Invited Editorial

Virtual currency, tangible return: Portfolio diversification with bitcoin

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ABSTRACT Bitcoin (BTC) is a major virtual currency. Using weekly data over the 2010–2013 period, we analyze a BTC investment from the standpoint of a US investor with a diversified portfolio including both traditional assets (worldwide stocks, bonds, hard currencies) and alternative investments (commodities, hedge funds, real estate). Over the period under consideration, BTC investment had highly distinctive features, including exceptionally high average return and volatility. Its correlation with other assets was remarkably low. Spanning tests confirm that BTC investment offers significant diversification benefits. We show that the inclusion of even a small proportion of BTCs may dramatically improve the risk-return trade-off of well-diversified portfolios. Results should however be taken with caution as the data may reflect early-stage behavior that may not last in the medium or long run.

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INTRODUCTION

The recent crisis has prompted investors to explore innovative investment opportunities.[1] Bitcoin (BTC), a virtual currency, has recently attracted substantial media attention and has now become a standard means of payment over the internet (ECB, 2012). More and more providers of goods and services – legal and illegal – trade in BTCs. Importantly, the projected launch of a BTC exchange-traded fund, Winklevoss BTC Trust, shows that BTC is now a credible investment vehicle (Arash and Alloway, 2013; Arthur, 2013; Balchunas, 2013). Even though currencies are commonly used to diversify financial portfolios, the literature has so far overlooked the investment characteristics of BTC.[2] Our article fills that gap.

BTC was invented in 2009 by a programmer known as Satoshi Nakamoto (Grinberg, 2012). The creation of BTC follows precise rules derived from the gold market. So-called 'miners' competitively use computer resources to solve cryptographic problems and verify the validity of transactions (Velde, 2013). Success is rewarded by newly issued BTC. The subsequent money creation evolves according to a fixed scheme pre-established by the inventor. As supply is perfectly predictable (bitcoin.org/en/how-it-works), BTC is free from any central-bank-like intervention (ECB, 2012). The value of BTC solely depends on supply and demand. Currently, BTCs are actively traded against 32 hard currencies on well-organized virtual exchange markets. These markets remain accessible during weekends, which is valuable to investors, especially in hectic times (Michie, 1999). As of December 2013, the BTC market capitalization was approximately USD 10 billion.

The ECB (2012, p. 13) defines BTC as 'a type of unregulated, digital money, which is issued and controlled by its developers, and used and accepted among the members of a specific virtual community'. Obviously, BTC is not legal tender.[3] BTCs are typically stored in virtual wallets, which attract hackers.[4] As a result, BTC tends to be more volatile than hard currencies, and more prone to speculative bubbles (Grinberg, 2012). On the other hand, virtual transactions are nearly anonymous and have low or inexistent transaction fees.

Computer science aside, the scarce academic literature on BTC is mostly dedicated to legal issues such as trading safety, money laundering and income tax. To our knowledge, investment aspects remain unaddressed. Here, we put BTC investment into a portfolio perspective. Our results confirm that BTC investment *per se* is extremely risky (ECB, 2012; Harper, 2013). More surprisingly, we show that the BTC rate of return presents statistical characteristics that differ markedly from those of other assets, including gold, oil and hedge funds. In addition, BTC investment is attractive because it delivers exceptionally high diversification benefits. This is because of low correlations not only with traditional financial assets but also with alternative investments. Results should however be taken with caution as BTC is still in its infancy and data may be subject to an early-stage behavior that may not continue in the future.

DATA AND RESULTS

Since 2009, 40 BTC exchanges have been created, 20 of which are still active today (Moore and Christin, 2013). BTC liquidity has improved dramatically since the currency was created (see Figure A1 in Appendix). Currently, more than 50 000 transactions are handled daily on BTC exchanges.[5] We use weekly BTC closing exchange rates against the USD retrieved from the *Bitcoincharts* Website for the period from 23 July 2010 to 27 December 2013. BTC has already experienced two major speculative crises in its short history (see Figure A2 in Appendix). The first started in June 2011 and ended in a crash after the first major BTC theft in July 2011 (www.forbes.com/sites/timworstall/2011/06/17/bitcoin-the-first-500000-theft/). The second coincided with the Cyprus crisis (Rushe, 2013). A period of price inflation started in March 2013 just after the United States published legislative guidance on virtual currencies, and ended in April 2013 when BTC lost nearly half of its value in a couple of hours. Our sample period covers both crises.

We consider the situation of a US investor holding a diversified portfolio comprising both traditional assets (worldwide stocks, bonds, hard currencies) and alternative investments (commodities, hedge funds, real estate). Each asset class is represented by several liquid financial indices.[6] The weekly returns of these indices are retrieved from Datastream (total return indices in USD).

Figure 1 draws cumulative performances for the 13 assets under study, and Table 1 provides descriptive statistics. BTC returns are exceptional in many regards. The average return is skyrocketing (404 per cent annually), but so is volatility (176 per cent annually). These exceptionally high figures reflect the risks in BTC investment, including non-survival risk.[7] Financial innovations are hard to value and assets linked to these financial innovations are likely to exhibit bubble-like features (Frehen *et al*, 2013). The returns observed on our sample may thus be linked to novelty and may not be reached again in subsequent periods. In other words, BTC past returns should be used with care when assessing future expected returns.[8] The presence of significant extreme risks is reflected in kurtosis values of up to 9.10, comparable with those of emerging government bonds (8.96). Even more striking is the extremely high skewness (1.85), a real curiosity for financial analysts. Positive skewness levels of this magnitude are known to be reachable only by sophisticated strategies such as volatility investments meant to hedge financial portfolios against crises (Brière *et al*, 2010).[9] This evidence, though still frail, suggests that BTC could act as a partial hedge against crises. Overall, it looks like something new in the investment universe.[10]

Table 2 shows that BTC benefits from low correlations with the other assets. Only two assets exhibit a significant correlation with BTC, gold (14 per cent) and inflation-linked bonds (14 per cent). This is hardly surprising as the fully predictable BTC supply is often presented as an inflation hedge (ECB, 2012; Harper, 2013), which is attractive to investors (Bodie, 1976).

The low correlations between BTC and other investment vehicles should be interpreted with caution as they were computed on a bullish period. Correlations are known to be unstable and can change

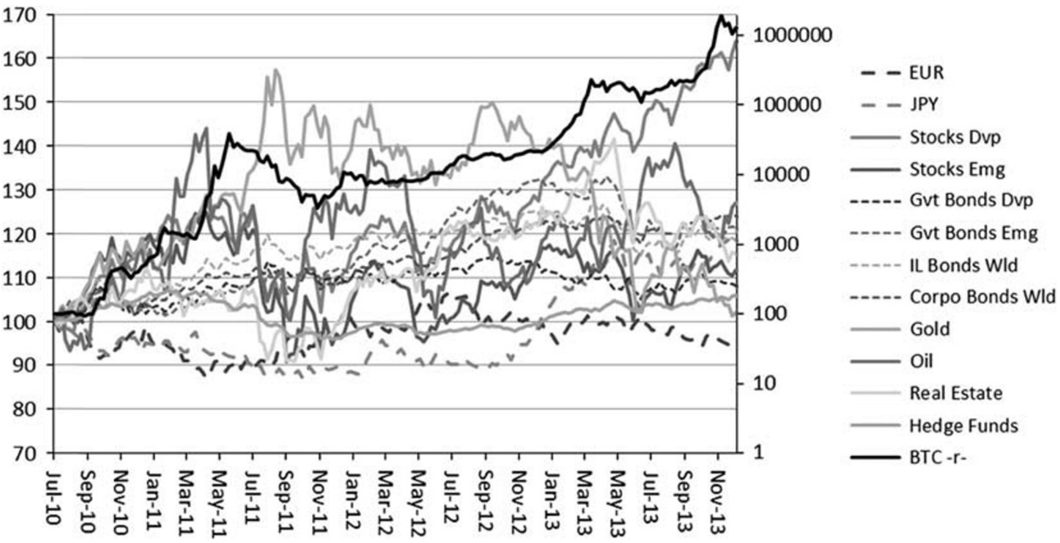

Figure 1: Performances of BTC and traditional investment.
This figure shows the performance in USD of BTC investment (logarithmic right scale) compared with those of traditional and alternative assets (left scale) over the time period 23 July 2010–27 December 2013. Traditional assets are money market investments (1-week interbank interest rates) in hard currencies, EUR and JPY, developed and emerging equities (Stocks Dvp and Stocks Emg), developed and emerging government bonds (Gvt Bonds Dvp and Gvt Bonds Emg), World inflation-linked bonds (IL Bonds Wld), World corporate bonds (Corpo Bonds Wld), gold, oil, hedge funds and listed World real estate.

Table 1: Descriptive statistics

	BTC	*EUR*	*JPY*	*Stocks dvp*	*Stocks emg*	*Gvt bonds dvp*	*Gvt bonds emg*	*IL bonds wld*	*Corpo bonds wld*	*Gold*	*Oil*	*Real estate*	*Hedge funds*
Mean	7.79%	−0.02%	0.11%	0.30%	0.09%	0.05%	0.11%	0.10%	0.12%	0.04%	0.20%	0.10%	0.03%
Annual mean	404.89%	−1.20%	5.93%	15.64%	4.91%	2.45%	5.88%	5.16%	6.38%	2.20%	10.24%	5.19%	1.75%
Median	3.32%	−0.01%	0.00%	0.43%	0.10%	0.07%	0.20%	0.05%	0.14%	0.19%	0.25%	0.22%	0.12%
Maximum	137.62%	4.17%	3.97%	8.27%	9.46%	2.25%	3.23%	2.28%	1.83%	7.14%	13.51%	5.91%	0.90%
Minimum	−41.78%	−3.19%	−3.55%	−8.81%	−11.62%	−2.85%	−5.90%	−3.51%	−2.55%	−7.11%	−14.57%	−9.04%	−2.49%
Standard deviation	24.43%	1.39%	1.31%	2.20%	2.58%	0.84%	1.04%	0.96%	0.70%	2.47%	3.56%	2.03%	0.46%
Volatility	176.15%	10.03%	9.43%	15.89%	18.61%	6.05%	7.53%	6.89%	5.06%	17.82%	25.68%	14.61%	3.33%
Skewness	1.85	0.31	0.14	−0.44	−0.28	−0.24	−1.07	−0.22	−0.29	−0.21	−0.17	−0.64	−1.35
Kurtosis	9.10	2.95	2.96	5.34	6.35	3.31	8.96	3.42	3.69	3.61	5.13	5.48	7.36
Sharpe ratio	2.30	−0.14	0.61	0.97	0.25	0.37	0.75	0.72	1.22	0.11	0.39	0.34	0.47
Observations	179	179	179	179	179	179	179	179	179	179	179	179	179

Notes: This table shows descriptive statistics (mean, median, maximum and minimum returns, standard deviation, volatility, skewness, kurtosis and Sharpe ratio) of weekly returns in USD of BTC, traditional and alternative assets over the time period between 23 July 2010 and 27 December 2013. Traditional assets are money market investments (1-week interbank interest rates) in hard currencies, EUR and JPY, developed and emerging equities (Stocks Dvp and Stocks Emg), developed and emerging government bonds (Gvt Bonds Dvp and Gvt Bonds Emg), World inflation-linked bonds (IL Bonds Wld), World corporate bonds (Corpo Bonds Wld), gold, oil, hedge funds and listed World real estate.

dramatically during crises (Goetzmann *et al*, 2005; Brière *et al*, 2012). Unfortunately, the limited period of observation does not allow us to test whether BTC correlations with other assets remain low when markets are bearish.

To gauge the interest of BTC from an investment perspective, we conduct spanning tests, which check whether adding a given asset (here BTC) to a predetermined universe improves investment opportunities. We use the mean–variance spanning test proposed by Huberman and Kandel (1987) and Ferson *et al* (1993). First, the test developed by Huberman and Kandel (1987) involves running OLS regressions of BTC return R_E on the returns of K benchmark assets, R_B^k, $k=1, \ldots, K$.

$$R_{E,t} = \alpha + \sum_{k=1}^{K} \beta_k R_{B,t}^k + \varepsilon_t \quad t = 1, 2 \ \ldots \ T$$

The necessary and sufficient condition for spanning is:

$$H_0 : \alpha = 0 \text{ and } \sum_{k=1}^{K} \beta_k = 1$$

Under the null of spanning, there exists a portfolio comprising K benchmark assets, which has the same expected return but a lower variance than the test asset as the K benchmark assets are uncorrelated with ε_t. We run a Wald test to assess spanning under the assumption of independent and identically distributed disturbances ε_t with a multivariate centered normal distribution and covariance matrix Σ. The Wald test statistic has the following asymptotic distribution (Berndt and Savin, 1977):

$$W = T(\lambda_1 + \lambda_2) \sim \chi_2^2,$$

where:

$$\lambda_1 = \max_r \frac{1+\hat{\theta}_2^2(r)}{1+\hat{\theta}_1^2(r)} - 1,$$

$$\lambda_2 = \min_r \frac{1+\hat{\theta}_2^2(r)}{1+\hat{\theta}_1^2(r)} - 1,$$

and $\hat{\theta}_1^2(r)$ and $\hat{\theta}_2^2(r)$ are the Sharpe ratios obtained for the risk-free rate r and the

Table 2: Correlations (in %)

	BTCs	*Euro*	*Yen*	*Stocks dvp*	*Stocks emg*	*Gvt bonds dvp*	*Gvt bonds emg*	*IL bonds wld*	*Corpo bonds wld*	*Gold*	*Oil*	*Real estate*	*Hedge funds*
BTCs	—	—	—	—	—	—	—	—	—	—	—	—	—
Euro	−4	—	—	—	—	—	—	—	—	—	—	—	—
Yen	−6	21***	—	—	—	—	—	—	—	—	—	—	—
Stocks dvp	5	−53***	4	—	—	—	—	—	—	—	—	—	—
Stocks emg	4	−45***	6	80***	—	—	—	—	—	—	—	—	—
Gvt bonds dvp	8	−64***	−74***	16**	20***	—	—	—	—	—	—	—	—
Gvt bonds emg	3	−27***	−5	34***	53***	39***	—	—	—	—	—	—	—
IL bonds wld	14*	−60***	−44***	23***	30***	84***	48***	—	—	—	—	—	—
Corpo bonds wld	10	−70***	−38***	38***	49***	81***	61***	81***	—	—	—	—	—
Gold	14*	−38***	−36***	21***	31***	49***	31***	50***	48***	—	—	—	—
Oil	−1	−34***	−6	50***	47***	14*	20***	23***	21***	30***	—	—	—
Real estate	0	13*	15**	63***	66***	−11	46***	2	14*	0	28***		—
Hedge funds	9	−34***	15**	77***	71***	7	32***	23***	37***	17**	49***	60***	—

Notes: This table displays the correlation matrix between the weekly returns in USD of the 13 asset classes under study (BTC and traditional investments) over the time period between 23 July 2010 and 27 December 2013. Traditional and alternative assets are money market investments (one-week interbank interest rates) in hard currencies, EUR and JPY, developed and emerging equities (Stocks Dvp and Stocks Emg), developed and emerging government bonds (Gvt Bonds Dvp and Gvt Bonds Emg), World inflation-linked bonds (IL Bonds Wld), World corporate bonds (Corpo Bonds Wld), gold, oil, hedge funds and listed World real estate. *, **, *** indicate that the coefficient estimates are significantly different from zero at the 10 per cent, 5 per cent, 1 per cent level.

tangency portfolios comprising the K benchmark assets and the $K+1$ assets including BTC, respectively.

Second, Ferson *et al* (1993) extend the same testing approach to Hansen's (1982) Generalized Method of Moments (GMM) estimation, which allows them to assume away homoscedasticity and normality. Both test statistics have asymptotic χ^2 distributions with two degrees of freedom. Kan and Zhou (2012) compare the sizes and powers of the two tests under several return distributions. In particular, when the returns under study have a joint multivariate elliptical distribution with excess kurtosis, which is a common characteristic of financial returns, the regular Wald test tends to over-reject the null, and the problem persists when the sample size increases. In this respect, the GMM-based test proposed by Ferson *et al* (1993) performs better, but lifting away the normality assumption entails a significant loss in statistical power. Kan and Zhou (2012) show that the amplitude of the power loss depends on the characteristics of the test asset; it is especially high when the test asset affects the global minimum-variance portfolio.

Table 3: Spanning tests

	HK spanning test	*FFK spanning test*
Traditional assets	6.87***	4.64**
Alternative assets	10.45***	8.28***
All assets	6.93***	5.22***

Notes: This table reports the results of the spanning tests checking whether BTC investment spans a traditional investment universe made from traditional assets (currencies, stocks, bonds), alternative assets (commodities, hedge funds, real estate) or both (all assets). Weekly returns are used over the time period between 23 July 2010 and 27 December 2013. The first, respectively second, column reports Wald statistics for the mean-variance spanning tests of Huberman and Kandel (HK) (1987), respectively Ferson *et al* (FFK) (1993). *, **, *** indicate that the coefficient estimates are significantly different from zero at the 10 per cent, 5 per cent, 1 per cent level.

Table 3 provides the results of the mean-variance spanning tests. We add BTC to portfolios made of (i) traditional assets (currencies, stocks and bonds), (ii) alternative assets (commodities, real estate and hedge funds) and (iii) all assets together. We find that BTC significantly spans all asset categories. The results imply that BTC-inclusive portfolios deliver superior mean-variance trade-offs than do similar BTC-free portfolios.

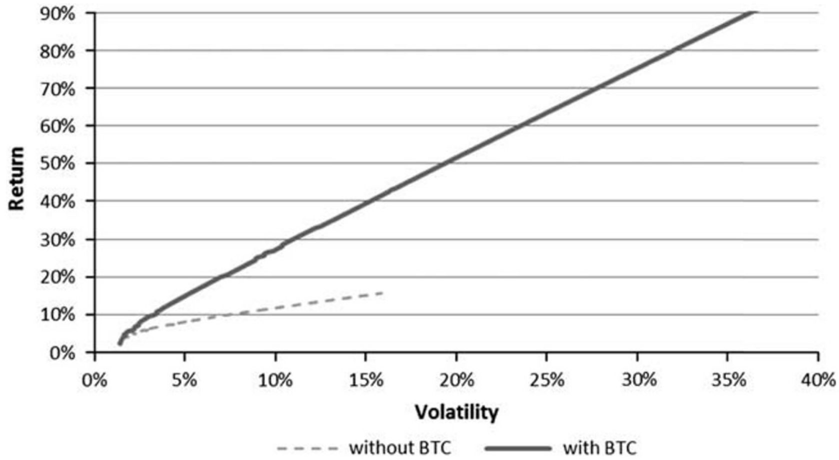

Figure 2: Mean-variance efficient frontiers without and with BTC.
This figure presents two efficient frontiers. The dotted line, labeled 'without BTC', is derived from an investment universe including traditional and alternative investments only (currencies, stocks, bonds, commodities, hedge funds and real estate). The plain line, labeled 'with BTC', is derived from the same investment universe plus BTC. We use weekly returns from 23 July 2010 to 27 December 2013.

Next, we investigate the importance of the risk-return benefits gained by including BTC in a well-diversified portfolio. We exclude short positions in order to stick to realistic investment possibilities. First, we build and compare the equally-weighted portfolios without and with BTC, respectively. Although the relevance of equally-weighted portfolios is debatable in the context of such diverse asset classes, the exercice is simple and intuitive. It appears that BTC improves performances dramatically, with the Sharpe ratio increasing from 0.78 (annualized return of 5.38 per cent) to 2.36 (annualized return of 36.11 per cent), while annual volatility more than doubles (from 6.38 to 15.15 per cent). In addition, including BTC creates positive asymmetry in returns. One might however object that the BTC-inclusive portfolio has 7.7 per cent of BTC, which may seem too high for the vast majority of reasonably risk-averse investors.

Second, we make a more refined analysis involving portfolio optimization. Figure 2 draws the mean-variance efficient frontiers without and with BTC. It shows that the BTC-inclusive frontier is much steeper than its BTC-free counterpart. As expected, the minimal-variance portfolio excludes BTC.

Table 4: Portfolio performances without and with BTC

	Efficient portfolio			
	6% volatility		*12% volatility*	
	without BTC	*with BTC*	*without BTC*	*with BTC*
Annual mean	8.84%	17.59%	13.10%	32.51%
Annual semi-variance	4.19%	2.82%	8.85%	5.38%
Sharpe ratio	1.39	2.83	1.05	2.66
Sortino ratio	2.00	6.07	1.43	5.96
Adjusted sharpe ratio	0.80	−1.45	0.73	−1.14
BTC (%)	0	3	0	6
Observations	179	179	179	179

Notes: This table compares the annualized mean return, semi-variance, Sharpe and Sortino ratios (and adjusted Sharpe ratio) of same-volatility efficient portfolios without and with BTC. The first two portfolios (columns 1 and 2) achieve 6 per cent volatility over the sample period while the last two portfolios have 12 per cent volatility over the same period. We use weekly returns from 23 July 2010 to 27 December 2013.

Despite its high diversification potential, BTC remains too volatile to be included in the lowest-risk portfolio. However, a slight increase in the investor's risk tolerance is associated with a sharp increase in the average returns obtained for a given level of risk.

Table 4 compares performance indicators of same-volatility efficient portfolios without and with BTC. At the 6 per cent volatility level, including BTC in the portfolio makes the average annual return jump from 8.8 to 17.6 per cent. Meanwhile, the annualized semi-variance decreases from 4.2 to 2.8 per cent when a scant 3 per cent of BTC is included. The decrease in semi-variance reflects the low level of downside risk of BTC investment, which exhibits heavy but positively skewed tails of the distribution. The Sharpe and Sortino ratios[11] increase considerably with the inclusion of BTC, from 1.39 to 2.83 and from 2 to 6.1, respectively. However, the adjusted Sharpe ratio[12] taking extreme risks into account decreases sharply, from 0.8 to −1.45, demonstrating that a small share of BTC can seriously harm the investor's position in terms of extreme risk (fatter tails of the distribution).

At the 12 per cent volatility level, Table 4 shows that including 6 per cent of BTC in the investor's portfolio would yield a 19 per cent jump in average return (from 13.1 to 32.5 per cent) and a 3.5 per cent decline in annualized semi-variance (from 8.8 to 5.4 per cent). At the same time, the Sharpe and Sortino ratios increase and the adjusted Sharpe ratio decreases strongly (from 0.7 to −1.1). In sum, even for moderately risk-averse investors, BTC may lead to substantial financial gains, but simultaneously to a significant increase in extreme risk.

CONCLUDING REMARKS

BTC is a recent concept and subsequently a still rather unexplored financial asset with a short history. Some might even argue that BTC is just a bubble. Figuring out the fundamental value of BTC is a difficult task, and history has shown that assets linked to innovations (financial or real) are more bubble-prone (Frehen *et al*, 2013). Furthermore, our data is contaminated by early-stage behavior that might compromise the analysis of future performance. Past performance is obviously no forecast for future asset prices, particularly for young and highly risky assets such as BTC. The fact that BTC has low correlations with other assets over the time frame of this study (2010–2013) does not necessarily imply that BTC correlations will remain this low in times of crises, as correlations are known to increase during crises. As such, it is hard to say how BTC will be perceived in future time of crises. The correlations observed would tend to place BTC in the safe-haven category, but history is replete with examples of assets initially presented as safe havens and not fulfilling that promise. Keeping this caveat in mind, we carefully exploit the most recent, most robust spanning testing methodology to explore the diversification potential of BTC.

As Internet-based transaction systems, virtual currencies fulfill a useful economic function. From the investor's standpoint, the distinctive features of the BTC make it a unique asset. BTCs are currently traded on several exchanges, and the launch of exchange-traded funds is now being planned.[13] This article shows that BTC investment exhibits very high volatility but also very high returns. In addition, for holders of well diversified portfolios, high risk is compensated by low correlations with other assets. Including even a small proportion of BTCs in a well-diversified portfolio may dramatically improve risk-return characteristics. Overall, our key message is that virtual currencies deserve to be taken seriously by financial analysts.

NOTES

1. Yet, alternative investment goods, such as artworks, deliver mixed financial results (David *et al*, 2013; Renneboog and Spaenjers, 2013).
2. In contrast to hard currencies, BTCs pay no interest.
3. Arguably, this could imply that BTC has no intrinsic value. Things are changing fast, however. According to the regulation issued by the US Financial Crimes Enforcement Network on 18 March 2013, BTC exchanges and miners are required to register as Money Services Businesses and comply with anti-money laundering regulations (fincen.gov/statutes_regs/guidance/html/FIN-2013-G001.html).

Furthermore, Germany recognized BTC for legal and tax purposes in August 2013 (Gotthold and Eckert, 2013).

4. Stolen BTCs are never recoverable. A recent cyber-attack against a BTC exchange resulted in the theft of the equivalent of USD 9 million (ECB, 2012).
5. Daily number of transactions and daily traded volumes can be retrieved from bitcoincharts.com.
6. We use the following indices. (i) Equities: developed and emerging (MSCI World, MSCI Emerging); (ii) Bonds: developed and emerging government bonds (JPMorgan GBI Broad, JPM EMBI+), World inflation linked bonds (Barclays Global Inflation World) and World corporate bonds (Merrill Lynch Global Broad Market Corporate and High Yield); (3) Commodities: gold and oil (gold bullion and WTI); (4) Hard currencies: money market investments in Euro and Yen; and (5) Alternatives: hedge funds (HFRX Hedge Fund Index) and listed World real estate (FTSE Global NAREIT). Data come from Datastream. Working with weekly returns, we are unable to account for art investments, where indices are computed on an annual basis.
7. Other important risks are liquidity risk, legal risk and the risk of security breaches in electronic portfolios. Moreover, like cash transactions, BTC settlements are irreversible.
8. The use of realized returns for studying expected returns is debatable. There are, however, few alternatives. As pointed out by Elton (1999), 'Almost all of the testing (…) involves using realized returns as a proxy for expected returns'. Therefore, this article follows the traditional approach.
9. The asymmetry to the left of a return distribution means that prices tend to fall sharply during crashes. Besides volatility derivatives, there are few assets exhibiting such characteristics.
10. In addition, BTC investment achieves a Sharpe ratio of 2.12, which is particularly attractive compared with asset classes.
11. Whereas the Sharpe ratio performance indicator divides the portfolio excess return over the risk-free rate by its volatility, the Sortino ratio replaces the volatility by the standard deviation of negative asset returns.
12. The adjusted Sharpe ratio is an alternative to the standard Sharpe ratio when returns are not normally distributed. The measure is derived from a Taylor series expansion of an exponential utility function.
13. The current development of virtual currencies is impressive. More than 50 new ones have been created recently following BTC and its little brother, Litecoin (www.cryptsy.com/).

REFERENCES

Arash, M. and Alloway, T. (2013) Bitcoin ETF plan struggles to find support. *The Financial Times* 16 July.

Arthur, C. (2013) Bitcoin: Man charged over Alleged Multimillion-Dollar Ponzi Fraud. *The Guardian* 24 July.

Balchunas, E. (2013) Diamonds and Kazakhs and Bitcoins, Oh My: An ETF Parade. *Bloomberg*, 12 July, http://www.bloomberg.com/news/2013-07-12/diamonds-and-kazakhs-and-bitcoins-oh-my-an-etf-parade.html, accessed 26 July 2013.

Berndt, E.R. and Savin, N.E. (1977) Conflict among criteria for testing hypotheses in the multivariate linear regression model. *Econometrica* 45(5): 1263–1278.

Bodie, Z. (1976) Common stocks as a hedge against inflation. *Journal of Finance* 31(2): 459–470.

Brière, M., Burgues, A. and Signori, O. (2010) Volatility exposure for strategic asset allocation. *Journal of Portfolio Management* 36(3): 105–116.

Brière, M., Chapelle, A. and Szafarz, A. (2012) No contagion, only globalization and flight to quality. *Journal of International Money and Finance* 31(6): 1729–1744.

David, G., Oosterlinck, K. and Szafarz, A. (2013) Art market inefficiency. *Economics Letters* 121(1): 23–25.

Elton, E.J. (1999) Expected return realized return and asset pricing tests. *Journal of Finance* 54(4): 1199–1220.

European Central Bank (ECB) (2012) Virtual Currency Schemes. http://www.ecb.int/pub/pdf/other/virtualcurrencyschemes201210en.pdf, accessed 26 July 2013.

Ferson, W.E., Foerster, S.R. and Keim, D.B. (1993) General tests of latent variable models and mean-variance spanning. *Journal of Finance* 48(1): 131–156.

Frehen, R.G.P., Goetzmann, W.N. and Rouwenhorst, K.G. (2013) New evidence on the first financial bubble. *Journal of Financial Economics* 108(3): 585–607.

Goetzmann, W.N., Li, L. and Rouwenhorst, K.G. (2005) Long-term global market correlations. *Journal of Business* 78(1): 1–38.

Gotthold, K. and Eckert, D. (2013) Deutschland erkennt Bitcoin als 'privates Geld' an. *Die Welt* 16 August.

Grinberg, R. (2012) Bitcoin: An innovative alternative digital currency. *Hastings Science & Technology Law Journal* 4: 160–207.

Hansen, L.P. (1982) Large sample properties of the generalized method of moments estimators. *Econometrica* 50(4): 1029–1054.

Harper, J. (2013) What is the value of Bitcoin? Cato institute, http://www.cato.org/blog/what-value-bitcoin, accessed 26 July 2013.

Huberman, G. and Kandel, S. (1987) Mean-variance spanning. *Journal of Finance* 42(4): 873–888.

Kan, R. and Zhou, G. (2012) Tests of mean-variance spanning. *Annals of Economics and Finance* 13(1): 145–193.

Michie, R. (1999) *The London Stock Exchange. A History*, Oxford: Oxford University Press.

Moore, T. and Christin, N. (2013) Beware the middleman: Empirical analysis of Bitcoin-Exchange risk. *Financial Cryptography and Data Security, Lecture Notes in Computer Science* 7859: 25–33.

Renneboog, L. and Spaenjers, C. (2013) Buying beauty: On prices and returns in the art market. *Management Science* 59(1): 36–53.

Rushe, D. (2013) Bitcoin hits new high before losing $160 in value in one day. *The Guardian* 10 April.

Velde, F.R. (2013) Bitcoins: A Primer. Chicago, IL: The Federal Reserve Bank of Chicago. Essays on Issues: 317, December.

APPENDIX

Figure A1 gives the daily number of BTC transactions over the sample period: January 2009–December 2013. Figure A2 draws the BTC/USD weekly exchange rate on a logarithmic scale.

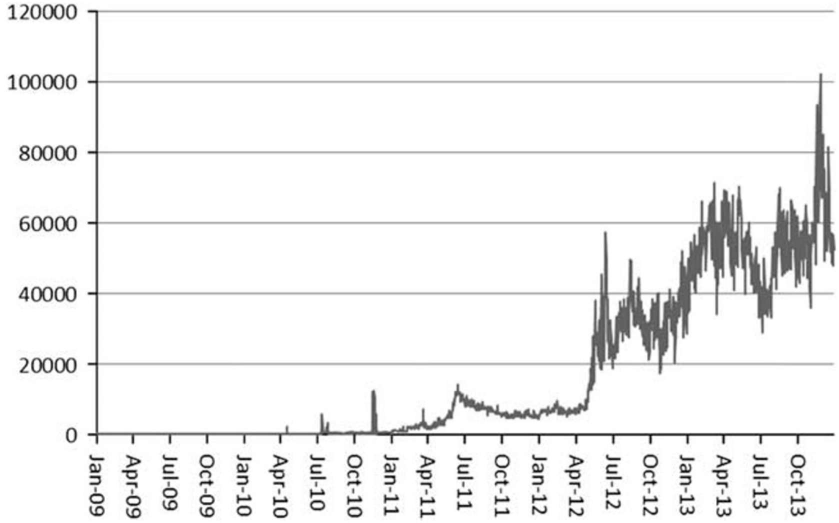

Figure A1: Daily number of BTC transactions (January 2009–December 2013).
Source: blockchain.info.

Figure A2: Weekly BTC/USD exchange rate (January 2009–December 2013).
The figure uses a logarithmic scale. Data are sourced from the *Bitcoincharts* Website.