The Crypto Carry Trade*

Nicolas Christin
School of Computer Science and Department of Engineering and Public Policy
Carnegie Mellon University

Bryan R. Routledge
Tepper School of Business
Carnegie Mellon University

Kyle Soska
The Grainger College of Engineering
University of Illinois

Ariel Zetlin-Jones
Tepper School of Business
Carnegie Mellon University

August 1, 2022

Abstract:
We study the most widely traded derivative cryptocurrency contracts on one of the largest cryptocurrency exchanges. We construct a measure that shows the large volume in derivative trading is driven by the long side. Specifically, we show that a trade that is short a futures contract, hedged with a long position in the spot market - the crypto carry trade - is unusually profitable producing in-sample annual Sharpe ratios in the range of 7 to 10. The properties of this strategys returns give us insight into many of the risks unique to cryptocurrency exchanges and helps understand the role financialization plays in cryptocurrency price dynamics.

*Thanks for helpful comments to Burton Hollifield and participants at the NBER's Big Data and High-Performance Computing for Financial Economics Conference, Society for Economic Dynamics Annual Meeting. We are thankful for the financial support of the PNC Center for Financial Services Innovation at Carnegie Mellon University. Contact authors at: nicolasc@andrew.cmu.edu, routledge@cmu.edu, soska2@illinois.edu, azj@andrew.cmu.edu.

1 Introduction

Most cryptocurrency transactions occur on a centralized exchange. Many exchanges facilitate spot transactions swapping fiat currency for cryptocurrency (US Dollars and Bitcoin) or spot transactions swapping two different cryptocurrencies (Ethereum and Algorand). These spot market transactions involve change in claims to ownership of the coins. Such trades on centralized exchanges may or may not involve an actual transaction recorded on the blockchain supporting the given cryptocurrency involved in the transaction. More commonly, such trades are recorded within the exchange. The ownership of the underlying cryptocurrency in these cases is indirect, for example, with a trader owning a claim at Coinbase and Coinbase owning a Bitcoin. These spot transactions are analogous to trades of equity or physical commodities where the assets are in positive net supply. In contrast, trades of derivative securities do not involve changes in ownership of a cryptocurrency asset but a contract for a contingent payment between two parties. Figure 1 shows the relative trading volume in cryptocurrency spot and derivatives. In the past few years, the volume in the trade of cryptocurrency derivatives has risen sharply – particularly in the first and second quarter of 2021.

The connection between derivative market transactions – financialization – and the price dynamics in the underlying spot market is important in many markets.[1] For example, the period from 2004 to 2008 saw both increasing commodity prices, oil in particular, and increases in the degree of financialization of commodities (e.g. the growth in the trade volume of commodity index funds. CFTC (2008). The high-profile senate testimony of Michael Masters (Masters (2008)) summarized many of the key concerns with financialization – the financialization was "causing" the higher prices. Similarly, concerns were raised about food prices, e.g., "The food bubble: How Wall Street starved millions and got away with it" Kaufman (2010). On the other side of the discussion is that the derivative trading does not involve consumption of the commodity and so has minimal impact on the spot price (Hamilton (2009) and Wright (2011)). Bitcoin and cryptocurrencies seem an asset where differences of opinion and heterogenous beliefs might be large. Here, a derivative market facilitates both short and levered-long positions. So the introduction of a derivative market

[1] Harrison and Kreps (1978).

might have appeal to both optimists and pessimists. Hence, the impact of derivative trading opportunities on spot-market holdings is ambiguous.

In this paper we explore one popular derivative contract, the "perpetual futures" contract, and use its design features to measure the pressure on spot prices that might be coming from either the long or short side of the derivative contract. Is there more demand to be long or short? Of course, we cannot measure that directly since long and shorts are matched by construction (zero net-supply). Instead, we use the design characteristics of the perpetual futures contract to construct a trading strategy that is reminiscent of the "carry trade" in foreign exchange or traditional commodity markets. We show that a trade that is short a futures contract, hedged with a position in the spot market, is unusually profitable. Put differently, the long derivative position is a relatively expensive way to be long cryptocurrencies. Since people appear willing to pay a premium for long-side exposure to cryptocurrencies on a derivatives exchange relative to the spot market suggests much of the demand for cryptocurrency derivatives is on the long side.

The perpetual futures derivative contract is by far the most popular and liquid derivative contract in cryptocurrencies. The perpetual futures contract, initially created by the BitMEX platform was designed to let traders trade something like "spot" but in a derivative context.[2] The contract looks like a futures contract that is marked to market. However, there is no fixed settlement date. At date t, the long and short side enter the contract with terms – the futures price – denoted F_t. Similar to regular futures market, there is also no initial payment between the buyer and seller. Each period (in practice this is close to continuously), the positions are marked-to-market with profits $F_{t+1} - F_t$ for the long side and $F_t - F_{t+1}$ for the short side. The design goal is that the contract price F_t tracks a cryptocurrency spot price index P_t. Unlike a fixed-maturity-date forward contract, there is no one point where the futures price is pinned down by a settlement mechanism. To connect the futures and the spot market, the exchange has interim cash flows, called "funding," between the long and short side of the contract. Based on the notional value of the contract, a "funding rate," $r_{t,c}$ is defined where the holders of long positions pay holders of short positions.

[2] The contract was initially created on the BitMEX exchange. See Soska, Dong, Khodaverdian, Zetlin-Jones, Routledge, and Christin (2021) and https://cryptotrade.cylab.cmu.edu/ for a detailed description.

The direction of the payments is just a matter of convention in the definition of the funding rate. Empirically, we observe that the funding rate is typically positive so longs pay shorts is most common (see Table 6). However, we do see episodes of a negative rate in our sample. In these cases, the payment flow is from short side to the long side. The rate is set by the exchange and transfers are made every eight hours. The formula for calculating the funding rate is public and the rate is posted by the exchange.[3] The idea is that the funding rate ought to drive the basis spread $F_t - P_t$ towards zero by adjusting the returns of the long and short positions. Empirically, we see that the contract does achieve this goal and the perpetual futures price tracks the spot price within a very tight band (see Table 7).

To isolate the impact of funding and the basis spread, we construct the returns to a trade that is long one bitcoin in the spot market and short an equivalently sized position in the perpetual futures market. The short position in the perpetual future earns the funding $r_{t,c}$ (if it happens to be positive). The long-spot and short-forward positions offer an imperfect hedge for changes in cryptocurrency prices. The hedge is imperfect since the two positions are in different markets and the basis next period, $F_{t+1} - P_{t+1}$ relative to current $F_t - P_t$ is stochastic. Empirically, we see that this trade earns an unusually attractive return and is reminiscent of carry trades we see in other settings. In foreign currency markets, the carry trade involves a long and short position in two currencies to earn a spread on the interest rate differential (akin to the funding) at the risk of movement in the relative exchange rates (the basis risk in this trade). See Ready, Roussanov, and Ward (2017), for example. In physical commodity markets, the carry trade involves buying a physical commodity on the spot market and a short position in a forward contract. Here, the return comes from the difference in current spot price and the forward price net of storage costs (paralleling the funding). The basis risk at maturity comes from the settlement provisions.[4]

The data we use is for the Binance Exchange, which over our sample period was one

[3] On Binance, the funding rate is set at is 0.01% per eight-hour period plus an adjustment that depends on the basis, $\frac{F_t - P_t}{P_t}$. The actual calculation is weighted by quantities in the order book and the measurement is designed to discourage manipulation of the spot-index price. The exact details are available on the exchange website (`https://www.binance.com/en/support/faq/360033525031`). Other exchanges, like BitMEX, are similar with slight variation in how/when the funding is calculated.

[4] Often this basis risk is small. An extreme example occurred in April, 2020, when shipping and pipeline disruptions caused the forward settlement price to be – negative \$37.63 a barrel.

of the largest exchanges by volume. Our data is harvested from the Binance API from 2020-08-11 – 2022-06-20. The data is at the minute frequency, but here we focus on the 8-hour funding periods. Over this sample, the prices of cryptocurrencies happen to have two significant price run ups and drops. We focus on the heavily traded Bitcoin contract, but also show results for 17 additional cryptocurrencies. Each of the 18 coins are traded in two distinct perpetual futures contracts. One contract has cash flows that settle in Tether (a US dollar "stable-coin") and the other settles in Bitcoin. Empirically, we will show that the crypto-carry returns we document here are lower for the Bitcoin-settled contracts than for the Tether-settled contracts. The sample period also captures a period of heavy trading volume in the first half of 2021.

We document that the return on the crypto carry trade is high and the volatility of the return is small. We find in-sample Sharpe ratios (annual) are large. For example, for the BTC contracts we study, the Sharpe ratios are 12.8 and 7.0. These contracts differ in terms of the currency used for settlement. We explore this variation in delivery currency and the variation across contracts on different cryptocurrencies in detail. We also document the Sharpe Ratio of the crypto carry trade is largely decoupled from the trend movements in the underlying BTC price. In periods of large increases or decreases in the BTC price, the crypto carry trade is consistently large and positive.

Why is the return to this strategy particularly large? One explanation, we argue, is that the returns to the crypto carry trade capture the long-side's willingness to pay for access to leverage. That is a natural place to look for an explanation as retail access to high leverage is a distinct characteristic of cryptocurrency derivative exchanges.[5] We explore this hypothesis in two ways. First, our sample spans a dramatic change in Binance leverage policy. In July of 2021, Binance reduced the maximum possible leverage from 125x to 50x. We see this corresponds to a drop in crypto carry trade returns. Second, the two flavors of perpetual contracts Binance offers, Tether-based and coin-based, have different risk implications for the same level of initial margin. A trader seeking a levered long position, all else equal, prefers the Tether-based contract while a trader seeking a levered short position prefers the coin-based product. This preference aligns with the empirical finding that the Tether-based crypto carry return

[5] Soska, Dong, Khodaverdian, Zetlin-Jones, Routledge, and Christin (2021) discusses BitMEX, a pioneer in of cryptocurrency derivative exchanges. Arthur Hayes, BitMEX co-founder, "You can trade Bitcoin with 100x leverage on the most volatile asset in the history of the world, its a lot of fun.

is larger than in the coin-based contract.

The paper describes the cash-flows and details for the carry trade in Section 2. The main empirical results are presented in Section 3. Section 4 explores potential explanations for the main result. Section 5 concludes.

2 The Carry Trade

We start by describing the cash flows for a trading strategy using the perpetual futures contract. Here, we abstract from margin, leverage, transaction costs, and other details particular to the exchange. These are important details, of course, and we revisit them below. To fix ideas, we focus on a trade that is initiated at t and closed out at $t+1$. Our period is 8 hours or three per day. This coincides with the periodicity of funding on the Binance exchange. At date t, the long and short side enter the contract with terms – the futures price – denoted F_t. Similar to regular futures market, there is also no initial payment between the buyer and seller. At date-$t+1$, these positions are marked-to-market at the new futures price F_{t+1}. In addition, there is a transfer of $r_{t,c}F_t$ from the long to the short side of the contract. The funding rate $r_{t,c}$ can be positive or negative, so the direction of the payment is just a convention. (Empirically, it is typically positive.) The rate is calculated by the exchange with a formula that is public. It changes each period based on the spread between the futures price F_t and the spot index price S_t. The timing on Binance happens to be that the rate is set at date t but is paid at $t+1$.[6] Combining the mark-to-market and this funding payment, cash-flows (additions or subtractions from a margin account) are $F_{t+1} - F_t - r_{t,c}F_t$ for the long side and $F_t - F_{t+1} + r_{t,c}F_t$ for the short side.

In any paper involving multiple currencies, crypto or otherwise, it is helpful to be clear about currency unit for measuring cash flows and returns. Here, we convert all cash-flows to Unites States dollars (USD). We intentionally choose a non-cryptocurrency so that we can isolate the return characteristics of portfolio strategies separate from,

[6] Other exchanges, like BitMEX, have a slightly different timing convention. The specific timing impacts the specifics of how we define our crypto carry trade. But the broad empirical results are not sensitive to the timing convention.

say, a long position in a cryptocurrency. To convert cryptocurrency balances, we use a spot index price P_t (again, abstracting from transaction costs).

2.1 Tether Denominated and Settled

Binance has two types of perpetual futures contract. One is denominated and settled in the cryptocurrency (e.g., Bitcoin). The other type is settled in Tether. Tether is a cryptocurrency that is pegged to the US Dollar – a "stable-coin". It is owned/controlled by the the exchange Bitfinex and is backed by low-risk reserves like commercial-paper.[7] Empirically, Tether has traded very close to par with the US Dollar. Whether or not there is a material risk of devaluation is an interesting question (see for example, Griffin and Shams (2020) and Routledge and Zetlin-Jones (2021)). Initially, to describe cash flows, we treat Tether as fully backed and fungible with US dollars.

The basic components of the crypto-carry trade strategy is to own the "physical" coin (i.e., on the spot market) and hedge using a perpetual futures on the derivatives exchange. Table 1 outlines the Tether (think USD) cash-flows for one eight-hour trading period. The first line is a long position in BTC; bought at P_t (e.g., the USD price of one Bitcoin) and sold at P_{t+1}. The second line are the cash flows from the position on the exchange. Since we abstract from collateral the initial cash flow is zero. The contract's value at date $t+1$ includes the change in futures price and the funding $r_{t,c}$. Recall, that by convention the funding $r_{t,c} > 0$ is a payment to the short side of the contract.[8]. We can use these cash-flows to define an excess return,

[7] Binance has its own backed stable coin called BUSD launched in September 2019. However, many Binance products still use Tether.

[8] The calculation of the funding we use here coincides with the contract details at Binance. Other exchanges have slightly different conventions about when the funding rate is determined $r_{t,c}0$ vs $r_{t+1,c}$ and the measurement of the position size F_t or F_{t+1} For the moment, we focus on unconditional moments of this strategy where this specific timing assumption has little empirical impact.

$\phi_{t+1,\text{tether}}$, (excess of the USD risk-free rate, $r_{t,\$}$).[9]

$$\begin{aligned}\phi_{t+1,\text{tether}} &= \frac{P_{t+1} + (F_t - F_{t+1}) + r_{t,c}F_t}{P_t} - (1 + r_{t,\$}) \\ &= r_{t,c}\frac{F_t}{P_t} - r_{t,\$} + \left(\frac{F_t - P_t}{P_t}\right) - \left(\frac{F_{t+1} - P_{t+1}}{P_{t+1}}\right)\frac{P_{t+1}}{P_t} \qquad (1)\end{aligned}$$

The return is composed of two parts. The first is the spread in rates between the funding rate paid to the short-side perpetual future contract above the risk-free rate (and literally this difference when $F_t = P_t$). This portion of the $t + 1$ return is determined at t. The second component is the change in basis between the perpetual futures price and the spot (index) price that happens from t to $t + 1$.

As constructed, and with the usual (mild) assumptions on the stochastic processes for S_t and F_t, the excess return $\phi_{t+1,\text{tether}}$ is stationary, so the risk premium $E[\phi_{t+1,\text{tether}}]$ and conditional risk premium $E_t[\phi_{t+1,\text{tether}}]$ (and higher moments) are well defined.

2.2 Coin Denominated and Settled Futures

Binance and other exchanges also offer perpetual futures contracts that are settled in the underlying cryptocurrency coin. It is helpful to think of these as a risky gamble on the US Dollar price of a cryptocurrency that pays off in that cryptocurrency. For concreteness, we describe the case of an inverse perpetual futures contract for Bitcoin which is a gamble on the USD price of Bitcoin that is also settled in Bitcoin. Coin-settled futures are sometimes called "inverse futures" since the contract is based on the Bitcoin price of US dollars, or $1/P_t$. The notional size of the contract size is specified as X US dollars (i.e., \$1.00 worth of the contract) at the perpetual price F_t (denominated as USD per BTC). The payoff at date $t + 1$ depends on the change in the perpetual price and is defined as $(X/F_t - X/F_{t+1})$ Bitcoins if you are long and $(X/F_{t+1} - X/F_t)$ Bitcoins if you are short. The funding payment is also in Bitcoin, so the funding for this example would be $r_{t,c}X/F_t$ (think of the quantity X/F_t as the Bitcoin denominated size of the contract). As above, the convention is that $r_{t,c} > 0$

[9] Notice that $P_t > 0$. For this to be a well-defined definition of a return, $P_{t+1}+(F_t-F_{t+1})+r_{t,c}F_t > 0$. Empirically, F_{t+1} is close to P_{t+1} so the quantity is positive. For completeness, Appendix A derives an equivalent definition of a risk-premium using just the cash flows sidestepping the need to define a return.

indicates payment from the long side to the short side of the trade. (Recall, we use $r_{t,c}$ to indicate the generic funding rate for any perpetual future but we expect and find this rate to differ across contracts.)

The crypto-carry trade in this market again involves a long position in the cryptocurrency and a short position on the exchange. The cash flows are listed in Table 2. Notice that the table converts the cash flows in cryptocurrency back to USD. Similar to Tether Denominated contracts, we define returns net of the risk-free rate (excess return), $\phi_{t+1,\text{coin}}$ as:

$$\phi_{t+1,\text{coin}} = \frac{P_{t+1}}{P_t} + \left(X \left(\frac{1}{F_{t+1}} - \frac{1}{F_t} \right) + r_{t,c} \frac{X}{F_t} \right) \frac{P_{t+1}}{P_t} - (1 + r_{t,\$})$$

This return (and the table) are for a long position in one unit of the cryptocurrency and a short position of X contracts. One could choose a position size X to, say, minimize variance. Here, we choose the "hedge-ratio" and set $X = F_t/(1 - r_{t,c})$. This hedge will be perfect in the absence of basis risk. With this chosen position size, X, the excess return satisfies:

$$\begin{aligned} \phi_{t+1,\text{coin}} &= \frac{1}{1 - r_{t,c}} \frac{F}{F_{t+1}} \frac{P_{t+1}}{P_t} - (1 + r_{t,\$}) \\ &= (1 - r_{t,c})^{-1} \left(\frac{F}{F_{t+1}} \frac{P_{t+1}}{P_t} - 1 + r_{t,c} - r_{t,\$} + r_{t,c} r_{t,\$} \right) \\ &= \frac{r_{t,c} - r_{t,\$} + r_{t,c} r_{t,\$}}{1 - r_{t,c}} + \left(\frac{F_t - P_t}{P_t} - \frac{F_{t+1} - P_{t+1}}{P_{t+1}} \right) \frac{P_{t+1}}{F_{t+1}(1 - r_{t,c})} \end{aligned} \quad (2)$$

The return here has similar components as for the Tether contract in (1). The first term is the date-t funding return net of the risk free rate (roughly $r_{t,c} - r_{t,\$}$). The second term reflects the risk that comes from the change in basis between the perpetual futures price and the spot-index price across the dates t and $t + 1$.

3 The Carry Trade - Empirical Facts

3.1 Data

The data we use is for the Binance Exchange, which over our sample period was one of the largest exchanges by volume. We use perpetual futures prices, funding rates, and spot index prices for 18 different cryptocurrencies. For each currency we have price and funding data for both the Tether-based contract and the coin-based contract. Of the cryptocurrencies, the Bitcoin contracts are by far the most heavily traded. Our data period is 2020-08-11 – 2022-06-20. The data is at the minute frequency, but here we focus on the 8-hour funding periods. Over this sample, the prices of cryptocurrencies happen to have two significant price run ups and drops. The sample period also captures a period of heavy trading volume in the first half of 2021. See Figures 1 and 2.

3.2 Bitcoin

Table 3 shows the returns to the crypto-carry trade for Bitcoin over our sample. Strategy returns are calculated as defined in equations (1) and (2). We convert to continuously compounded excess returns as $\log(1 + \phi_t)$.[10] The exchange operates continuously so we annualize using $3 \times 365 = 1095$ eight-hour funding periods per year. For comparison, the table reports the continuously compounded returns from a strategy that holds a long position in BTC on the exchange. These returns are net of funding so the returns to the Tether-based and coin-based long position are slightly different but not material given the large and volatile return of the underlying Bitcoin. Finally, the table shows the performance of US equities over this time period.

What stands out in Table 3 is the large Sharpe ratio of the crypto-carry trade. The volatility is particularly small relative to, say, the underlying price of Bitcoin or US equities. This is apparent in Figure 3 that shows the accumulated (log) wealth from one-dollar investment (i.e., the cumulative returns). For comparison, the accumulated wealth from a long position in BTC over this period is on the right axis. A simple long (buy-and-hold) position does grow more (note the two different scales on the plot), but is also much more volatile.

Our sample period covers a couple bull-bear runs in the price of Bitcoin. Interestingly, the crypto-carry trade return characteristics are similar across different sample periods. Table 4 shows results across four periods. In two of the four periods the

[10] Continuously compounded excess return is $\log(1 + \phi_t + r_{t\$}) - \log(1 + r_{t,\$})$. However, since the one-month t-bill rate over our sample period is tiny (ranging from 0.0% to 0.19% and averaging 0.05% per year), we set the risk-free rate constant as $r_{t,\$} = 0$.

price of BTC was generally rising and in the other two the BTC price as falling. You can see these different time periods in Figure 2 (lightly colored regions). The one exception to note is that the crypto carry trade return in the Tether contract is particularly large in the 2020-08-10 2021-04-14 period. We will return to consider this period further below. Along the same lines, Table 5 shows the return characteristics for more narrow windows of two to four weeks where the underlying price of bitcoin was particularly volatile (see the darker colored areas in Figure 2). Again, the return to the crypto-carry trade is similar across these samples.

3.3 Bitcoin - Return Decomposition

Recall from equations (1) and (2) that the excess return is comprised of the funding rate and the realized change in basis (between the spot index price and the perpetual futures price). Table 6 shows the distribution of funding rates and realized basis. Notice the median funding rate is 0.01% per funding period (equivalent to about 11% per year). This is the arbitrary rate set by the exchange when basis is zero ($F_t = P_t$).[11] The median basis, however, is close to zero. This suggests that it is the funding rate that is driving the profitability of the trade. To explore this further, for the Tether denominated contract, we can decompose the trade return in equation (1) into two components. Define.

$$\begin{aligned}
\phi_{t+1,\text{tether}} &= x_t + y_{t+1} \\
x_t &= r_{t,c}\frac{F_t}{P_t} - r_{t,\$} \\
y_{t+1} &= \left(\frac{F_t - P_t}{P_t}\right) - \left(\frac{F_{t+1} - P_{t+1}}{P_{t+1}}\right)\frac{P_{t+1}}{P_t}
\end{aligned}$$

The x_t component is the funding (and happens to be measurable with date-t information). The y_{t+1} is the component of the return that comes from the change in the

[11] See https://www.binance.com/en/support/faq/360033525031.

basis between the spot index and perpetual futures price.[12]

Table 8 shows the contribution of the funding and basis to the crypto-carry trade return. Indeed, the funding rate drives the high mean return (the x component). The variation in the return is coming from both the funding and the change in spot-futures basis (the y component). The correlation between the two components is close to zero (0.11 for Tether and 0.12 for coin), hence the negative item in line 6 of the table. This is also reflected in Figure 4. The return component from the change in basis, y_{t+1} on the righthand column of the figure appears *i.i.d.*. The funding component of the return, x_t in the lefthand column, appears serially correlated. It is notable how often the funding rate is pinned to the 0.01% per eight-hour period.

The timing convention used on the Binance exchange means the funding component of the $t+1$ return is known at date t. This means we could investigate a conditional version of the cryto-carry trade where, for example, the position is only placed when $x_t > 0$. Over this sample, however, $x_t > 0$ is true for much of the sample and the conditional strategy performance is similar to the unconditional strategy. Similarly, we can run the familiar regression used in commodity or uncovered interest rate parity of $y_{t+1} = a + bx_t + \epsilon_{t+1}$ (as in Fama (1984) or Hollifield and Uppal (1997)). The usual interpretation in such a regression is that $b \neq 1$ implies a risk premium that is not constant. That is, $E_t[\phi_{t+1,\text{tether}}]$ is not constant. However, that conclusion is evident from Table 8 and Figure 4. The expected return is driven by the variation in the funding component.[13]

[12] We can do a similar decomposition for the coin-denominated strategy in equation (2)

$$\begin{aligned}
\phi_{t+1,\text{coin}} &= x_t + y_{t+1} \\
x_t &= \frac{r_{t,c} - r_{t,\$} + r_{t,c} r_{t,\$}}{1 - r_{t,c}} \\
y_{t+1} &= \left(\frac{F_t - P_t}{P_t} - \frac{F_{t+1} - P_{t+1}}{P_{t+1}} \right) \frac{P_{t+1}}{F_{t+1}(1 - r_{t,c})}
\end{aligned}$$

Again, x_t captures the funding and y_{t+1} the basis risk. The $(1 - r_{t,c})^{-1}$ from the payment of funding in the crypto-coin muddles the decomposition slightly.

[13] See also Clarida, Davis, and Pedersen (2009), Ready, Roussanov, and Ward (2017), and Lustig, Stathopoulos, and Verdelhan (2019)).

3.4 Other Cryptocurrencies

There are now many cryptocurrencies in circulation. The website, Coinmarketcap, lists close to 10,000 coins. Bitcoin is, of course, the largest by market cap. Many others also have sizable market capitalizations. For context, the top 100 coins have market capitalizations ranging from $800 billion to $700 million.[14] Many of these coins trade on exchanges. Our data includes 18 coins trading on Binance. Which coins get traded is a choice of the exchange, in contrast to an equity IPO listing decision.

The returns from the crytpo-carry trade for the Tether and coin denominated contracts are in Table 9. The broad conclusions we might draw here are seen in Figure 5. The crytpo-carry trade has high realized returns and low realized variance. The Sharpe ratios are, for most coins, relatively high. In particular, note that the performance of the crypto-carry trade is largely unrelated to the realized performance of the buy-and-hold strategy. Second, as we saw for Bitcoin. The performance using the Tether-denominated contact is typically larger than the coin-denominated contract. Finally, a the bottom of the table, Filecoin (FIL) and Bitcoin Cash (BCH) experienced unusually high volatility in their crypto-carry returns.

Figure 6 plots the cumulative (log) returns from an investment in the crypto-carry trade for each of these coins. This is the log wealth from $1 initial investment in each. A few of the contracts were introduced after the start of our data. The top panel is the Tether denominated contract and the bottom panel shows the coin-denominated contracts. Broadly, for many of the coins, the performance is similar to that of BTC. However, the plot highlights a few odd ducks. Elrond (EGLD), Filecoin (FIL), Bitcoin Cash (BCH), Binance Coin (BNB) are plotted in Figure 7.

Figures 8 to Figure 11 show the return decomposition into funding and change in basis for each of these coins. This is the same decomposition we did with Bitcoin in Figure 4. In Figure 8 for Binance Coin (BNB) and Figure 9 for Elrond (EGLD), we see larger variation in the funding rate. BNB has a funding rate that is negative more frequently than the other coins in our sample. Elrond (EGLD) has one episode where the funding rate is negative in late 2021. In contrast, Figure 11 for Filecoin (FIL)

[14] `https://coinmarketcap.com/coins/`. Values are as of 03/23/2022.

and Figure 10 for Bitcoin Cash (BCH) are notable for the unusual basis (note the scale on the figures on the right). There are several large deviations of the perpetual futures price from the spot index price. Table 10 compares the funding and basis for these coins.

.

4 Contract Design and Exchange Policies

We have documented that the return characteristics to the crypto-carry trade are attractive. This trade is short a future contract on the exchange (hedged with a long position in the spot market). Driving this performance is the "funding rate" payment from the long side of the contract to the short position holders. This suggests that the large volume we see in this derivative market reflects the demand from the long side. That is, people are willing to pay a premium for long-side exposure to cryptocurrencies on an exchange relative to the spot market.

4.1 Exchange Leverage Policy

One of the main advantages to an exchange-based long position is leverage. The leverage policy of the exchange is implemented via their margin requirements. For example, when a trader enters into a perpetual futures contract at price F_t, they establish a margin position at the exchange by depositing αF_t dollars (for a moment, focus on the Tether-denominated account). Equivalently, this can be expressed as the leverage ratio $1/\alpha$ – the rate of change in your margin balance per change in the underlying cryptocurrency price. The exchange sets a minimum bound on α for initiating a new position. Unlike traditional derivative exchanges, the implicit borrowing in the levered position is without recourse. If a margin balance decreases (say, close to zero), the position is automatically liquidated. While a trader could add additional funds to prevent liquidation, they are not required to do so.[15]

[15]The exchange has an "initial margin" requirement that determines the maximum leverage when a trade is initiated. For example, 10% implies an initial leverage of 100x. Subsequently, the exchange has a "maintenance margin" requirement that is used as the trigger for liquidation. The size of the

We can see the connection between leverage, the crypto-carry trade performance, and its implied statement about long-side demand from a change in Binance's leverage policy. In the early portion of our sample Binance's maximum leverage was 125x (this figure dates from 2019-09-13; prior to the start of our sample). On 2021-07-23, Binance began a series of changes related to leverage. In particular, maximum leverage was reduced to 50x. There were also stricter leverage maximums for newly created accounts and new educational material targeted towards smaller traders.[16]

Table 11 shows the properties of the crypto-carry trade across the two leverage eras of Binance for Bitcoin (BTC) and Ethereum (ETH), two of the largest currencies in our sample. In the period where Binance offered lower leverage, the average return is substantially lower. This is driven by lower funding rates (see Figure 4). While the variation in the returns is also smaller, overall, the Sharpe ratios are smaller. This change in Sharpe ratios across the periods is larger in the Tether denominated contract. Figure 12 confirms we see this across most of the exchange traded coins. In the period where Binance was offering less leverage, funding rates were dramatically smaller.

4.2 Market-Clearing Funding Rates

We have been looking at two types of perpetual futures contract. The Tether-denominated contract is settled in Tether (USD) and the coin-denominated contract is settled in the crypto-currency. The differences in the two contracts are evident in the definition of the crypto-carry trade returns in Tables 1 and 2. Both contracts are designed to track the same underlying cryptocurrency spot price. A simple long position in either contract has virtually identical results (Table 3). Yet, judging by

maintenance margin varies by account size and initial leverage but is typically less than 1/2 of the initial margin. The automated liquidation sells (or buys) until your position is back within limits (at an additional transaction cost or "liquidation fee") With the volatility of cryptocurrency prices, complete liquidations are not uncommon. Finally, traders can choose to have one margin account supporting multiple positions (called "cross margin") or to have isolated margin balances for each trade.

[16]The announcement was concurrent to a New York Times article that was critical of high-leverage exchanges ("Crypto Nomads: Surfing the World for Risk and Profit" by Eric Lipton and Ephrat Livni, New York Times, 2021-07-23, `https://www.nytimes.com/2021/07/23/us/politics/crypto-billionaires.html`). Note, the the New York Times article references Soska, Dong, Khodaverdian, Zetlin-Jones, Routledge, and Christin (2021).

funding rate paid from long positions to short positions – driving the carry trade return – long traders on the Tether-based contract appear willing to pay more than long traders on the coin-based contract.

To see how leverage and the contract definitions can combine to generate the empirical results we see, consider a simple one-period model of derivatives trade in the spirit of Harrison and Kreps (1978). For concreteness, think of the single cryptocurrency as Bitcoin with spot price of BTC as P_0 and $\log \frac{P_1}{P_0} \sim N(\mu, \sigma)$. Abstracting from basis risk, the perpetual futures contract price is identical to the spot price, $F_t = P_t$. This pins down the cash-flows from the perpetual contract, and we will solve for the market-clearing funding rate r.

Investors have initial wealth W_0. To motivate trade in a derivative, measure w_a have mean belief μ_a about the underlying cryptocurrency price return and measure $w_b = 1 - w_a$ use mean belief μ_b. Setting $\mu_b < 0 < \mu_a$ we can think of a as the long-biased traders with b as short-biased. Investors, $i \in \{a, b\}$, can purchase n perpetual futures contracts to solve:

$$\begin{aligned} \max_{n \geq 0} \quad & E_i[u(W_1)] \\ s.t \quad & W_0 - n\alpha F_0 \geq 0. \end{aligned}$$

The utility function has the usual $u' > 0$ and $u'' < 0$ properties. It is also helpful to assume $u''' \leq 0$ so futures demands are monotonic in the funding rate.[17]. The definition of W_1 depends on the contract type, Tether or coin denominated, and on whether the trade is long or short. The budget constraint comes from the exchange's margin requirement. The position size, $n \geq 0$, is the number of contracts the trader chooses. We will define the payoffs for long, $n_l \geq 0$, and short, $n_s \geq 0$ separately below. As a convention, think of these as "Bitcoin-sized" with each position having the notional value of F_0. So the minimum margin requirement imposed by the exchange, α (say 30% for example), imposes an upper-bound on position size. Whether or not this constraint binds at the optimum will depend on parameters. Wealth not used for derivative trading is invested in a risk-free asset with a risk-free return of zero.

[17]Risk aversion that does not decrease with wealth, $u''' \leq 0$, is sufficient to ensure that asset demand increases with the mean return. See Hollifield and Kraus (2009).

4.2.1 Demand: Tether-based contract

The date-1 wealth from a position of n_l long Tether-based contracts are

$$W_1 \quad = \quad W_0 - \alpha n_l F_0 + n_l([F_1 - F_0 - rF_0 + \alpha F_0]_+) \tag{3}$$

Initial wealth less margin, $W_0 - \alpha n_l F_0$ is invested outside the derivative market (at risk-free rate of zero). The payoffs on the exchange, the term in brackets, is comprised of the trading gain or loss, the funding, and the initial margin balance. The exchange is non-recourse, so the cash-flows from the exchange are bounded, hence operator $[x]_+ = \max(x, 0)$.[18] To simplify, we focus on the situation where the where the exchange cash flows are strictly positive almost surely. For example, in our calibrated example we focus on a short 8-hour window. In this case, date one wealth is

$$W_1 \quad = \quad F_0 \left(\frac{W_0}{F_0} + n_l \left(\frac{F_1}{F_0} - 1 - r \right) \right) \tag{4}$$

An analogous exercise shows the wealth to a short position of size n_s Tether contracts is

$$W_1 \quad = \quad F_0 \left(\frac{W_0}{F_0} + n_s \left(1 - \frac{F_1}{F_0} + r \right) \right)$$

Recall the convention is that funding is paid from the long side to the short side at rate r where the rate could be positive or negative (empirically we observe it is most frequently positive).

4.2.2 Demand: Coin-based contract

The date-1 wealth from a position of n_l long coin-based contracts are

$$W_1 \quad = \quad W_0 - \alpha n_l F_0 + \left(\left[(n_l F_0) \left(\frac{1}{F_0} - \frac{1}{F_1} \right) - n_l r + \alpha n_l \right]_+ \right) F_1 \tag{5}$$

[18]Positions on the exchange are "non-recourse" in that you are not required to post additional margin. Our single-period discrete-time model abstracts from the exchange policy of near-continuous mark-to-market. That is in practice, the price path influences payoffs (analogous to a "knock-out" option").

As above, $W_0 - \alpha n_l F_0$ is wealth invested outside the derivative market (at rate zero). The cash-flows from the exchange are more complicated since they are denominated/paid in BTC. These BTC cash-flows are trading gain, funding, and margin balance. They are converted to dollars at the price F_1 (which is equivalent to P_1 under our setting). Again, consider the case where where the exchange cash flows from profit and margin are strictly positive. Then,

$$W_1 = \; = \; F_0 \left(\frac{W_0}{F_0} + n_l \left(\frac{F_1}{F_0} - 1 - r \right) + n_l(\alpha - r) \left(\frac{F_1}{F_0} - 1 \right) \right) \tag{6}$$

Comparing (4) to (6), shows the difference between the Tether and Coin denominated contracts. The coin-based contract has additional exposure to the date-one BTC price because the margin and funding are in BTC. Similarly, for a short position, wealth is

$$W_1 \; = \; F_0 \left(\frac{W_0}{F_0} + n_s \left(1 - \frac{F_1}{F_0} + r \right) + n_s(\alpha + r) \left(\frac{F_1}{F_0} - 1 \right) \right)$$

Here, the margin and the funding paid in BTC offsets some of the exposure from the short position.

4.2.3 Tether based versus coin-based contract

To compare the contract types, define (overall) leverage as the (absolute value of the) percentage change in your date-one wealth relative to a percentage change in the cryptocurrency price. Since we are comparing across contracts, think of $n_{T,l}$ and $n_{C,l}$ as long positions in Tether-based and coin-based contracts. Similarly, for short positions $n_{T,s}$ and $n_{C,s}$ in Tether-based and coin-based. All of these calculations are under the simplifying assumption that margin balance less trading losses remains positive.

$$L \; = \; \left| \frac{\partial W_1 / W_0}{\partial F_1 / F_0} \right| = \frac{F_0}{W_0} \begin{cases} & \text{Tether-based} & \text{Coin-based} \\ \text{long} & n_{T,l} & n_{C,l}(1 + \alpha - r) \\ \text{short} & n_{T,s} & n_{C,s}(1 - \alpha - r) \end{cases} \tag{7}$$

For the long position in the Tether contract, the leverage is the notional amount of your position $F_0 n_{T,l}$ relative to your wealth W_0. However, for the coin-based contract this is amplified by the margin position and funding that are paid in BTC. Quantitatively, the minimum margin requirement (say $\alpha = 0.3$) is an order of magnitude larger than the funding rate ($r = 0.003$ per 8-hour period). On the short-side, the exposure created by a short position is mitigated by the margin position and funding-received that are both in BTC.

A trader's choice of a desired level of cryptocurrency exposure, L, will depend on preferences, u, and beliefs, μ_i. The importance of equation (7) is in translating this L, to the number of contracts. For a given L, a long trader will choose $n_{T,l} > n_{C,l}$ while a short trader will choose $n_{T,s} < n_{C,s}$. This will imply the market-clearing funding rate for Tether-based contracts is higher than for Coin-based contracts. This is consistent with what we have seen in the data.[19]

4.2.4 Market-Clearing - Numerical Examples

In this setting, the beliefs about mean future spot prices are $\mu_b < 0 < \mu_a$. So b traders are short and a traders are long. Since we have assumed the contract price is pinned to the spot price, $F_t = P_t$, the funding rate r adjusts so the aggregate demand of longs and shorts is equal: $w_a n_l + w_b n_s = 0$ (the futures market is zero-net supply). For illustration, we treat the Tether and coin-based contracts separately and then compare their equilibrium outcomes. Some numerical illustrations are in Figures 13 and 14. The parameters are gathered in Table 12. For context, think of the spot index calibrated from BTC with $\log \frac{P_1}{P_0} \sim N(\mu, \sigma)$ setting $\mu = 0$ and $\sigma = 0.0227$ – an 8-hour volatility. The traders beliefs are aggressive, with $\mu_a = 0.02$ and $\mu_b = -0.01$, but they are risk averse with a relative risk aversion of 6.[20] This combination is not necessary but it makes for helpful examples as the sensitivity of contract demands to the funding rate is apparent in the plots.

In Figure 13(a) the proportion of wealth of the long, a, and short, b, traders is about equal with $w_a = 0.49$ and $w_b = 0.51$. The exchange's minimum margin is $\alpha = 0.15$.

[19]This holds when position sizes are strictly positive. The conditions that imply $n_{T,l} = 0$ or $n_{C,l} = 0$ (e.g., a high value of r) are slightly different across the contract types.

[20]Preferences are $u(W_1) = 1/\gamma(c + W_1)^\gamma$ with $\gamma = -5$ and $c = 0.1$. The c term is helpful for computations when W_1 happens to be close to zero. However, in this example, calibrated to 8-hour trading window, using 10,000 draws $\frac{P_1}{P_0}$ $W_1 > 0$ for each traders over the range of contract choices in the plot. This is consistent with the simplifying assumption above. It is not necessary. Examples where $W_1 = 0$ with positive probability produce similar figures.

Notice that, for the Tether contract, at low funding rates, the long trader hits the margin constraint and aggregate long demand is capped at $w_a/\alpha = 0.49/0.15 = 3.27$. Similarly for the coin-denominated short position. Here, the case of high funding rates. Here the aggregate short position is constrained at $w_b/\alpha = 0.51/0.15 = 3.40$. The Tether short and coin long also hit these constraints but for values of funding not shown on the plot. In this example, the market-clearing funding rates are 0.509% for the Tether contract and 0.264% for the coin contract. That the Tether funding rate is higher than the coin rate is consistent with equation (7). For both contracts, the volume of trade (or open interest) at these equilibrium funding rates is not constrained by the exchange minimum margin or $\alpha = 0.15$. In this example, the volume of coin contracts is larger than Tether, but that is particular to the parameters.

As mentioned above, in July of 2021, Binance reduced the amount of leverage on their exchange by increasing the minimum margin rate. To see the implications of this change in our illustrations, Figure Figures 13(b) has the same parameterization as in (a) except the minimum margin rate is increased to $\alpha = 0.16\%$. Notice that this reduces maximum position for the long and short side for both Tether and coin contracts. However, the constraint imposed by this new minimum margin requirement is still not binding at the market-clearing funding rate. So the market-clearing rate for the Tether contract is unchanged at 0.509%. For the Tether contract, as we saw in equation (4), the α plays no role in the determining payoffs.[21] This is not the case for the coin contract. Since the margin is stored in the native cryptocurrency, the change in the minimum margin impacts the demands of the long and short side (see equation (7)). The short-side demands increase, the long-side demands decrease and for the coin contract, the market-clearing funding rate is lower at 0.248%.

The implications of change in minimum margin we see in our numerical example in Figure 13 does not seem consistent what we saw from Binance's July 2021 changes (Table 11 and Figure 12). In particular, the Binance change impacted both coin and Tether contracts similarly. Figure 14 presents a numerical example that, perhaps, captures the Binance policy change better. The parameters here are all the same except the wealth of the two groups are more disperse with $w_a = 0.42$ and $w_b = 0.58$.

[21] The leverage in your position matters – the size of the future's position relative to your wealth. But given our simplified setting where the exchange cash flows are strictly positive almost surely, whether or not your wealth is on margin at the exchange or in an outside bank account is unimportant for the Tether contract.

In this case, starting with Figure 14(a), the margin minimum is a binding constraint for the long side for both Tether and coin contracts. Here, the market-clearing funding rate is 0.315% for Tether and 0.096% for coin. The lower rate for the coin contract is, again, driven by the short traders "extra" demand for contracts to offset the exposure from the margin position held in the cryptocurrency (equation (7)). Since the margin minimum is binding, not surprisingly, increasing the margin minimum to $\alpha = 0.16$ in Figure 14(b) impacts the funding rate in both contracts. The market-clearing rates fall for both contracts 0.231% for Tether and 0.0262% for coin. And, of course, also the volumes. That the Binance leverage change impacted funding rates for both coin and Tether contracts is consistent with a binding minimum margin rate. That the funding rate fell is consistent with constraint being binding on the long side.[22].

4.3 Liquidation (bankruptcy)

It would not come as a surprise that the combination of high volatility of cryptocurrency prices and highly levered positions will result in many positions having trading losses that exceed their posted margin. Indeed, these liquidations where the exchange closes the position and the trader receives zero are common.[23] In the previous section we abstracted from liquidation. This helped illustrate the role the exchange's margin requirement, α, has on trader demands by altering exposure to the underlying cryptocurrency. Incorporating liquidation into numerical examples is straightforward (i.e., higher volatility of the underlying). This can yield examples similar to those in Figures 13 and 14.

Interesting, perhaps, for the same margin rate, the probability of liquidation differs across the Tether and coin denominated contracts. If we look at equation (3) for Tether and equation (5) for coin, the conditions for the position being liquid (i.e.,

[22]In cases where the short side is constrained by the margin requirement, increasing the minimum margin requirement increases the funding rates on both Tether and coin contracts.

[23]See Soska, Dong, Khodaverdian, Zetlin-Jones, Routledge, and Christin (2021) for liquidations on BitMEX exchange. They are also common on Binance. Footnote 15 has more details on Binance's process for liquidation.

trading losses are not larger than the margin) are:

$$\text{Tether:} \quad \frac{F_{t+1}}{F_t} \geq 1 - \alpha - r \tag{8}$$

$$\text{Coin:} \quad \frac{F_{t+1}}{F_t} \geq \frac{1}{1 + \alpha - r} \tag{9}$$

The long position in the Tether-based contract is a familiar. If you choose to fully collateralize your position with $\alpha = 1{+}r$ there is effectively no leverage and liquidation is avoided with certainty (assuming prices are positive). With the long position in the coin contract, things are different. Here, no value for α can amount of margin that can avoid liquidation with certainty (unless prices are bounded from above). Here the long position in Bitcoin is effectively a short position on dollars.

Figure 15 helps quantify the importance of this difference. We use the same calibration as above with $\log F_{t+1}/F_t \sim N(\mu, \sigma^2)$ with $\mu = 0$ and $\sigma = 0.0227$ (15(a)), calibrated to an eight-hour window and $\sigma = 0.7503$ (15(b)), an annual calibration. In this example we set the funding rate to zero. For this exercise, after the initial margin position of α is established no additional funds are deposited or withdrawn. The liquidation threshold here is zero In practice, liquidation occurs when the margin balance falls below a "maintenance margin" threshold. Notice that at a given margin level probability of liquidation is lower for a Tether contract than for a coin-based contract. The probability of liquidation is small over one short eight-hour window (left plot) but is, obviously, higher if the position is held for the full year at the same margin level (right plot). The analysis is, of course, symmetric. If an investor was seeking a (naked) short position, the coin-based future has a lower liquidation probability than a similarly sized margin account initiated in the Tether-based contract. So at the margin, a trader seeking long-leverage leans towards the Tether-based contract while a trader seeking a short position leans towards the coin-based contract. This is consistent with the funding rates, and the crypto-carry trade performance, being higher for the Tether

5 Conclusion

In this paper, we study the properties of a cryptocurrency derivative exchange. Specifically, we document that the return on the crypto carry trade is high and the volatility return is small. This trade that has a short position on the exchange has particularly attractive returns (high Sharpe ratio). The driving component for this return is the payment – called "funding" on the exchange – from the long-side contract holder. This implies that a long exchange position is an expensive way to be long cryptocurrencies. We argue that this represents long-side's willingness to pay for access to leverage. This view seems consistent with the data and the cross-sectional characteristics of the exchange's contract offerings.

Regulating cryptocurrencies and the related technologies of blockchain is, of course, a huge challenge with both a quickly changing landscape and ambiguity about which agency domain.[24]. In addition, and more specifically to exchanges, there is yet little understanding of who is trading in these markets and why. In this paper, we document the characteristic of crypto-exchanges that demand for the products is for leverage and on the long side.

[24]For example, "A big fight is brewing over cryptocurrencies. These are some key players to watch," David Gura, NPR, 2021-11-06 https://www.npr.org/2021/11/06/1050430801/cryptocurrencies-bitcoin-elizabeth-warren-gary-gensler.

References

CFTC (2008): "Staff Report on Commodity Swap Dealers and Index Traders with Commission Recommendations," Discussion paper, Commodity Futures Trading Commission.

Clarida, R., J. Davis, and N. Pedersen (2009): "Currency carry trade regimes: Beyond the Fama regression," *Journal of International Money and Finance*, 28(8), 1375–1389.

Fama, E. F. (1984): "Forward and spot exchange rates," *Journal of monetary economics*, 14(3), 319–338.

Griffin, J. M., and A. Shams (2020): "Is Bitcoin really untethered?," *The Journal of Finance*, 75(4), 1913–1964.

Hamilton, J. (2009): "Causes and Consequences of the Oil Shock of 2007-08," *NBER Working Paper*.

Harrison, J. M., and D. M. Kreps (1978): "Speculative investor behavior in a stock market with heterogeneous expectations," *The Quarterly Journal of Economics*, 92(2), 323–336.

Hollifield, B., and A. Kraus (2009): "Defining bad news: changes in return distributions that decrease risky asset demand," *Management science*, 55(7), 1227–1236.

Hollifield, B., and R. Uppal (1997): "An examination of uncovered interest rate parity in segmented international commodity markets," *The Journal of Finance*, 52(5), 2145–2170.

Kaufman, F. (2010): "The Food Bubble: How Wall Street starved millions and got away with it," *Harpers Magazine*, pp. 27–34.

Lustig, H., A. Stathopoulos, and A. Verdelhan (2019): "The term structure of currency carry trade risk premia," *American Economic Review*, 109(12), 4142–77.

Masters, M. W. (2008): "Testimony before the committee on homeland security and governmental affairs," *US Senate, Washington, May*, 20.

Ready, R., N. Roussanov, and C. Ward (2017): "Commodity trade and the carry trade: A tale of two countries," *The Journal of Finance*, 72(6), 2629–2684.

Routledge, B., and A. Zetlin-Jones (2021): "Currency stability using blockchain technology," *Journal of Economic Dynamics and Control*, p. 104155.

Soska, K., J.-D. Dong, A. Khodaverdian, A. Zetlin-Jones, B. Routledge, and N. Christin (2021): "Towards Understanding Cryptocurrency Derivatives: A Case Study of BitMEX," in *Proceedings of the 30th international conference on World Wide Web*.

Wright, B. D. (2011): "The Economics of Grain Price Volatility," *Applied Economic Perspectives and Policy*, 33, 32–58.

Table 1: Tether Denominated and Settled

	$t=0$	$t=1$
Buy one "physical" coin	$-P_t$	P_{t+1}
Hedge with perpetual	0	$(F_t - F_{t+1}) + r_{t,c}F_t$
	$-P_t$	$P_{t+1} + (F_t - F_{t+1}) + r_{t,c}F_t$

The cash-flows from the positions established at date $t = 0$ are realized at date $t = 1$ (a period in our empirical analysis is 8 hours). Cash flows are Tether (equivalent to USD). Note this abstracts from transaction costs and exchange margin requirements.

Table 2: Coin Denominated and Settled

(USD Cash Flows)	$t=0$	$t=1$
Buy 1 Bitcoin coin	$-P_t$	P_{t+1}
Hedge with X perpetual contracts.	0	$\left(X\left(\frac{1}{F_{t+1}} - \frac{1}{F_t}\right) + r_{t,c}\frac{X}{F_t}\right)P_{t+1}$
	$-P_t$	$P_{t+1} + \left(X\left(\frac{1}{F_{t+1}} - \frac{1}{F_t}\right) + r_{t,c}\frac{X}{F_t}\right)P_{t+1}$

The cash-flows from the positions established at date $t = 0$ are realized at date $t = 1$ (a period in our empirical analysis is 8 hours). Cash flows shown are USD. The coin-based contract settles in cryptocurrency. We use P_{t+1} to convert to USD equivalent. Note these cash flows abstract from transaction costs and exchange margin requirements.

Table 3: Trading Strategy Returns

8 hour funding window - annualized

Strategy	Mean	Std	Sharpe
Carry Trade - Tether	21.84%	1.90%	11.468
Carry Trade - Coin	16.74%	2.61%	6.411
Long Spot (Perpetual Index Price)	30.65%	74.71%	0.410
Long Spot (Coin Index Price)	30.56%	75.08%	0.407
US Equities	18.28%	16.60%	1.102

The Carry Trade is defined in equation (1) for "Tether Contract" and in equation (2) for the "Coin Contract." The return to a long buy-and-hold using Tether and the Coin contracts is shown. These returns are close to identical and only the buy-and-hold for Tether is shown in following tables. BTC Data is from Binance Bitcoin (BTC): 2020-08-11 – 2022-06-20 (N=2036). US Equities is the excess return over the same period. Data is from Ken French/CRSP.

Table 4: Trading Strategy Returns
8 hour funding window - annualized

Strategy	Mean	Std	Sharpe	n
Epoch 1: 2020-08-10 – 2021-04-14				
Carry Trade - Tether	39.00%	2.29%	17.035	738
Carry Trade - Coin	29.88%	3.29%	9.080	738
Long Spot	250.77%	74.73%	3.356	738
Epoch 2: 2021-04-14 – 2021-07-19				
Carry Trade - Tether	19.57%	2.30%	8.500	288
Carry Trade - Coin	15.04%	2.68%	5.622	288
Long Spot	−263.42%	92.26%	−2.855	288
Epoch 3: 2021-07-19 – 2021-11-07				
Carry Trade - Tether	14.69%	1.50%	9.784	333
Carry Trade - Coin	10.66%	2.82%	3.782	333
Long Spot	216.89%	66.14%	3.279	333
Epoch 4: 2021-11-07 – 2022-08-02				
Carry Trade - Tether	7.63%	1.16%	6.572	677
Carry Trade - Coin	6.13%	1.22%	5.032	677
Long Spot	−175.50%	69.41%	−2.528	677

The Carry Trade is defined in equation (1) for “Tether Contract” and in equation (2) for the “Coin Contract.” The return to a long buy-and-hold is for the Tether contract. Subsamples are from from Binance Bitcoin (BTC): 2020-08-11 – 2022-06-20 (N=2036).

Table 5: Trading Strategy Returns

8 hour funding window - annualized

Strategy	Mean	Std	Sharpe	n
Up 1: 2021-01-26 – 2021-02-20				
Carry Trade - Tether	86.48%	3.18%	27.160	75
Carry Trade - Coin	62.46%	3.47%	17.991	75
Long Spot	799.94%	103.38%	7.738	75
Down 1: 2021-05-07 – 2021-05-22				
Carry Trade - Tether	50.81%	3.47%	14.626	45
Carry Trade - Coin	43.75%	4.88%	8.968	45
Long Spot	−1,010.62%	120.71%	−8.373	45
Up 2: 2021-09-27 – 2021-10-18				
Carry Trade - Tether	11.32%	1.34%	8.462	63
Carry Trade - Coin	9.82%	1.50%	6.549	63
Long Spot	616.56%	61.19%	10.077	63
Down 2: 2021-11-08 – 2021-12-05				
Carry Trade - Tether	20.15%	1.63%	12.339	81
Carry Trade - Coin	14.13%	1.62%	8.738	81
Long Spot	−340.50%	79.57%	−4.279	81
Down 3: 2022-04-10 – 2022-08-02				
Carry Trade - Tether	4.52%	1.02%	4.438	215
Carry Trade - Coin	1.30%	1.14%	1.141	215
Long Spot	−367.90%	77.15%	−4.768	215

The Carry Trade is defined in equation (1) for "Tether Contract" and in equation (2) for the "Coin Contract." The return to a long buy-and-hold is for the Tether contract. Subsamples are from from Binance Bitcoin (BTC): 2020-08-11 – 2022-06-20 (N=2036).

Table 6: Funding Rate - Deciles
per 8 hour funding window

Percentile	Tether	Coin
0.00	−0.090%	0.000%
0.01	−0.020%	0.000%
0.02	−0.015%	0.000%
0.10	−0.002%	0.000%
0.20	0.005%	0.000%
0.30	0.010%	0.000%
0.40	0.010%	0.000%
0.50	0.010%	0.000%
0.60	0.010%	0.000%
0.70	0.010%	0.000%
0.80	0.028%	0.000%
0.90	0.055%	0.000%
0.98	0.122%	0.000%
0.99	0.146%	0.000%
1.00	0.249%	0.000%

The “funding rate” is per 8-hour period. It is paid from the long-side to the short-side as a percentage of the notional contract value. (A negative value implies the payment direct in is from short to long). Payments is made each 8 hour window.Data is from Binance Bitcoin (BTC): 2020-08-11 – 2022-06-20 (N=2036).

Table 7: Futures to Spot Basis - Deciles

percent of spot

Percentile	Tether	Coin
0.00	−0.961%	−0.961%
0.01	−0.115%	−0.115%
0.02	−0.096%	−0.096%
0.10	−0.066%	−0.066%
0.20	−0.053%	−0.053%
0.30	−0.041%	−0.041%
0.40	−0.030%	−0.030%
0.50	−0.015%	−0.015%
0.60	0.005%	0.005%
0.70	0.031%	0.031%
0.80	0.060%	0.060%
0.90	0.094%	0.094%
0.98	0.162%	0.162%
0.99	0.180%	0.180%
1.00	0.782%	0.782%

The basis is defined as $(F_t - P_t)/P_t$ where F_t is the pertetual futures price and P_t is the spot index defined in the contract. The Tether-denominated and Coin-denominated contracts are shown.Data is from Binance Bitcoin (BTC): 2020-08-11 – 2022-06-20 (N=2036).

Table 8: Carry Trade - Tether

Simple returns (Annualized Return is Approximated)

R	Tether Per.Period	Tether Per.Year	Coin Per.Period	Coin Per.Year
Mean				
1. mean x	0.0194%	21.3%	0.0146%	16.0%
2. mean y	0.0006%	0.6%	0.0008%	0.8%
3. mean x+y	0.0200%	21.9%	0.0153%	16.8%
St. Deviation				
4. sd x	0.0309%	1.0%	0.0281%	0.9%
5. sd y	0.0457%	1.5%	0.0706%	2.3%
6. sd(x+y)-sd(x)-sd(y)	−0.0190%	−0.6%	−0.0198%	−0.7%
7. sd(x+y)	0.0576%	1.9%	0.0790%	2.6%

The excess return from the crypto-carry trade return $x + y$ is decomposed into the funding x and the change-in-basis y. Returns in this table are simple returns (not continuously compounded) and the annual returns are approximated with 365x3 periods per year. Data is from Binance Bitcoin (BTC): 2020-08-11 – 2022-06-20 (N=2036).

Table 9: Trading Strategy Returns

8 hour funding window - annualized

Tic	CoinName	Tether mean	Tether sd	Tether Sharpe	Coin mean	Coin sd	Coin Sharpe	BuyHold mean	BuyHold sd	BuyHold Sharpe	n
BTC	Bitcoin	21.8%	1.9%	11.47	16.7%	2.6%	6.41	30.6%	74.7%	0.41	2036
LTC	Litecoin	31.4%	2.9%	10.70	22.6%	3.4%	6.67	4.3%	110.3%	0.04	1952
EOS	EOS	29.6%	2.9%	10.26	22.6%	4.1%	5.45	−60.4%	120.0%	−0.50	1956
ETH	Ethereum	27.4%	2.7%	10.25	20.5%	3.2%	6.49	52.7%	96.1%	0.55	2015
LINK	Chainlink	31.8%	3.3%	9.72	21.9%	4.9%	4.47	−45.9%	129.1%	−0.36	2012
ADA	Cardano	28.9%	3.2%	9.16	21.3%	4.4%	4.83	80.9%	118.7%	0.68	1991
DOT	Polkadot	28.7%	3.3%	8.65	29.4%	4.8%	6.13	28.3%	131.1%	0.22	1995
DOGE	Dogecoin	31.4%	3.7%	8.51	33.2%	5.2%	6.37	42.1%	151.8%	0.28	1511
UNI	Uniswap	21.9%	2.7%	7.97	12.0%	5.1%	2.36	−179.1%	131.4%	−1.36	1301
THETA	THETA	24.0%	3.1%	7.71	16.2%	5.8%	2.81	−192.3%	146.6%	−1.31	1298
XLM	Stellar	20.2%	2.6%	7.67	20.1%	4.0%	4.98	−142.1%	111.9%	−1.27	1292
EGLD	Elrond	34.0%	5.2%	6.48	22.8%	7.3%	3.10	49.0%	142.0%	0.35	1640
TRX	TRON	17.3%	3.8%	4.50	13.8%	6.3%	2.20	39.0%	108.0%	0.36	1955
BCH	Bitcoin Cash	24.9%	5.8%	4.29	21.5%	26.3%	0.82	−35.5%	108.6%	−0.33	1952
XRP	XRP (Ripple)	33.0%	7.8%	4.24	22.6%	7.6%	2.98	17.4%	131.4%	0.13	1950
ETC	Ethereum Classic	20.1%	4.9%	4.13	23.8%	4.9%	4.85	64.9%	126.5%	0.51	1949
BNB	Binance Coin	9.6%	4.1%	2.34	7.2%	5.1%	1.43	122.6%	108.8%	1.13	2005
FIL	Filecoin	14.0%	12.1%	1.15	20.2%	12.9%	1.56	−88.1%	126.3%	−0.70	1817

The Carry Trade is defined in equation (1) for "Tether Contract" and in equation (2) for the "Coin Contract." The return to a long buy-and-hold is calculated using the Tether. BTC Data is from Binance Bitcoin (BTC): 2020-08-11 – 2022-06-20 (N=2036). The n is the sample for each coin as some were listed during the sample period.

Table 10: Carry Trade - Coin

Simple returns (Annualized Return is Approximated)

R	BTC Coin Per.Year	BTC Tether Per.Year	BCH Coin Per.Year	BCH Tether Per.Year	BNB Coin Per.Year	BNB Tether Per.Year	EGLD Coin Per.Year	EGLD Tether Per.Year	FIL Coin Per.Year	FIL Tether Per.Year
1. mean x	16.0%	21.3%	15.3%	21.9%	3.6%	7.8%	19.6%	29.6%	12.1%	12.1%
2. mean y	0.8%	0.6%	9.5%	3.2%	3.8%	1.8%	3.4%	4.6%	8.9%	2.6%
3. mean x+y	16.8%	21.9%	24.8%	25.1%	7.4%	9.6%	23.0%	34.1%	21.0%	14.7%
4. sd x	0.9%	1.0%	0.9%	1.6%	2.0%	2.0%	3.1%	3.2%	2.6%	3.2%
5. sd y	2.3%	1.5%	23.9%	5.3%	4.2%	3.4%	6.6%	4.0%	12.1%	11.5%
6. sd(x+y)-sd(x)-sd(y)	−0.7%	−0.6%	−0.9%	−1.3%	−1.2%	−1.4%	−2.3%	−2.0%	−2.2%	−2.7%
7. sd(x+y)	2.6%	1.9%	24.0%	5.7%	5.1%	4.1%	7.3%	5.3%	12.5%	12.0%

The excess return from the crypto-carry trade. The return $x + y$ is decomposed into the funding x and the change-in-basis y. Returns in this table are simple returns (not continuously compounded). the annual returns are approximated with 365x3 periods per year. Data is from Binance Bitcoin (BTC): 2020-08-11 – 2022-06-20 (N=2036).

Table 11: Trading Strategy Returns

8 hour funding window - annualized

Tic	Strategy	Mean	Std	Sharpe	n
Higher Leverage Era: 2020-08-10 – 2021-07-23					
BTC	Carry Trade - Tether	33.03%	2.30%	14.352	1038
BTC	Carry Trade - Coin	25.34%	3.38%	7.493	1038
ETH	Carry Trade - Tether	44.60%	3.40%	13.099	1017
ETH	Carry Trade - Coin	32.19%	4.09%	7.863	1017
Lower Leverage Era: 2021-07-24 – 2022-06-27					
BTC	Carry Trade - Tether	10.22%	1.29%	7.943	995
BTC	Carry Trade - Coin	7.69%	1.37%	5.610	995
ETH	Carry Trade - Tether	9.75%	1.42%	6.882	995
ETH	Carry Trade - Coin	8.49%	1.68%	5.058	995

The data is split around the date 2021-07-23. On this date, Binance reduced the maximum initial leverage from 125x to 50x (with further leverage reductions for new accounts). The Carry Trade is defined in equation (1) for "Tether Contract" and in equation (2) for the "Coin Contract." Data is from Binance.

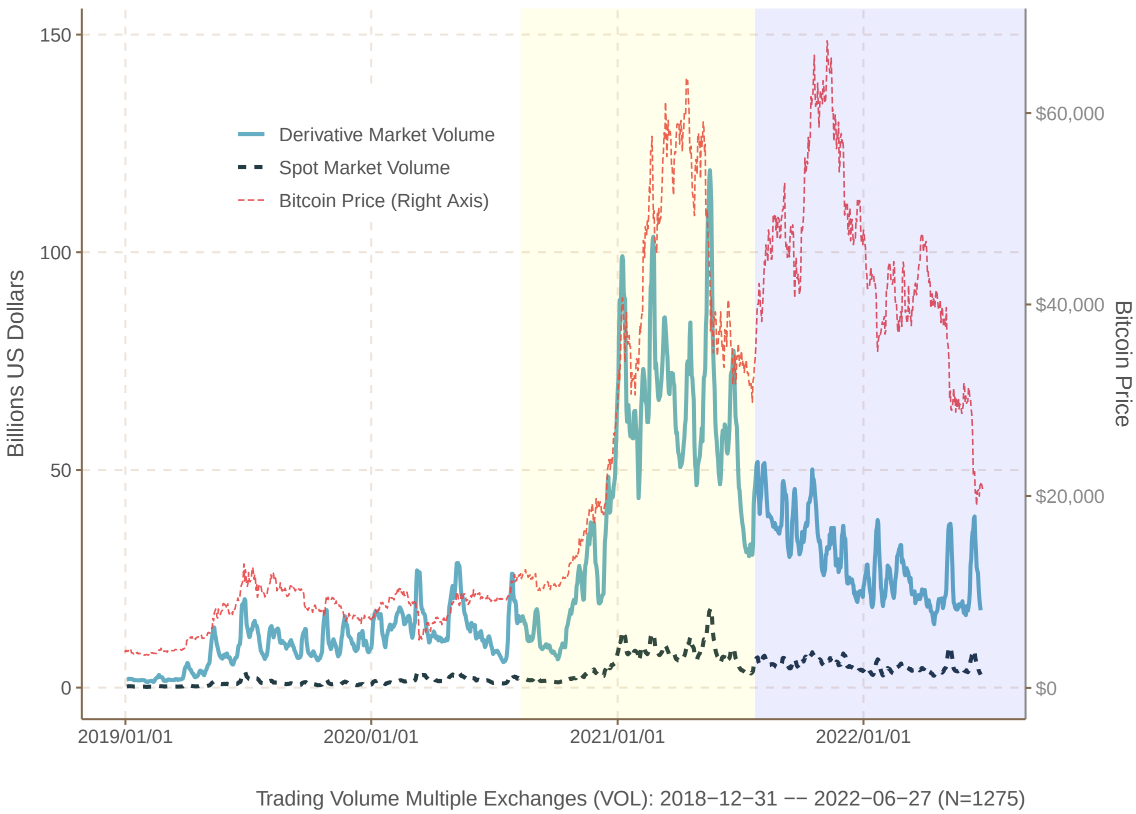
Table 12: Market-Clearing Funding Rate

Numerical Example Parameters

Figure	Long-Side Beliefs μ_a	Long-Side Wealth w_a	Short-Side Beliefs μ_b	Long-Side Wealth w_b	Exchange Margin Minimum α
13 (a)	2.0%	0.49	−1.0%	0.51	15.0%
13 (b)	2.0%	0.49	−1.0%	0.51	16.0%
14 (a)	2.0%	0.42	−1.0%	0.58	15.0%
14 (b)	2.0%	0.42	−1.0%	0.58	16.0%

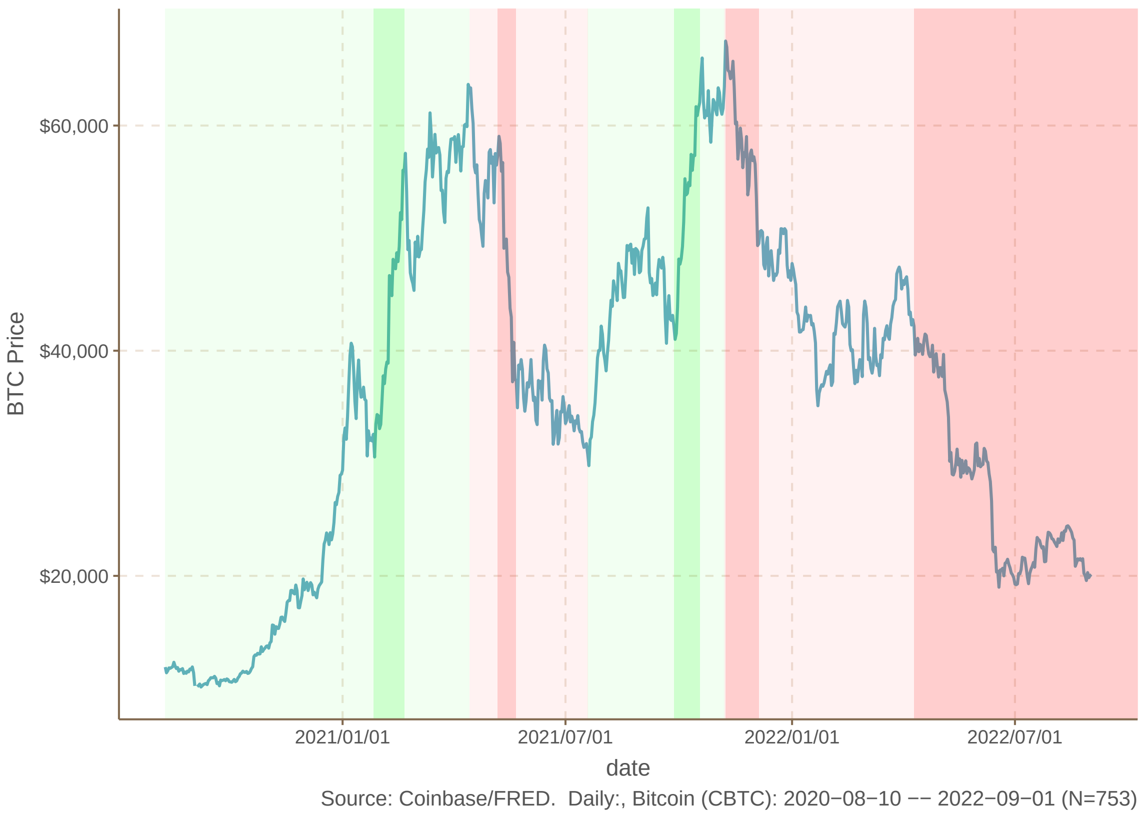
Preferences are $u(W_1) = 1/\gamma(c + W_1)^\gamma$ with $\gamma = -5$ and $c = 0.1$. The index price has $\log \frac{P_1}{P_0} \sim N(0, 0.0227^2)$ corresponding to BTC 8-hour volatility. Expectations are calculated with 10,000 draws.

Figure 1: Spot and Derivative Markets Trading Volume



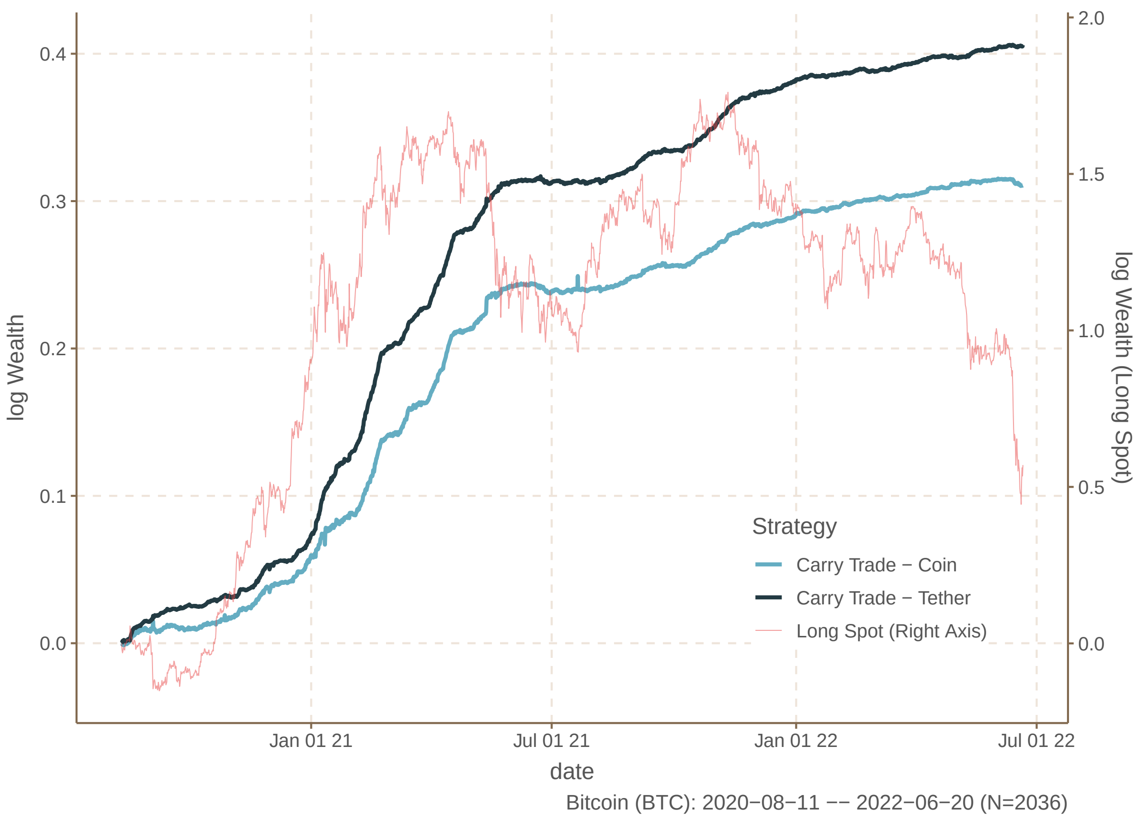
Trading volume statistic is aggregated from the data feeds of exchanges: FTX, Binance, Okex, Huobi, Bitmex, Coinbase, Kraken, Bitstamp, Bybit and Deribit. The derivative volume is the contract's notional value. Volume statistics are 7-day centered moving average. For reference, the right axis plots Coinbase Bitcoin (BTC) Index Price (See Figure 2). The combined shaded regions indicate the dates of the Binance data in Table 3. The different shades indicate the sub-samples used in Table 11.

Figure 2: Bitcoin (BTC) Price



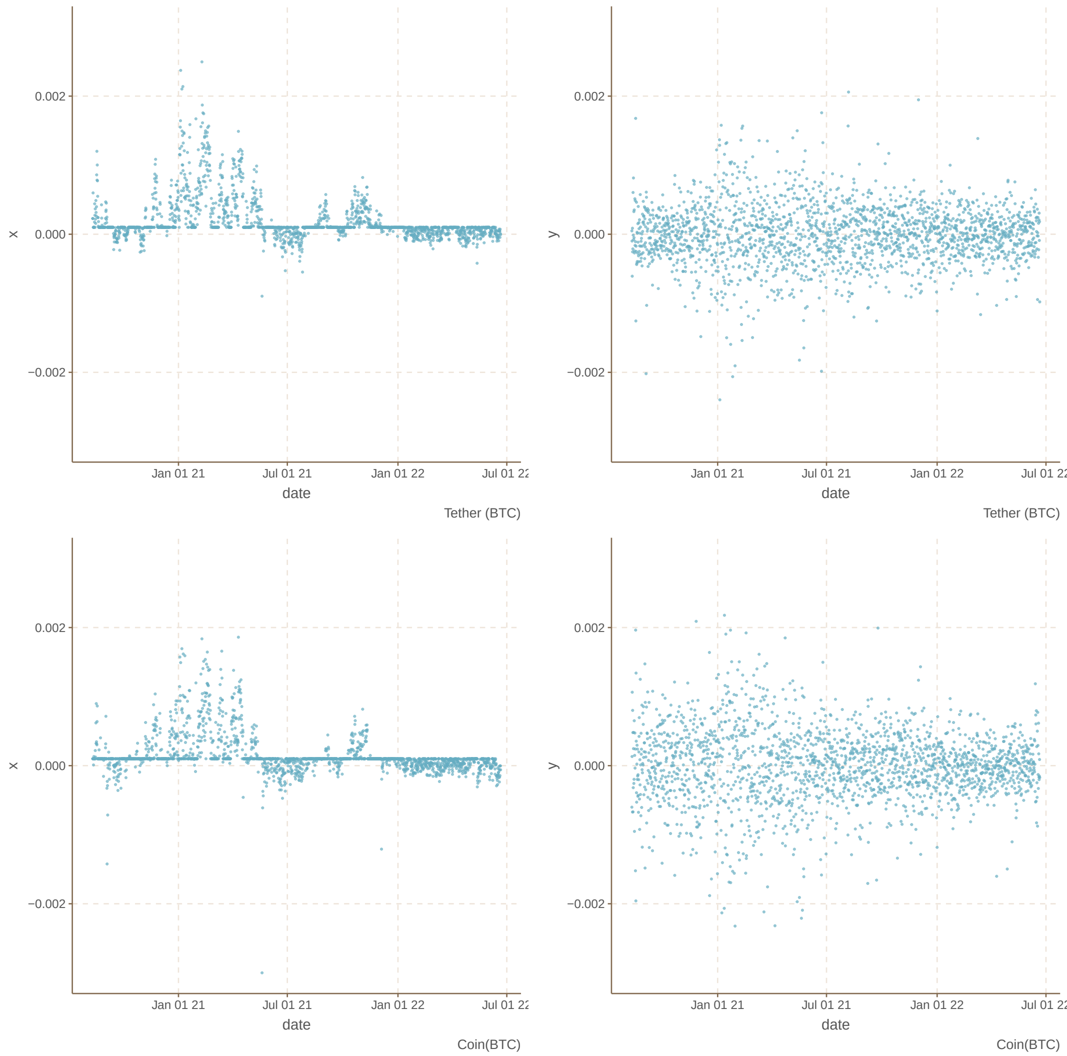
Coinbase Index Price of Bitcoin (BTC). Data is from the Federal Reserve Bank of St. Louis. The shaded regions highlight the subsamples presented in Tables 4 (lighter shading) and 5 (darker shading).

Figure 3: Carry Trade – Cumulative Returns



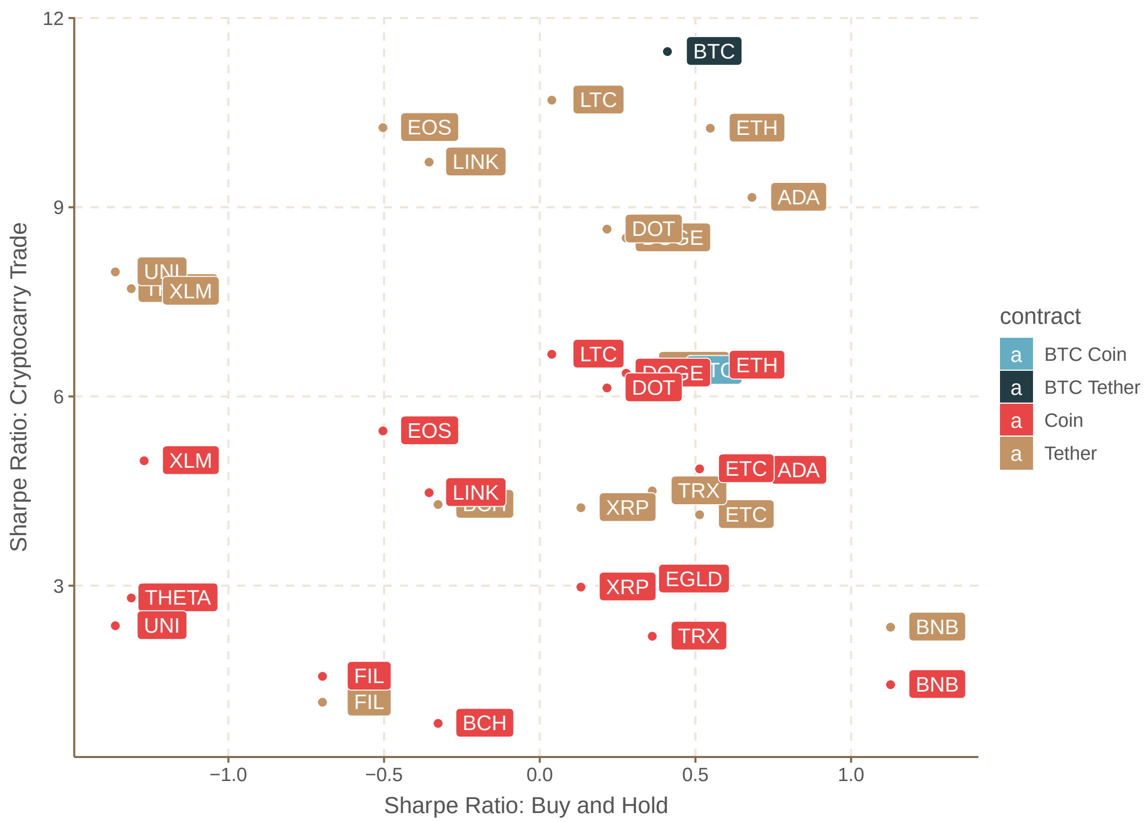
Cumulative Returns from Tether and Coin Carry Trades (i.e., the log wealth from a \$1.00 initial investment). The right-scale shows the cummulative reutures from an long buy-and-hold investment in Bitcoin. The Carry Trade is defined in Table 1 for "Tether Contract" and in Table 2 for the "Coin Contract."

Figure 4: Carry Trade – Return Components



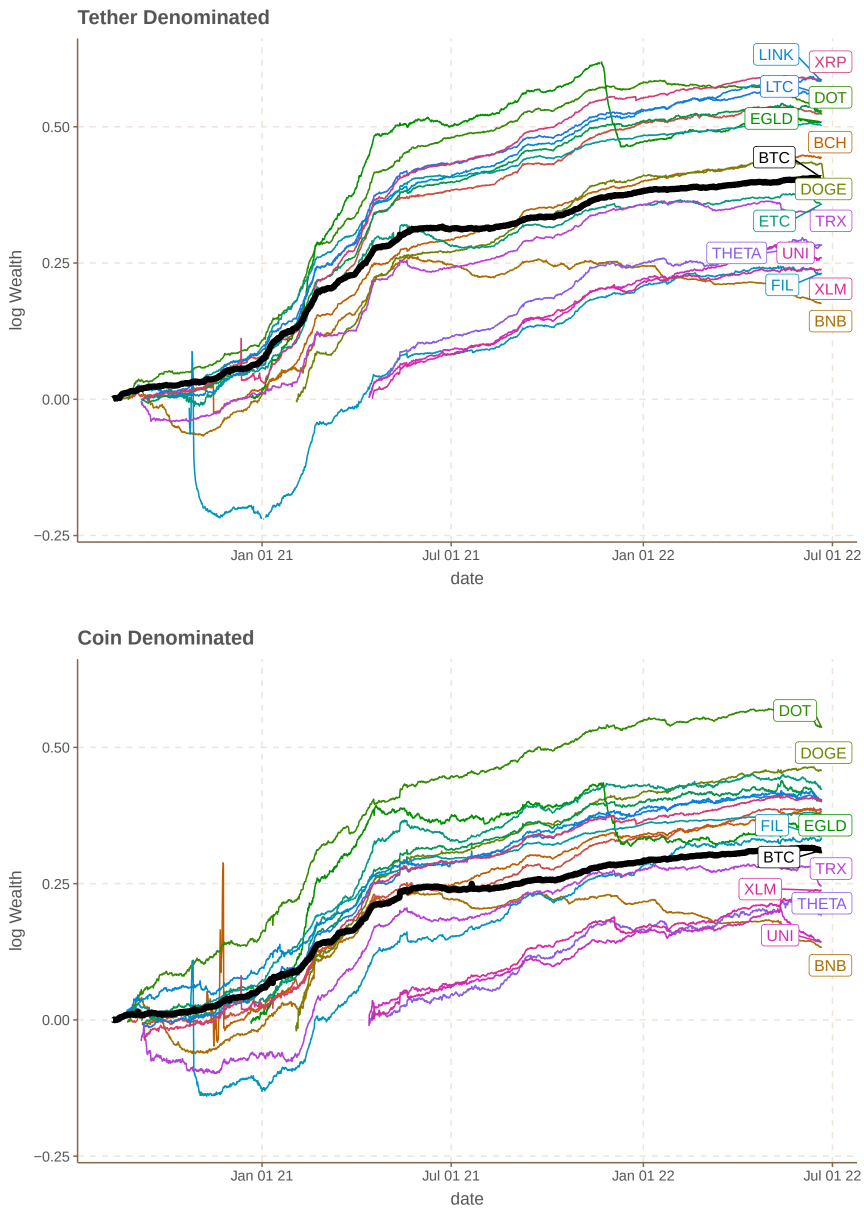
The excess return from the crypto-carry trade return $x + y$ is decomposed into the funding x (left column) and the change-in-basis y (right column). Returns in this figure are simple returns (not continuously compounded). Shown here is the Tether-based contract (top row) and Coin-based contract (bottom row) for BTC. Dates: 2020-08-11 – 2022-06-20.

Figure 5: Carry Trade – Sharpe Ratio



Sharpe Ratio for returns from Tether and Coin Carry Trades versus Sharpe Ration of returns from buy-and-hold the underlying coin. The right-scale shows the cumulative returns from an long buy-and-hold investment in Bitcoin. The Carry Trade is defined in equation (1) for “Tether Contract” and in equation (2) for the “Coin Contract.”

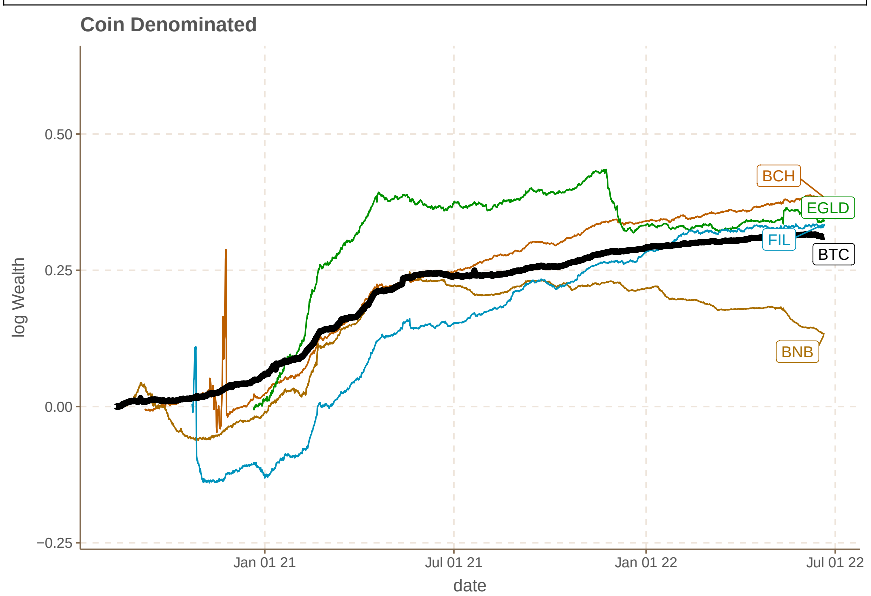
Figure 6: Carry Trade – Cumulative Returns



Cumulative Returns from Tether and Coin Carry Trades (i.e., the log wealth from a \$1.00 initial investment) across 18 cryptocurrency coins. For reference, the BTC is the thicker black line. The Carry Trade is defined in equation (1) for "Tether Contract" and in equation (2) for the "Coin Contract." Dates: 2020-08-11 – 2022-06-20.

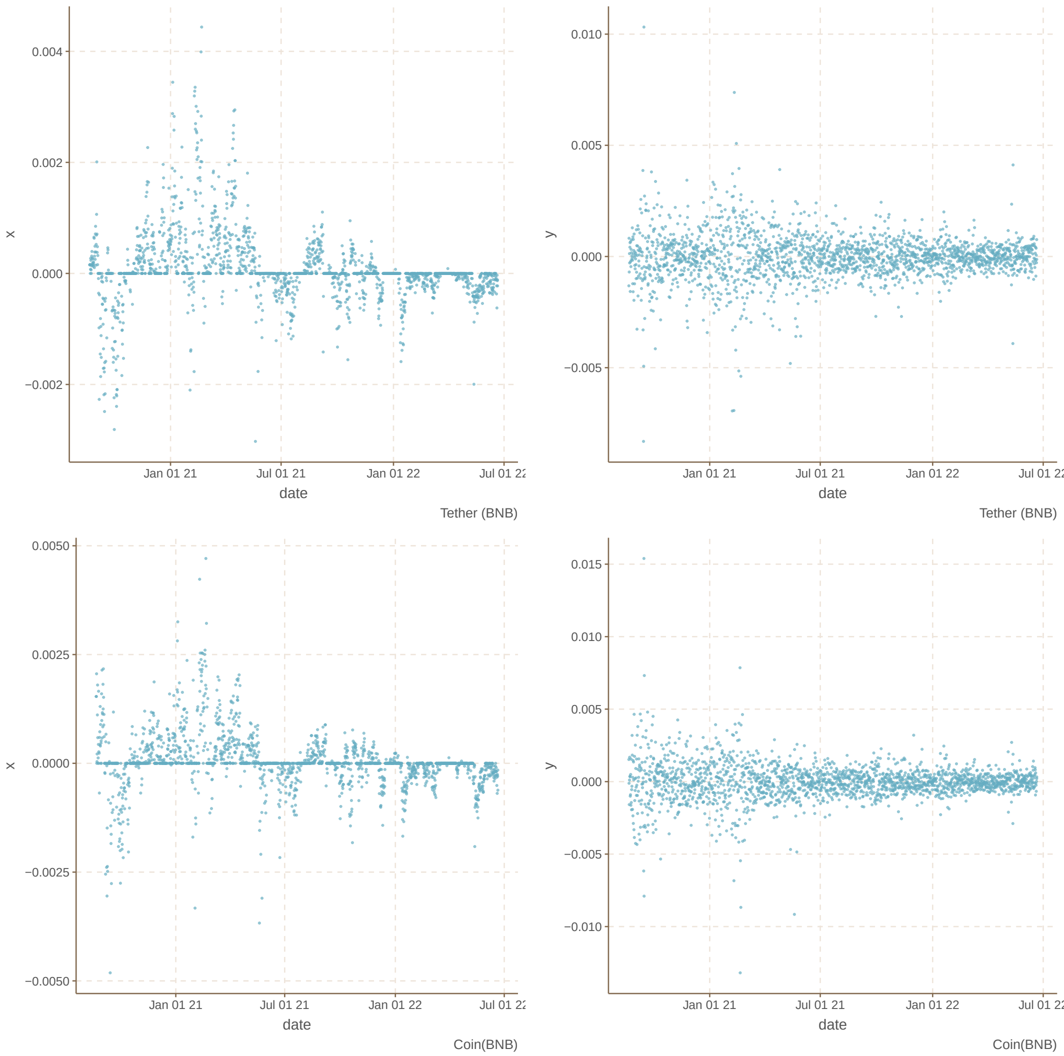
Figure 7: Carry Trade – Cumulative Returns

../Graphics/data.202206/All.CarryTrade.Interesting.logW.coin.BNB.BTC.EGLD.FIL.pdf



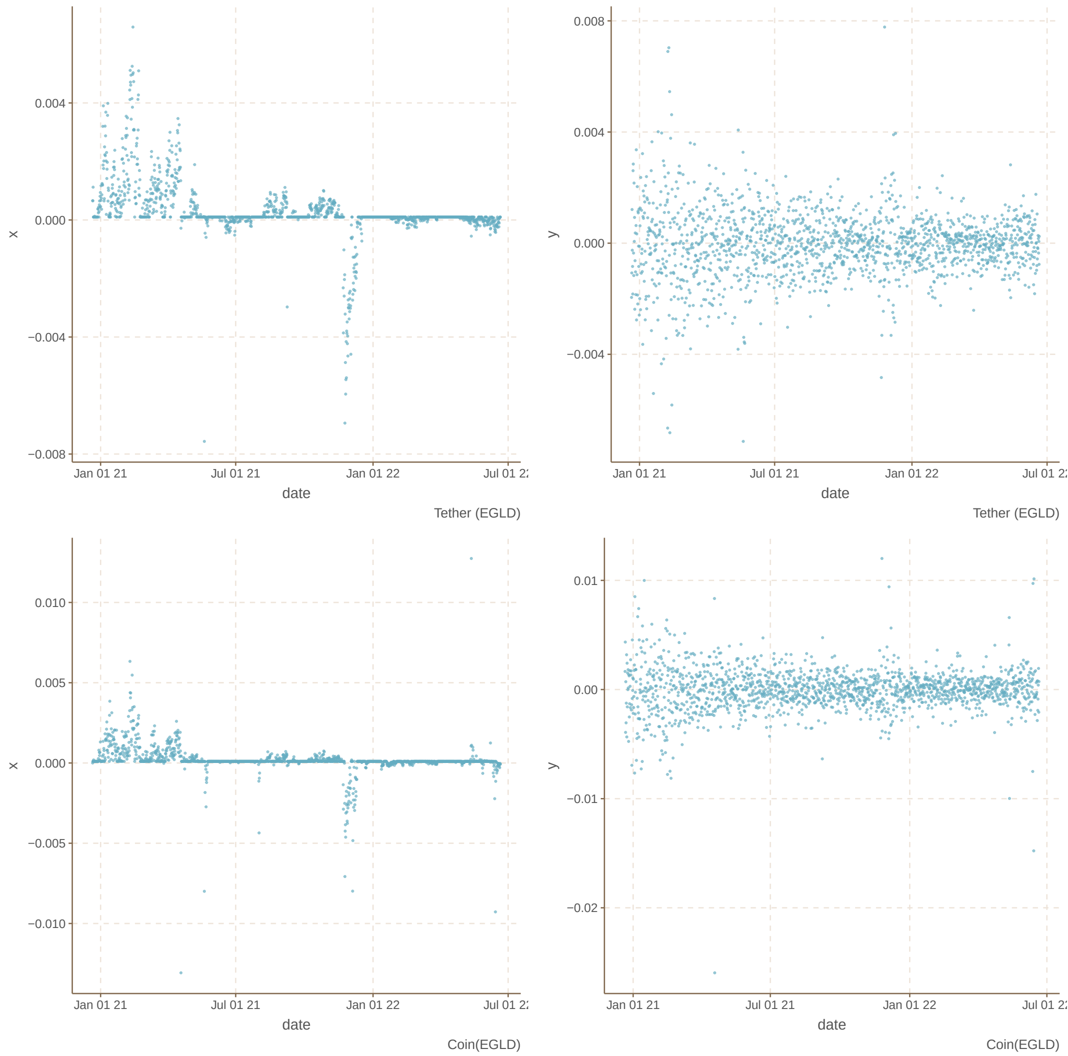
Cumulative Returns from Tether and Coin Carry Trades (i.e., the log wealth from a $1.00 initial investment) across a subset of cryptocurrency coins. For reference, the BTC is the thicker black line. The Carry Trade is defined in equation (1) for "Tether Contract" and in equation (2) for the "Coin Contract." Dates: 2020-08-11 – 2022-06-20.

Figure 8: Carry Trade – Return Components – BNB



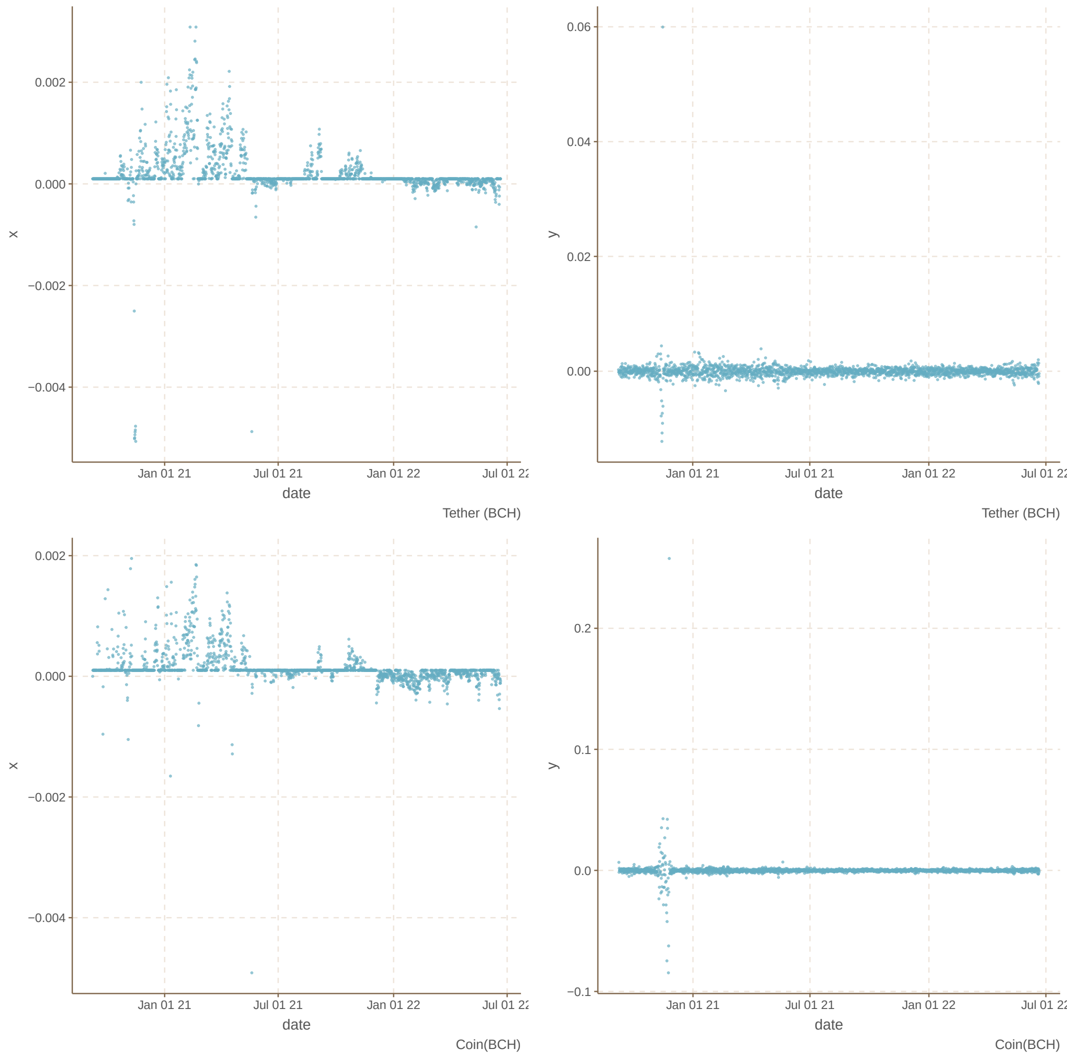
The excess return from the crypto-carry trade return $x + y$ is decomposed into the funding x (left column) and the change-in-basis y (right column). Returns in this figure are simple returns (not continuously compounded). Shown here is the Tether-based contract (top row) and Coin-based contract (bottom row) for BNB. Dates: 2020-08-11 – 2022-06-20.

Figure 9: Carry Trade – Return Components – EGLD



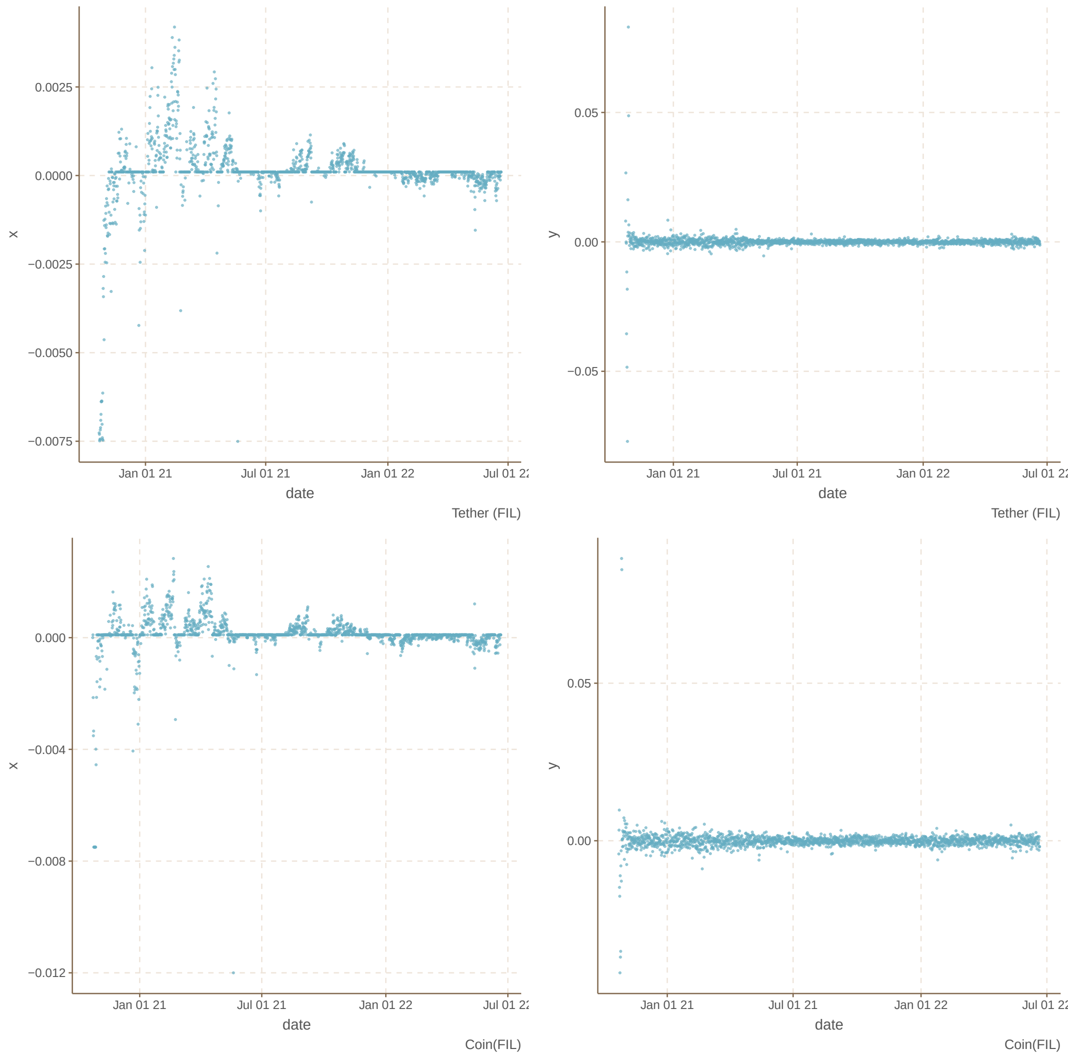
The excess return from the crypto-carry trade return $x + y$ is decomposed into the funding x (left column) and the change-in-basis y (right column). Returns in this figure are simple returns (not continuously compounded). Shown here is the Tether-based contract (top row) and Coin-based contract (bottom row) for EGLD. Dates: 2020-08-11 – 2022-06-20.

Figure 10: Carry Trade – Return Components – BCH



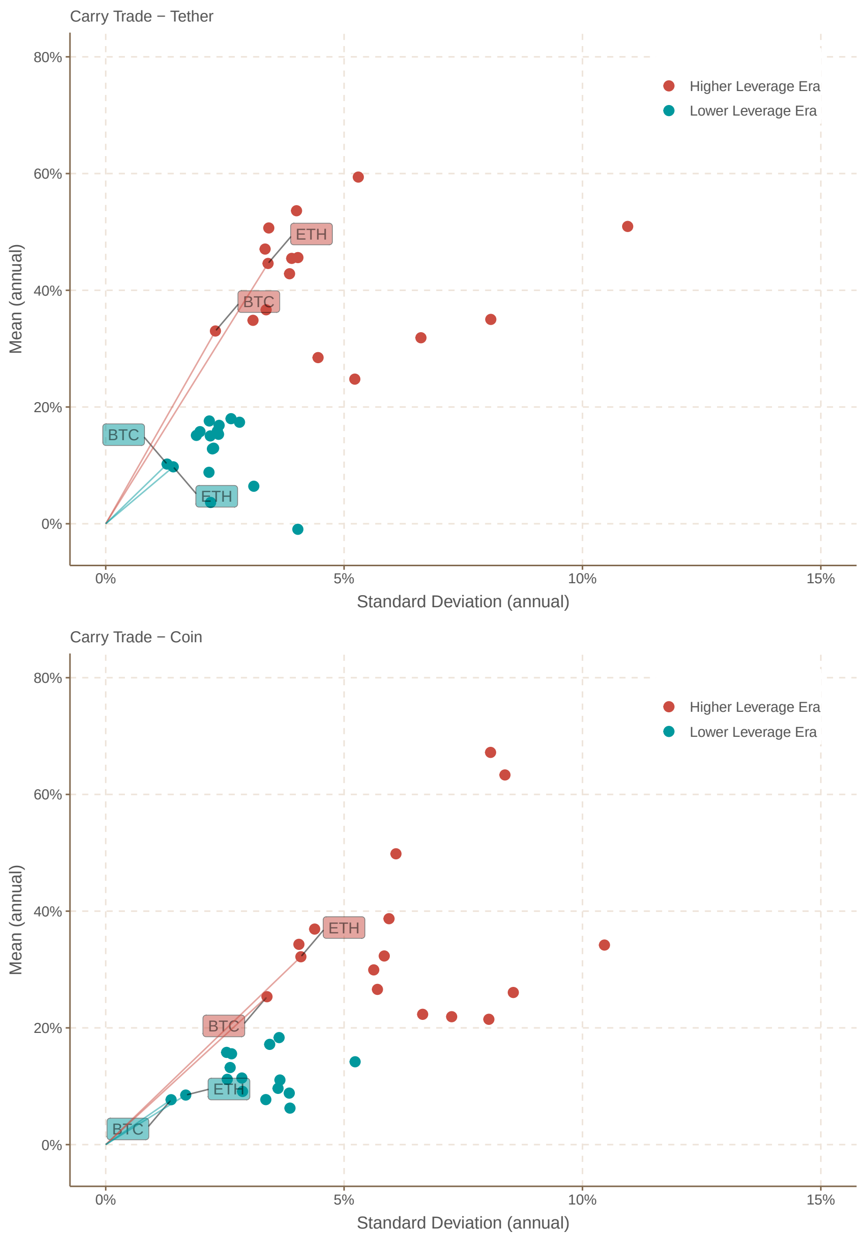
The excess return from the crypto-carry trade return $x + y$ is decomposed into the funding x (left column) and the change-in-basis y (right column). Returns in this figure are simple returns (not continuously compounded). Shown here is the Tether-based contract (top row) and Coin-based contract (bottom row) for BCH. Dates: 2020-08-11 – 2022-06-20.

Figure 11: Carry Trade – Return Components – FIL



The excess return from the crypto-carry trade return $x + y$ is decomposed into the funding x (left column) and the change-in-basis y (right column). Returns in this figure are simple returns (not continuously compounded). Shown here is the Tether-based contract (top row) and Coin-based contract (bottom row) for FIL. Dates: 2020-08-11 – 2022-06-20.

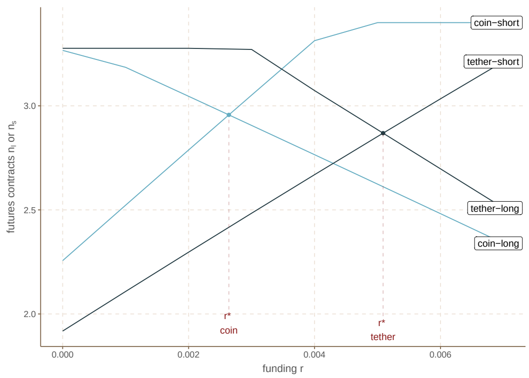
Figure 12: Carry Trade – Mean and Standard Deviation – Across Leverage Eras



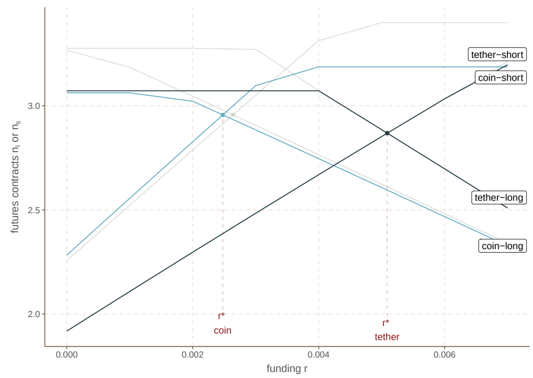
The Higher Leverage Era (125x) is from the start of our sample to 2021-07-23. The Lower Leverage Era (50x) is from 2021-07-24 to the end our our sample. The sample standard deviation and mean for the strategy return for each coin are shown. The ray from the origin for each point is the sample Sharpe ratio. The Carry Trade is defined in equation (1) for "Tether Contract" and in equation (2) for the "Coin Contract." Full sample dates: 2020-08-11 – 2022-06-20.

Figure 13: Market-Clearing Funding Rate - Margin Unconstrained

(a) $\alpha = 0.15$



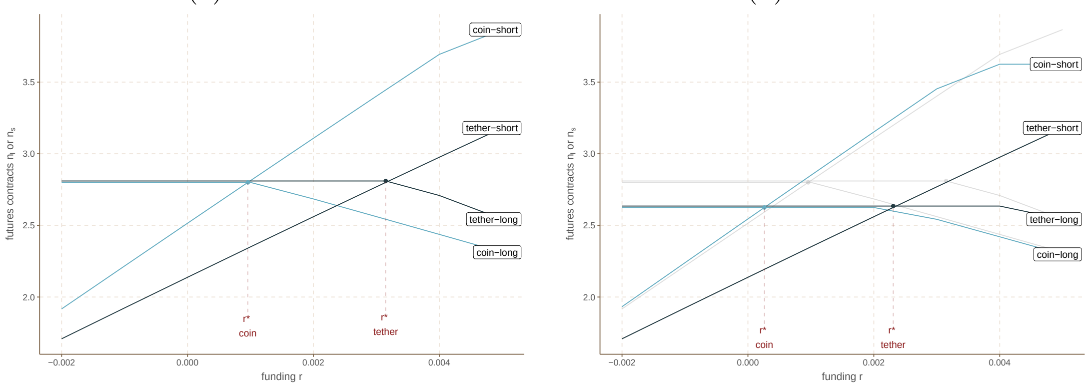
(b) $\alpha = 0.16$



Equilibrium funding rate for Tether-based and Coin-based contracts. In this numerical example, long-traders have belief $\mu_a = 0.02$ representing $w_a = 0.49$ of the wealth and short traders have have belief $\mu_b = -0.01$ representing $w_b = 0.51$. Preferences are $u(W_1) = 1/\gamma(c + W_1)^\gamma$ with $\gamma = -5$ and $c = 0.1$. The index price has $\log \frac{P_1}{P_0} \sim N(0, 0.0227^2)$ corresponding to BTC 8-hour volatility. Expectations are calculated with 10,000 draws. In all these cases, $W_1 > 0$ for each trader (i.e., no bankruptcy). The exchange margin limit is (a) $\alpha = 0.15$ and (b) (a) $\alpha = 0.16$. In both graphs, these margin limits are not binding. The "ghost lines" in graph (b) allow comparison to graph (a).

Figure 14: Market-Clearing Funding Rate - Margin Constrained

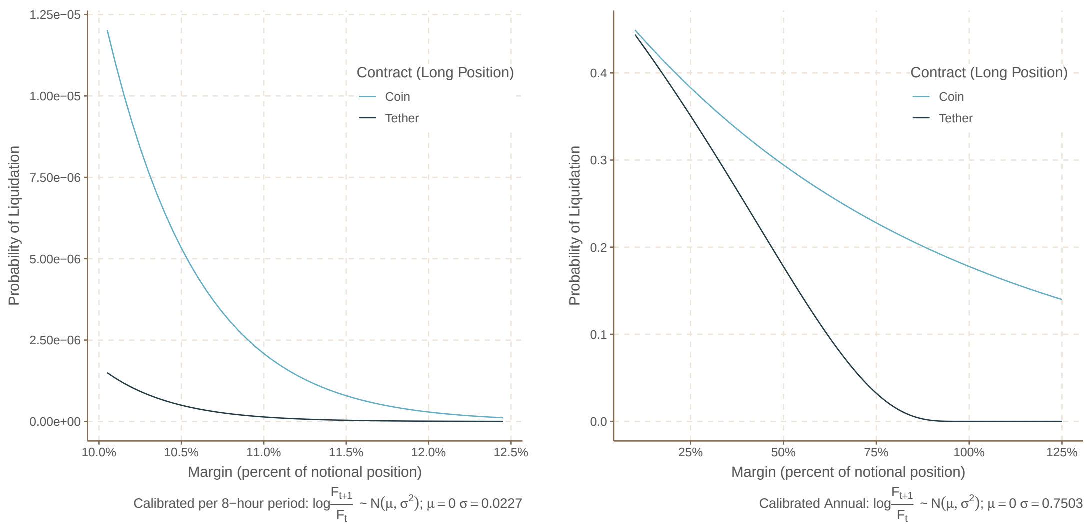
(a) $\alpha = 0.15$ (b) $\alpha = 0.16$



Equilibrium funding rate for Tether-based and Coin-based contracts. In this numerical example, long-traders have belief $\mu_a = 0.02$ representing $w_a = 0.42$ of the wealth and short traders have have belief $\mu_b = -0.01$ representing $w_b = 058$. Preferences are $u(W_1) = 1/\gamma(c + W_1)^\gamma$ with $\gamma = -5$ and $c = 0.1$. The index price has $\log \frac{P_1}{P_0} \sim N(0, 0.0227^2)$ corresponding to BTC 8-hour volatility. Expectations are calculated with 10,000 draws. In all these cases, $W_1 > 0$ for each trader (i.e., no bankruptcy). The exchange margin limit is (a) $\alpha = 0.15$ and (b) (a) $\alpha = 0.16$. In both graphs, these margin limits are binding for the long trader. The "ghost lines" in graph (b) allow comparison to graph (a) Since the lines for long Tether and Coin overlap when the margin constraint binds, they are plotted here with a slight off-set so they can be distinguished.

Figure 15: Margin and Liquidation Probability

(a) $\sigma = 0.0227$ (b) $\sigma = 0.7503$



Probability of liquidation is calculated assuming $\log \frac{F_{t+1}}{F_t} \sim N(\mu, \sigma^2)$ using equations (8) and (9) for the contract denominated in Tether and coin. $\mu = 0$ and (a) is calibrated for an 8-hour window, (b) is for one year. Here, funding is set to zero $r = 0$. Both plots assume an initial margin level α with no subsequent additions or withdrawals from the margin account. The threshold for liquidation is a margin balance of zero. In practice, liquidation occurs when the margin balance falls below a "maintenance margin" threshold.