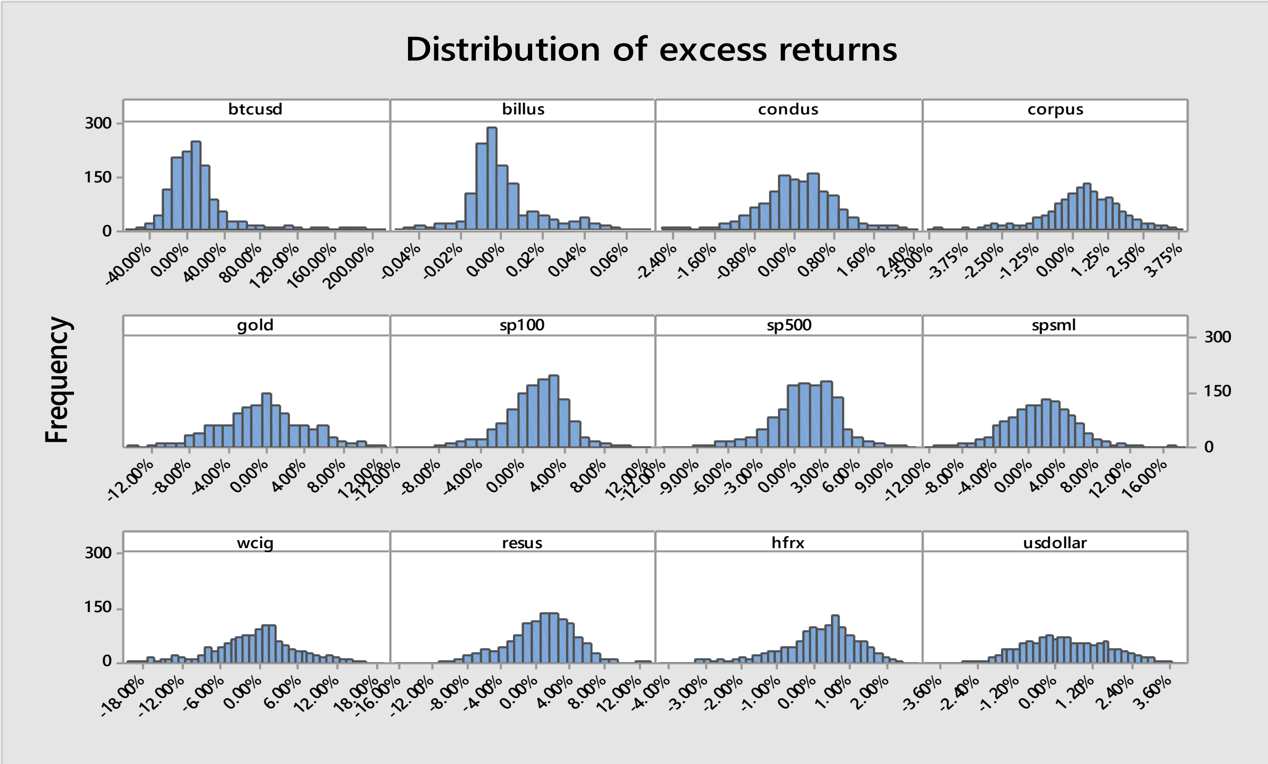

Figure 1C European Assets Distributions of Excess Returns

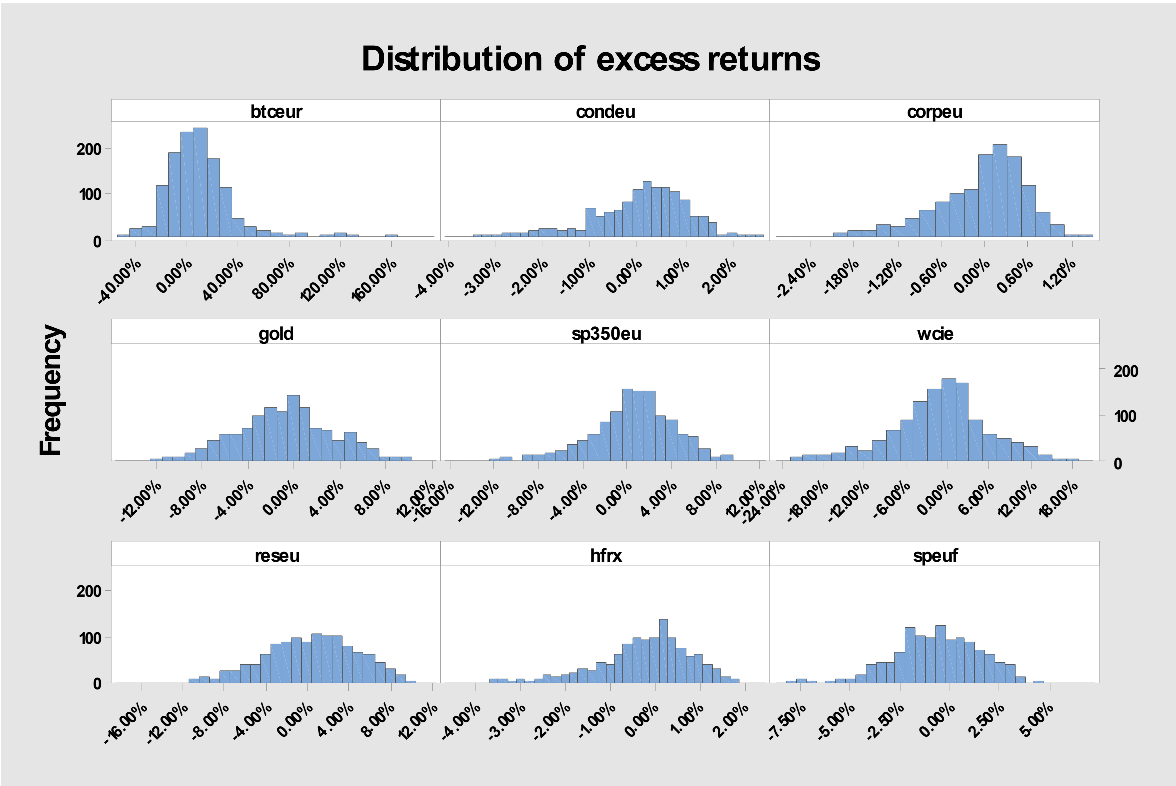

Figure 1C Chinese Assets Distributions of Excess Returns

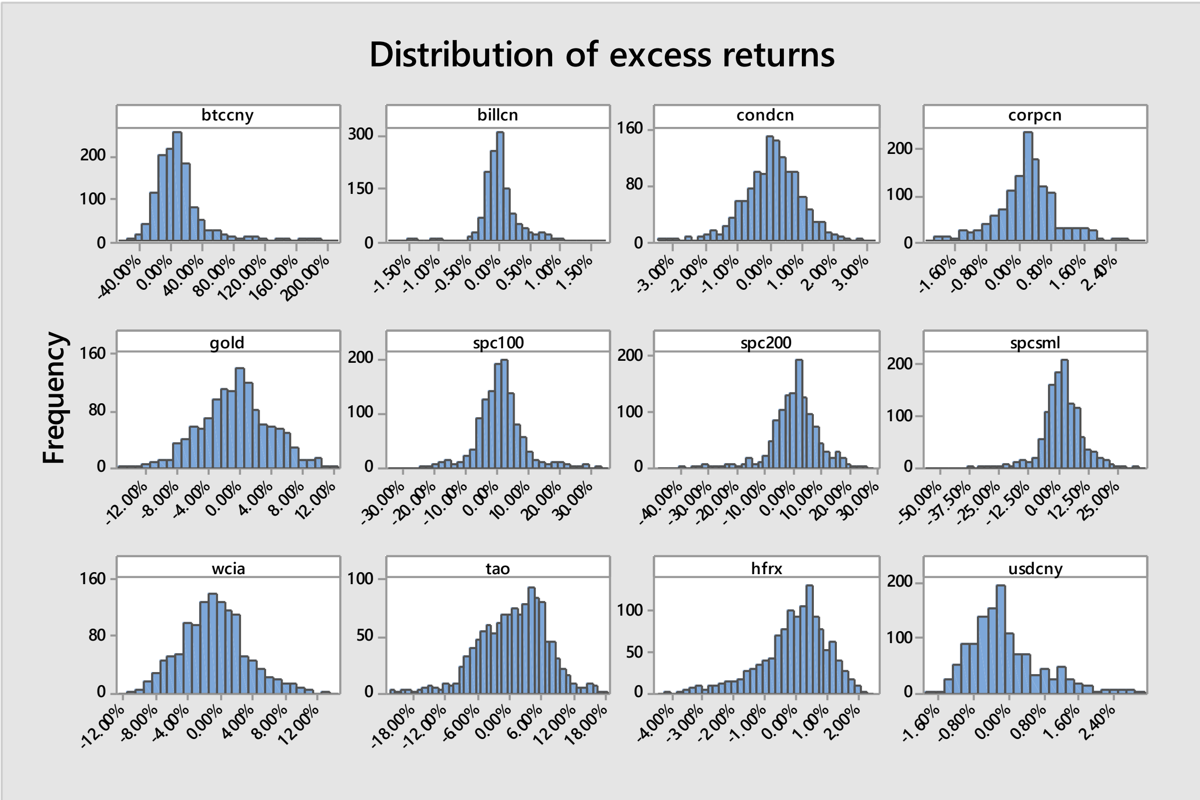

Table 3A Correlation Matrix U.S. Assets

Correlation Matrix Coefficients (*P-Values*)											
	btcusd	billus	condus	corpus	gold	sp100	sp500	spsml	wcig	resus	hfrx
billus	-0.087***										
condus	-0.051*	0.245***									
corpus	0.009	0.230***	0.772***								
gold	-0.183***	0.325***	0.424***	0.364***							
sp100	0.264***	-0.110***	-0.322***	0.028	-0.099***						
sp500	0.244***	-0.097***	-0.316***	0.042	-0.082***	0.990***					
spsml	0.150***	-0.057**	-0.407***	-0.081***	-0.101***	0.801***	0.850***				
wcig	0.063**	0.273***	-0.306***	-0.030	0.117***	0.354***	0.361***	0.387***			
resus	0.006	0.086***	0.335***	0.586***	0.137***	0.522***	0.564***	0.459***	0.007		
hfrx	0.187***	0.035	-0.289***	0.078**	-0.092***	0.763***	0.802***	0.760***	0.441***	0.440***	
usdollar	0.058**	-0.257***	-0.170***	-0.233***	-0.454***	-0.027	-0.027	0.014	-0.338***	-0.059**	0.044

Table 3B Correlation Matrix European Assets

Correlation Matrix Coefficients (*P-Values*)								
	btceur	condeu	corpeu	gold	sp350eu	wcie	reseu	hfrx
condeu	0.041							
corpeu	0.127***	0.793***						
gold	-0.191***	0.213***	0.144***					
sp350eu	0.145***	0.160***	0.394***	-0.083***				
wcie	0.060**	-0.254***	0.007	0.087***	0.291***			
reseu	0.021	0.298***	0.473***	0.074***	0.654***	0.216***		
hfrx	0.215***	0.04	0.308***	-0.092***	0.776***	0.445***	0.507***	
speuf	-0.090	-0.214***	-0.192***	0.302***	-0.316***	0.239***	0.197***	-0.100***

Table 3C Correlation Matrix Chinese Assets

Correlation Matrix Coefficients (*P-Values*)											
	btccny	billcn	condcn	corpcn	gold	spc100	spc200	spcsml	wcia	tao	hfrx
billcn	-0.357***										
condcn	-0.254***	0.619***									
corpcn	-0.250***	0.683***	0.863***								
gold	-0.183***	0.085***	0.049*	0.009							
spc100	-0.080***	0.051*	-0.060**	-0.121***	0.038						
spc200	-0.057**	0.193***	-0.045	-0.028	-0.015	0.845***					
spcsml	-0.051*	0.241***	-0.030	0.023	-0.009	0.736***	0.974***				
wcia	-0.100***	0.017	0.012	-0.038	0.635***	0.124***	0.050*	0.059**			
tao	-0.046	0.018	0.042	0.042	0.165***	0.496***	0.446***	0.403***	0.221***		
hfrx	0.187***	-0.050*	-0.160***	-0.089***	-0.092***	0.309***	0.361***	0.342***	0.089***	0.486***	
usdcny	-0.094***	-0.019	0.058**	0.071**	-0.055**	-0.157***	-0.213***	-0.202***	-0.075***	-0.403***	-0.283***

Table 4 Portfolio of U.S. Assets: Bitcoin Weights in Portfolio with Semi-Annual Rebalancing

Portfolio	**Long-only**	**Uncons.**	**Semi-C.**	**btc>1**
Jun-13	14.24%	4.83%	1.30%	1.30%
Dec-13	10.65%	16.21%	1.80%	1.80%
Jun-14	13.84%	-1.90%	3.70%	3.70%
Dec-14	0.00%	1.95%	0.01%	0.01%
Jun-15	0.00%	0.40%	0.74%	0.74%
Dec-15	0.48%	-2.29%	0.47%	0.47%
Jun-16	4.43%	1.70%	6.85%	6.85%
Dec-16	0.08%	-16.76%	8.19%	8.19%
Bitcoin Mean	5.47%	0.52%	2.88%	2.88%

Table 5 Portfolio of U.S. Assets: Performance – Average for the Period

Robustness tests of portfolios without rebalancing

	Naive		**Long-only**		**Unconstrained**		**Semi-constrained**		**BTC > 0***	
	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC
Mean monthly return	0.26%	0.86%	0.06%	1.37%	1.06%	1.09%	0.75%	0.57%	0.75%	0.57%
Mean monthly C-Var	1.27%	1.76%	0.07%	1.55%	2.04%	1.70%	0.91%	1.35%	0.91%	1.35%
Mean monthly Sharpe	0.20	0.49	0.84	0.89	0.52	0.64	0.82	0.42	0.82	0.42

Robustness tests of portfolios with semi-annual rebalancing

	Naive		**Long-only**		**Unconstrained**		**Semi-constrained**		**BTC > 0***	
	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC
Mean monthly return	0.26%	0.86%	0.19%	0.75%	2.35%	0.97%	0.60%	0.53%	0.60%	0.53%
Mean monthly C-Var	1.27%	1.76%	1.33%	1.59%	3.28%	3.59%	0.94%	0.95%	0.94%	0.95%
Mean monthly Sharpe	0.20	0.49	0.14	0.47	0.72	0.27	0.63	0.56	0.63	0.56

*(-100% < X < 100% with bitcoin where bitcoin > 0)

Table 6 Portfolio of U.S. Assets: Portfolio Performance

	Return				C-Var			Sharpe Ratio		
year	percentage of days BTC over-perfomerms	Average day performance (no BTC)	Average Daily Performce (with BTC)	Difference	Average C-Var (no BTC)	Average C-Var (with BTC)	Difference	Average sharpe ratio (no BTC)	Average Shapre ratio (with BTC)	Difference
	naïve portfolio									
2013	100%	0.57%	4.12%	3.54%	0.0086	0.0058	(0.0029)	0.6661	7.1334	6.4673
2014	43%	0.28%	0.78%	0.50%	0.0088	0.0214	0.0126	0.3212	0.3660	0.0447
2015	55%	-0.21%	-0.17%	0.04%	0.0179	0.0242	0.0063	(0.1177)	(0.0697)	0.0481
2016	80%	0.54%	1.23%	0.69%	0.0135	0.0134	(0.0001)	0.4000	0.9155	0.5155
	Long only portolfio									
2013	100%	0.10%	6.29%	6.19%	0.0013	(0.0053)	(0.0066)	0.7446	(11.8709)	(12.6155)
2014	41%	0.24%	0.87%	0.62%	0.0286	0.0369	0.0082	0.0855	0.2349	0.1494
2015	8%	0.36%	0.32%	-0.04%	0.0108	0.0106	(0.0003)	0.3286	0.3003	(0.0283)
2016	88%	0.05%	0.22%	0.17%	0.0074	0.0064	(0.0010)	0.0718	0.3470	0.2752
	Uncostrained portfolio									
2013	97%	3.58%	5.45%	1.87%	(0.0013)	(0.0133)	(0.0121)	(28.5982)	(4.0936)	24.5047
2014	42%	0.68%	-0.31%	-0.99%	0.0380	0.0584	0.0205	0.1796	(0.0522)	(0.2318)
2015	36%	6.22%	2.78%	-3.43%	0.0447	0.0297	(0.0150)	1.3907	0.9370	(0.4537)
2016	21%	1.25%	0.34%	-0.91%	0.0281	0.0188	(0.0093)	0.4447	0.1791	(0.2656)
	Semiconstrained portfolio									
2013	87%	1.92%	2.18%	0.26%	0.0019	0.0014	(0.0005)	10.3542	15.7466	5.3924
2014	29%	0.23%	-0.30%	-0.53%	0.0081	0.0116	0.0036	0.2860	(0.2600)	(0.5460)
2015	64%	0.69%	0.78%	0.09%	0.0078	0.0090	0.0012	0.8914	0.8698	(0.0216)
2016	53%	0.48%	0.67%	0.19%	0.0147	0.0093	(0.0055)	0.3224	0.7178	0.3954
	Semiconstrained portfolio (no shorting on BTC)									
2013	100%	1.92%	2.18%	0.26%	0.0019	0.0014	(0.0005)	10.3542	15.7466	5.3924
2014	60%	0.23%	-0.30%	-0.53%	0.0081	0.0116	0.0036	0.2860	(0.2600)	(0.5460)
2015	43%	0.69%	0.78%	0.09%	0.0078	0.0090	0.0012	0.8914	0.8698	(0.0216)
2016	57%	0.48%	0.67%	0.19%	0.0147	0.0093	(0.0055)	0.3224	0.7178	0.3954

Table 7 Portfolio of European Assets: Bitcoin Weights in Portfolio with Semi-Annual Rebalancing

Semi-annual BTC weights				
Portfolio	**Long-only**	**Uncons.**	**Semi-C.**	**btc>1**
Jun-13	35.46%	104.97%	11.52%	11.52%
Dec-13	17.53%	15.91%	6.82%	6.82%
Jun-14	16.25%	9.52%	1.39%	1.39%
Dec-14	0.28%	0.08%	0.01%	0.01%
Jun-15	0.00%	-3.91%	-2.02%	0.00%
Dec-15	55.05%	-10.18%	-2.37%	0.00%
Jun-16	26.15%	2.87%	1.26%	1.26%
Dec-16	56.31%	1.35%	1.71%	1.71%
Bitcoin Mean	25.88%	15.08%	2.29%	2.84%

Table 8 Portfolio of European Assets: Portfolio Performance – Period Average

Robustness tests of portfolios without rebalancing										
	Naive		**Long-only**		**Unconstrained**		**Semi-constrained**		**BTC > 0***	
	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC
Mean monthly return	-0.43%	0.45%	0.06%	2.38%	0.61%	6.65%	0.45%	0.73%	0.45%	0.73%
Mean monthly C-Var	0.02	0.03	0.03	0.05	0.05	0.15	0.03	0.02	0.03	0.02
Mean monthly Sharpe	-0.21	0.18	0.02	0.53	0.13	0.46	0.13	0.46	0.13	0.46

Robustness tests of portfolios with semi-annual rebalancing										
	Naive		**Long-only**		**Unconstrained**		**Semi-constrained**		**BTC > 0***	
	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC
Mean monthly return	-0.43%	0.45%	-0.43%	2.31%	1.27%	5.22%	0.38%	0.68%	0.38%	0.74%
Mean monthly C-Var	0.02	0.03	0.04	0.03	0.03	0.03	0.01	0.01	0.01	0.01
Mean monthly Sharpe	-0.21	0.18	-0.12	0.74	0.41	1.73	0.36	0.68	0.36	0.81

*(-100% < X < 100% with bitcoin where bitcoin > 0)

Table 9 Portfolio of European Assets: Portfolio Performance

	Return				C-Var			Sharpe Ratio		
year	percentage of days BTC over-perfomerms	Average day performance (no BTC)	Average Daily Performce (with BTC)	Difference	Average C-Var (no BTC)	Average C-Var (with BTC)	Difference	Average sharpe ratio (no BTC)	Average Shapre ratio (with BTC)	Difference
	naïve portfolio									
2013	100%	0.41%	4.87%	4.46%	0.0084	0.0093	0.0010	0.4922	5.2123	4.7201
2014	43%	-0.47%	0.21%	0.68%	0.0152	0.0301	0.0148	(0.3082)	0.0705	0.3787
2015	53%	-0.91%	-0.72%	0.19%	0.0276	0.0331	0.0055	(0.3285)	(0.2167)	0.1118
2016	80%	-0.29%	0.63%	0.92%	0.0233	0.0203	(0.0030)	(0.1244)	0.3098	0.4342
	Long only portolfio									
2013	100%	1.20%	14.83%	13.63%	0.0154	(0.0187)	(0.0341)	0.7830	(7.9243)	(8.7073)
2014	36%	-0.33%	1.72%	2.05%	0.0234	0.0319	0.0085	(0.1412)	0.5386	0.6798
2015	15%	-0.56%	-0.43%	0.13%	0.0306	0.0302	(0.0004)	(0.1838)	(0.1437)	0.0401
2016	87%	-1.09%	1.68%	2.78%	0.0566	0.0369	(0.0196)	(0.1935)	0.4562	0.6497
	Uncostrained portfolio									
2013	100%	3.06%	43.29%	40.23%	0.0156	(0.0505)	(0.0662)	1.9578	(8.5661)	(10.5239)
2014	46%	1.09%	9.10%	8.01%	0.0203	0.0040	(0.0163)	0.5359	22.9558	22.4199
2015	37%	3.31%	2.09%	-1.21%	0.0167	0.0279	0.0112	1.9783	0.7493	(1.2290)
2016	50%	-0.20%	-0.81%	-0.61%	0.0614	0.0503	(0.0111)	(0.0327)	(0.1612)	(0.1286)
	Semiconstrained portfolio									
2013	79%	2.25%	4.92%	2.68%	0.0115	(0.0072)	(0.0187)	1.9540	(6.8028)	(8.7568)
2014	48%	0.39%	1.18%	0.79%	0.0062	0.0055	(0.0007)	0.6287	2.1386	1.5099
2015	6%	0.77%	0.60%	-0.17%	0.0061	0.0071	0.0010	1.2689	0.8502	(0.4187)
2016	40%	-0.19%	-0.25%	-0.06%	0.0142	0.0163	0.0021	(0.1318)	(0.1525)	(0.0208)
	Semiconstrained portfolio (no shorting on BTC)									
2013	79%	2.25%	4.92%	2.68%	0.0115	(0.0072)	(0.0187)	1.9540	(6.8028)	(8.7568)
2014	48%	0.39%	1.18%	0.79%	0.0062	0.0055	(0.0007)	0.6287	2.1386	1.5099
2015	7%	0.77%	0.72%	-0.06%	0.0061	0.0064	0.0003	1.2689	1.1191	(0.1498)
2016	45%	-0.19%	-0.13%	0.06%	0.0142	0.0137	(0.0005)	(0.1318)	(0.0942)	0.0376

Table 10 Portfolio of Chinese Assets: Bitcoin Weights in Portfolio with Semi-Annual Rebalancing

Semi-annual BTC weights				
Portfolio	**Long-only**	**Uncons.**	**Semi-C.**	**BTC>0**
Jun-13	34.89%	-3.04%	0.74%	0.74%
Dec-13	9.31%	1.25%	0.79%	0.79%
Jun-14	4.33%	55.02%	4.78%	4.78%
Dec-14	0.31%	3.69%	0.44%	0.44%
Jun-15	0.00%	5.83%	0.10%	0.10%
Dec-15	0.75%	14.13%	-1.35%	2.42%
Jun-16	4.32%	75.05%	-2.22%	0.05%
Dec-16	3.42%	43.28%	0.69%	0.69%
Bitcoin Mean	7.17%	24.40%	0.50%	1.25%

Table 11 Portfolio of Chinese Assets: Portfolio Performance – Period Average

Robustness tests of portfolios without rebalancing										
	Naive		**Long-only**		**Unconstrained**		**Semi-constrained**		**BTC > 0***	
	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC
Mean monthly return	0.22%	0.81%	0.13%	2.76%	3.01%	0.19%	0.07%	0.05%	0.07%	0.05%
Mean monthly C-Var	0.02	0.02	0.01	0.05	0.22	0.03	0.02	0.01	0.02	0.01
Mean monthly Sharpe	0.09	0.33	0.21	0.58	0.14	0.06	0.04	0.04	0.04	0.04

Robustness tests of portfolios with semi-annual rebalancing										
	Naive		**Long-only**		**Unconstrained**		**Semi-constrained**		**BTC > 0***	
	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC	No BTC	with BTC
Mean monthly return	0.22%	0.81%	0.09%	1.58%	5.48%	9.41%	0.67%	0.66%	0.67%	0.79%
Mean monthly C-Var	0.02	0.02	0.02	0.02	0.29	0.37	0.01	0.01	0.01	0.01
Mean monthly Sharpe	0.09	0.33	0.04	0.67	0.19	0.25	0.51	0.51	0.51	0.63

Table 12 Portfolio of Chinese Assets: Portfolio Performance

year	Return				C-Var			Sharpe Ratio		
	percentage of days BTC over-perfomerms	Average day performance (no BTC)	Average Daily Performce (with BTC)	Difference	Average C-Var (no BTC)	Average C-Var (with BTC)	Difference	Average sharpe ratio (no BTC)	Average Shapre ratio (with BTC)	Difference
	naïve portfolio									
2013	100%	0.45%	3.99%	3.54%	0.0151	0.0110	(0.0041)	0.2981	3.6267	3.3287
2014	43%	0.17%	0.66%	0.49%	0.0150	0.0216	0.0065	0.1105	0.3057	0.1952
2015	47%	0.74%	0.69%	-0.05%	0.0355	0.0368	0.0014	0.2097	0.1875	(0.0222)
2016	83%	0.14%	0.85%	0.71%	0.0233	0.0210	(0.0024)	0.0618	0.4066	0.3448
	Long only portolfio									
2013	100%	-0.13%	14.83%	14.96%	0.0086	(0.0126)	(0.0212)	(0.1545)	(11.7342)	(11.5797)
2014	42%	0.30%	2.98%	2.68%	0.0058	0.0066	0.0008	0.5106	4.5311	4.0205
2015	35%	-0.47%	-0.53%	-0.06%	0.0690	0.0664	(0.0025)	(0.0683)	(0.0796)	(0.0113)
2016	78%	0.61%	0.81%	0.20%	0.0034	0.0011	(0.0023)	1.7926	7.0946	5.3020
	Uncostrained portfolio									
2013	65%	-2.01%	-2.52%	-0.50%	0.2995	0.0609	(0.2386)	(0.0673)	(0.4138)	(0.3465)
2014	33%	-1.93%	2.19%	4.13%	0.1363	0.0677	(0.0686)	(0.1419)	0.3242	0.4661
2015	28%	3.94%	6.12%	2.18%	0.6121	1.3131	0.7010	0.0644	0.0466	(0.0178)
2016	40%	24.22%	25.77%	1.55%	0.0815	0.0046	(0.0769)	2.9707	65.9055	62.9347
	Semiconstrained portfolio									
2013	100%	-0.15%	0.40%	0.56%	0.0199	0.0129	(0.0071)	(0.0774)	0.3138	0.3912
2014	60%	1.08%	0.85%	-0.23%	0.0057	0.0056	(0.0001)	1.8987	1.5150	(0.3836)
2015	43%	0.78%	0.73%	-0.06%	0.0277	0.0271	(0.0006)	0.2831	0.2685	(0.0146)
2016	28%	1.17%	0.95%	-0.23%	0.0032	0.0065	0.0034	3.7209	1.4528	(2.2681)
	Semiconstrained portfolio (no shorting on BTC)									
2013	100%	-0.15%	0.40%	0.56%	0.0199	0.0129	(0.0071)	(0.0774)	0.3138	0.3912
2014	60%	1.08%	0.85%	-0.23%	0.0057	0.0056	(0.0001)	1.8987	1.5150	(0.3836)
2015	43%	0.78%	0.74%	-0.04%	0.0277	0.0270	(0.0007)	0.2831	0.2749	(0.0082)
2016	57%	1.17%	1.20%	0.03%	0.0032	0.0051	0.0020	3.7209	2.3602	(1.3608)