The Crypto Carry Trade*

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Abstract:
The primary derivative contract on cryptocurrency exchanges is the perpetual futures contract. These contracts are denominated in either Tether (dollar) or coin (cryptocurrency). We study the empirical properties for 18 cryptocurrencies (36 contracts). We define a strategy, "crypto carry trade" that is short perpetual futures and long spot market and document that it has a high Sharpe ratio (e.g., 8.76 per year for Bitcoin Tether contract; 4.93 per year for coin). We interpret these results through the lens of a simple heterogeneous beliefs model to suggest that cryptocurrency exchange markets were facilitating leverage for long-side traders.

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1 Introduction

Spot transactions of cryptocurrency involve a change in ownership of the coins. Some of these transactions may include an entry on a blockchain ledger. Some spot cryptocurrency transactions occur on centralized exchanges where the ownership of the underlying cryptocurrency is indirect (e.g., Coinbase owns the coins and a trader owns a liability of Coinbase). Each of 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. The connection between derivative market transactions – financialization – and the price dynamics in the underlying spot market is important in many markets. Harrison and Kreps (1978), for example, show the importance of short-sale contracts on spot prices of equity. In commodities, the period from 2004 to 2008 saw both increasing 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. 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)).

In this paper we explore the most popular derivative contract in cryptocurrencies, the "perpetual futures" contract, and use its unusual design to study the financialization of cryptocurrencies. Bitcoin and cryptocurrencies seem an asset where differences of opinion and heterogenous beliefs might be large. Here, financialization through a derivative market facilitates both short positions and levered-long positions. So a derivative market might have appeal to both optimists and pessimists. Hence, the impact of derivative trading opportunities on spot-market holdings is ambiguous. Is there more demand to be long or short? Of course, we cannot measure demand pressure 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 to see demand pressure. We show that a trade that is short a futures contract and 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 volume of traded derivatives in cryptocurrency is sizable. Figure 1 shows the trading volume for Bitcoin (BTC) on centralized spot markets and derivative markets aggregated across major markets (measured in units of BTC to avoid distorting volumes with the large variation in the price of Bitcoin over this period). The bulk of that volume is on exchanges located outside typical U.S. regulation like Binance, FTX, and BitMEX.[1] Of that derivative volume, the perpetual futures derivative contract is by far the most popular and liquid derivative contract in cryptocurrencies. Perpetual derivatives account for 98.2% of the Bitcoin futures volume in our sample with traditional dated-delivery futures contracts the tiny remaining fraction (see Figure 2). The perpetual futures contract, initially used 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. The salient feature of these contracts is that 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 markets, 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

[1] Augustin, Rubtsov, and Shin (2023) analyses the introduction of Bitcoin futures on the CBOE and the Chicago Mercantile Exchange (CME) in December 2017. Their paper looks at the impact of the derivatives on price efficiency, market quality, and liquidity. Interestingly, volumes at the CBOE and CME were initially very small – CBOE stopped trading BTC futures in 2019. The percentage of overall volume on the CME has increased following the collapse of Luna in March 2022 and then FTX in November.

[2] The idea of the perpetual contract dates to Shiller (1993). BitMEX is the first major derivatives market that pioneered the perpetual futures contract.. See Soska, Dong, Khodaverdian, Zetlin-Jones, Routledge, and Christin (2021) and `https://cryptotrade.cylab.cmu.edu/` for a detailed description.

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. 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 paying shorts is most common. However, we do see episodes of a negative rate in our sample, as around the time of the FTX bankruptcy. 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.

To isolate the impact of funding and the basis spread, we construct the returns to a trade that is long one Bitcoin (using BTC as an example), 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. 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 (see Routledge, Seppi, and Spatt (2000)). The basis risk at maturity comes from the settlement provisions.[4]

[3] On Binance, the funding rate is set at 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.

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 (described in more detail in Section 2). Of the cryptocurrencies, the Bitcoin contracts are by far the most heavily traded. Our data period is 2020-08-11 – 2023-06-23. 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 several significant price run ups and drops (see Figure 3). The latter part of the sample includes the systemic events involving Terra/Luna (2022-05-09), Three Arrows Capital (2022-06-22), and FTX (2022-11-11), as well as bankruptcy of Silicon Valley Bank (2023-03-10).

We document that the return on the crypto carry trade is typically high and the volatility of the return is small. Across our whole sample and across many underlying cryptocurrencies, the Sharpe ratios are large. For example, the full-sample Sharpe ratio for Bitcoin (BTC) is 8.76 per year for the Tether denominated contract and 4.93 per year for the coin denominated contract. For this same period, 2020-08-11 – 2023-06-23, the buy-and-hold Sharpe ratio is 0.46 per year for a long Bitcoin position and 0.33 for US equities. We also see that the Sharpe ratio from the crypto carry trade are broadly unrelated to the performance of the underlying cryptocurrency. In subsamples where the price of BTC increased and decreased, the crypto carry trade is consistently large and positive. We document that the Sharpe ratios are particularly large in the earlier part of our sample when exchange policies permitted for very large leverage. The Sharpe ratios are much smaller in the later part of the sample that includes the bankruptcy of FTX and several other systemic events. The exchange trades two types of contract for each cryptocurrency. One is denominated in Tether (a stable coin pegged to the US dollar) and one is denominated in the underlying coin. The returns to the carry trade are consistently higher for the Tether denominated contract.

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]

[5]Soska, Dong, Khodaverdian, Zetlin-Jones, Routledge, and Christin (2021) discusses BitMEX,

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 is larger than in the coin-based contract.

Relative to traditional derivative exchanges, the risk directly related to the viability of cryptocurrency exchange is particularly relevant. Many cryptocurrency exchanges have failed. FTX in November 2022 was the largest in a surprisingly long list. Several other exchanges have been sanctioned or are in jeopardy from the Commodity Futures Trading Commission (CFTC) and the Securities and Exchange Commission (SEC). For example, In August of 2021, a CFTC complaint lead to a $100 million fine against BitMEX and in June, 2023, the SEC filed charges against both Binance and Coinbase. This risk is relevant to the crypto carry trade is two fold. First, margin balance is lost if the exchange fails. Second, the long coin position is unhedged without the short position on the exchange. To quantify the risk specifically to the crypto carry trade, we use a calibration to show that a large 30%-40% annual probability of exchange bankruptcy would offset large Sharpe ratios we have observed. The FTX bankruptcy was a systemic event, and one of several large-scale institution failures that occur in this period. We use the return to the carry trade to explore this period. We see that the return is generally lower around these large events suggesting lower net-demand for long perpetual futures. We also see a few short-lived periods of very low returns to the crypto carry trade. The intensity and duration suggest they are related to the behavior of a few large accounts.

The paper describes the cash-flows and details for the carry trade in Section 2. The empirical results focussed on Bitcoin, the largest cryptocurrency, presented in Section 3. Section 4 develops a model of the market-clearing funding rate driving the crypto

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, it's a lot of fun."

carry trade returns to understand the role contract designs and exchange policies. Section 5 describes the empirical properties for seventeen additional cryptocurrencies. Section 6 considers the role bankruptcy and systemic risk using the crypto carry trader return. Section 7 concludes.

2 Perpetual Futures and 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 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 P_t. The timing on Binance happens to be that the rate is set at date t but is paid at $t+1$. 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, 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 underlying cryptocurrency (e.g., Bitcoin). But first, we will describe the one that is settled in Tether. Tether is a cryptocurrency "stable-coin" that is pegged to the US Dollar. The exchange Bitfinex owns and controls Tether and backs it with fiat currency, U.S. Treasury bonds and low-risk reserves like commercial-paper.[6] 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 Tether denominated contract has higher trading volumes in our sample; as shown in Figure 2. For Bitcoin, for example, the Tether denominated contract is 84% of the perpetual volume with the coin-denominated contract, explained below, accounting for 16% of the volume.

The basic components of the crypto-carry trade strategy are 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 in Table 1 shows the cash flows from 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 in Table 1 shows the cash flows from the short perpetual futures contract on the exchange. Since, for the moment, we abstract from collateral the initial cash flow on the perpetual future 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 from the long-side to the short-side of the contract.[7]. We can use these cash-flows to define an excess return, $\phi_{t+1,\text{tether}}$, (excess of the USD risk-free rate,

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

[7]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 $r_{t,c}$ 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.

$r_{t,\$}$).[8]

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

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 assumptions on the stochastic processes for P_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 $r_{t,c} > 0$ indicates payment from the long side to the short side of the trade. (Recall, we use

[8] 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. We can define an equivalent definition of a risk-premium using just the cash flows sidestepping the need to define a return.

$r_{t,c}$ 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 Table 2 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 for Bitcoin

We start with Bitcoin since it is both the largest cryptocurrency and most heavily traded cryptocurrency. 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). The exchange operates continuously, so we annualize using $3 \times 365 = 1095$

eight-hour funding periods per year. To calculate excess returns we use the one-month U.S. Treasury.[9] We compute the continuously compounded excess returns as $\log(1 + \phi_t + r_{t\$}) - \log(1 + r_{t,\$})$. For exposition, note that if $r_{t\$} \approx 0$, then the continuously compounded excess return is approximately $\log(1 + \phi_t) \approx \phi_t$.

For comparison, Table 3 reports the continuously compounded excess returns from a strategy that holds a long position in BTC on the exchange. These returns are calculated from the spot index for each contract.[10] 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. Bitcoin (BTC) the Sharpe ratio is 8.76 per year for the Tether denominated contract and 4.93 per year for the coin denominated contract. Over this same period, 2020-08-11 – 2023-06-23, the buy-and-hold Sharpe ratio is 0.46 per year for a long Bitcoin position and 0.33 for US equities. The high Sharpe ratios are from high average returns and particularly low volatility is particularly – much lower than a BTC long position or US equities. This is apparent in Figure 4 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 of 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 the return characteristics for narrow windows of two to four weeks where the underlying price of bitcoin was particularly volatile. Notice the crypto carry trade Sharpe Ratio is large across up and down markets. We see a similar pattern if we look over longer periods. Table 5 shows results across five periods. The crypto carry return in the two periods where BTC prices were falling is similar to the return in periods where BTC was rising. You can see these different time periods marked in Figure 3.

[9] The daily observations of the one-month treasury yield, DGS1MO series from Federal Reserve Bank of St. Louisare converted to an equivalent rate per eight-hour period. We assume the rate is constant across the day and across weekends.

[10] The two indices are close to identical and also similar to other indices, like that of Coinbase on Federal Reserve Bank of St. Louis. The slight variation is from the exchange weightings of recent trades and order-book information.

There are two items to to note in Table 5. First, notice that the crypto carry trade return in the Tether contract is particularly large in the 2020-08-11 – 2021-04-14 (Epoch 1). This was an era where Binance allowed exceptionally high leverage ratios. We discuss the role exchange leverage and the crypto carry trade return in more detail in Section 4. Second, during the period 2022-05-09 – 2023-06-23 (Epoch 5), the crypto carry trade return is at its lowest. This period includes the collapse of Terra/Luna, Three Arrows Capital, the bankruptcy of FTX, and the bank failure of Silicon Valley Bank. We will discuss these events in Section 6.

3.1 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.

$$\phi_{t+1,\text{tether}} = x_t + y_{t+1}$$

with

$$x_t = r_{t,c}\frac{F_t}{P_t} - r_{t,\$} \tag{3}$$

$$y_{t+1} = \left(\frac{F_t - P_t}{P_t}\right) - \left(\frac{F_{t+1} - P_{t+1}}{P_{t+1}}\right)\frac{P_{t+1}}{P_t} \tag{4}$$

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, hence the negative item in line six of the table. This is also reflected in Figure 5. 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 5. 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)).

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 Market-Clearing Funding Rates

There are two types of perpetual futures contract. The Tether-denominated contract is settled in Tether (USD) and the coin-denominated contract is settled in the cryptocurrency. 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 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 understand this empirical property, we develop 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 prices of BTC as P_0 and P_1. With the date one price, P_1 as a random variable. Here, we abstract from basis risk, and pin the perpetual futures contract price to the spot price, $F_t = P_t$. These assumptions pin down the cash-flows from the perpetual contracts, 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:

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

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.[14] 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.

4.1.1 Demand: Tether-based contract

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

$$W_1 = W_0 - \alpha n_l F_0 + n_l([F_1 - F_0 - rF_0 + \alpha F_0]_+) \tag{5}$$

Initial wealth less margin, $W_0 - \alpha n_l F_0$ is invested outside the derivative market (at risk-free rate of zero). The payoff 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 $[x]_+ = \max(x, 0)$.[15] To simplify, we focus on the situation where the margin balance is larger and the exchange cash flows are strictly positive almost surely. In this case, date one wealth is

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

[14] 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).

[15] 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").

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

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

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).

4.1.2 Demand: Coin-based contract

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

$$W_1 \;=\; W_0 - \alpha n_l F_0 + \left(\left[(n_l F_0) \left(\frac{1}{F_0} - \frac{1}{F_1} \right) - n_l r + \alpha n_l \right]_+ \right) F_1 \tag{7}$$

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 the exchange cash flows from profit and margin are strictly positive. Then,

$$W_1 \;=\; F_0 \left(\frac{W_0}{F_0} + n_l \left(\frac{F_1}{F_0} - 1 - r \right) + n_l(\alpha - r) \left(\frac{F_1}{F_0} - 1 \right)\right) \tag{8}$$

Comparing (6) to (8), 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.

4.1.3 Tether based versus coin-based contract

To compare the contract types, define (overall) leverage as the (absolute value of the) percentage change in 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.

$$L = \left|\frac{\partial W_1/W_0}{\partial F_1/F_0}\right| = \frac{F_0}{W_0}\begin{cases} & \text{Tether-based} & \text{Coin-based} \\ \text{long} & n_{T,l} & n_{C,l}(1+\alpha-r) \\ \text{short} & n_{T,s} & n_{C,s}(1-\alpha-r). \end{cases} \quad (9)$$

For the long position in the Tether contract, the leverage is the notional amount of the position $F_0 n_{T,l}$ relative to 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 ($r = 0.001$ 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 (9) 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 $n_{T,s} < n_{C,s}$.[16] 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 for BTC in Table 3. As we will explore below, this also holds for other cryptocurrencies.

[16]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.

4.1.4 Market-Clearing and Leverage

An important and unusual feature of cryptocurrency derivative markets is very high leverage. 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 (an $\alpha = 0.008$). On 2021-07-23, Binance made several 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.[17] We can use our model to understand the potential impact of a change in leverage. As we will see, the change in leverage policy only has an impact if the exchange's leverage constraint is binding.

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 Figure 9. For context, think of BTC with $\log \frac{F_1}{F_0} \sim N(\mu, \sigma)$ setting and $\sigma = 0.0203$ – an 8-hour volatility (equivalent to a 0.6729 per year). This is calibrated to observed volatility in our sample. 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 7.5.[18]

In Figure 9(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 $\alpha = 0.15$. At very low funding rates, the long demand is constrained by the exchange's minimum margin requirement. At very high funding rates, the short-side demand is constrained.

[17] 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).

[18] Preferences are $u(W_1) = 1/\gamma(c + W_1)^\gamma$ with $\gamma = -6.5$ and $c = 0.1$. The c term is helpful for computations when W_1 happens to be close to zero. However, in this calibration, over the 100,000 draws $W_1 > 0$ for both traders. Other calibrations can yield $W_1 = 0$ with positive probability. However, they produce similar figures.

However, with these parameters, the market-clearing funding rates for both the Tether and coin denominated contracts occurs where both sides are unconstrained by the margin requirement. Notice that the Tether funding rate is higher than the coin rate is consistent with equation (9).

Figure Figures 9(b) has the same parameterization as in (a) except the minimum margin rate is increased to $\alpha = 0.16$. This lowers the maximum leverage. Notice that this reduces the 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. For the Tether contract, as we saw in equation (6), the α plays no role in the determining payoffs.[19] For the coin-denominated 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 (9)). However, the change to the market-clearing funding rate is small.

Figure 9(c) and (d) present a numerical example where a change in leverage policy has a larger impact. The parameters here are all the same except the wealth of the two groups are more disperse with $w_a = 0.42$ and $w_b = 0.58$. In this case, starting with Figure 9(c), the margin minimum, $\alpha = 0.15$, is a binding constraint for the long side for both Tether and coin contracts. Notice the market-clearing funding rate coincides with the long-side constraint. 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 (9)). Since the margin minimum is binding, not surprisingly, increasing the margin minimum to $\alpha = 0.16$ in Figure 9(d) impacts the funding rate in both contracts. Here, the market-clearing rates fall for both contracts Tether and coin denominated contracts. And, in this case, trading volume also falls.

In the Bitcoin data, the higher leverage era has much higher funding rates. Table 11 shows the crypto carry trade Sharpe ratios for a window around the change in leverage. This is also seen in the Table 3 where "Epoch 1" coincides with higher

[19]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.

leverage at Binance. 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.[20] We also explore this result across other cryptocurrencies below.

5 The Carry Trade - Empirical Facts

We have focussed on Bitcoin since it is both the largest and most heavily traded. Our data includes Bitcoin and seventeen other large cryptocurrency coins that had both a Tether and Coin denominated perpetual futures contract at the beginning of our sample on 2020-08-11. For each of these contracts, we calculate the crypto carry trade returns in the same manor as with BTC. The return is defined in equation (1) for "Tether Contract" and in equation (2) for the "Coin Contract." The returns from the crypto carry trade for the Tether and coin denominated contracts are in Table 9 and in Figure 6. The results mirror what we saw in Bitcoin. First, the crypto carry trade has high realized returns and low realized variance. The Sharpe ratios are, for most coins, relatively high. Second, as with BTC, the crypto carry trade performance is unrelated to the realized performance of the buy-and-hold strategy for that coin (Figure 6). Third, the performance using the Tether-denominated contact is typically larger than the coin-denominated contract. Finally, as with the BTC trade, the higher leverage era has much higher funding rates. Figure 8 plots the carry trade mean and standard deviation across the higher and lower leverage period (a window around the July 2021 policy announcement of Binance). It is interesting to note that the leverage policy also reduced the volatility of the carry trade return. This primarily reflects a lower variation in the funding rate after July 2021. Overall, Sharpe ratios decreased across the coins following the leverage change.

Our simple model of the market-clearing funding rate that drives the crypto carry trade returns is a "sentiment" (the wealth weights and heterogenous beliefs). Perhaps not surprising, that sentiment is positively correlated across different cryptocurrencies. The correlation across crypto carry trade returns across the different coins is

[20] 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.

generally positive. For Tether contracts, the cross-carry-trade correlations range from 0.06 to 0.56. The range is similar for the Coin denominated contracts from −0.01 to 0.45. For both contract types, the Bitcoin-Ether (BTC-ETH) pair has the highest correlation. All the correlation pairs are plotted in Figure 7. Within each coin and across contract types, the return correlations, shown in Table 12 are also positive.

The one cryptocurrency that stands out is Binance Coin (BNB). BNB was created at the Initial Coin Offering (ICO) of the Binance exchange in July of 2017. It was created as a "utility token" where the coin can be used to pay trading fees on the exchange. Initially, like most ICOs of that time, the BNB coin existed on the Ethereum blockchain (an "ERC-20" token). In April 2019, Binance created a new blockchain, "Binance Chain" that also records BNB coin ledger transactions. The Sharpe ratio for the crypto carry trade on BNB is at the lowest of those shown on Table 9. Table 10 documents the reason is the unusually low, funding rate (the x component of the carry-trade return in equation (3)). BNB is the only currency in our sample with mean funding rates that are negative. Recall, that by convention, the negative funding rate means that holders short contract positions pay to holders of long positions in BNB. Many of the coins listed in Table 9 share a similar evolution to BNB. For some, the underlying blockchain is Ethereum and others it is a coin native to another blockchain. Many also are issued as "utility tokens" with some ability to cover transaction costs. That the BNB coin, issued by the exchange, happens to trade with distinct properties is interesting.

6 Liquidation, Bankruptcy, and Systemic Risk

Cryptocurrencies and cryptocurrency exchanges are unsettled along many dimensions. In this section we look at three dimensions of this risk. First, cryptocurrency prices are volatile and we quantify the importance of "liquidation." Second, crypto exchanges are risky. FTX bankruptcy in November, 2022 was very large but one of many failed exchanges. We explore the implications of exchange bankruptcy for the carry trade. Finally, FTX was only one of several systemic risk events that occurred in this period. We use the crypto carry trade returns through this May 2022 to March 2023 period to explore how perpetual futures markets reflected this market instability.

6.1 Liquidation Risk

The high volatility of cryptocurrency prices and highly levered positions 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 (Soska, Dong, Khodaverdian, Zetlin-Jones, Routledge, and Christin (2021)). As mentioned, the positions on the exchange are "non-recourse" so traders can choose to post additional margin to avoid liquidation, but are not required to do so. Liquidation, however, is not costless. 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). The exchange policy has a minimum bound on α for initiating a new position. Subsequently, the exchange has a "maintenance margin" requirement that is used as the trigger for liquidation. The size of the 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 and charges a "liquidation fee." With the volatility of cryptocurrency prices, complete liquidations are not uncommon. Effectively, this is costly since the position is closed prior to the margin balance reaching zero but with the trader receiving zero.

How does the margin size determine the probability of liquidation? Interestingly, the probability of liquidation differs across the Tether and coin denominated contracts. If we look at equation (5) for a Tether long position and the analogously for a short position, the conditions for the position being liquid (i.e., trading losses are not larger than the margin) are:

$$\text{Long Tether:} \qquad \frac{F_{t+1}}{F_t} \geq 1 - \alpha - r \tag{10}$$

$$\text{Short Tether:} \qquad \frac{F_{t+1}}{F_t} \leq 1 + \alpha + r \tag{11}$$

Similarly, for the coin denominated contract from equation (7). Here, solvency requires:

$$\text{Long Coin:} \qquad \frac{F_{t+1}}{F_t} \geq \frac{1}{1 + \alpha - r} \tag{12}$$

$$\text{Short Coin:} \qquad \frac{F_{t+1}}{F_t} \leq \frac{1}{1 - \alpha - r} \tag{13}$$

The long position in the Tether-based contract is familiar. If you choose to fully collateralize your position with $\alpha = 1 + r$ there is 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 avoid liquidation with certainty (unless prices are bounded from above). For a coin-denominated contract, a long position in Bitcoin is effectively a short position on dollars. This is similar to the analysis in Section 4.1.3. A long investor "prefers" the Tether over coin contract. If an investor was seeking a long position with a fixed margin level α, the Tether-based future has a lower liquidation probability than a coin-based contract. A short investor has the opposite preference. There is lower liquidation probability in the coin denominated contract than in the the Tether denominated contract.

Quantitatively, we explore margin and liquidation probability in Figure 10. We calibrate this to 8-hour periods. At the start of each period, margin is set to α. In the interim, no additional funds are deposited or withdrawn. Liquidation occurs if the margin balance at the end of the period is negative. Assume $\log(F_{t+1}/F_t) \sim N(\mu, \sigma^2)$. We set $\mu = 0$ and the funding rate, $r = 0$ to focus on the key volatility parameter. For volatility, we explore two values for σ. First, we use the the sample standard deviation of the log change in BTC Tether-denominated perpetual futures price over our sample.[21] This value is $\sigma = 0.0203$ per period (0.6729 per year) in Figure 10 (a) and (b). The second value we take from a seven-day rolling volatility estimate. From this calculation, the 99th percentile is. This value is $\sigma = 0.0400$ per period (1.3237 per year) and is used in Figure 10 (c) and (d). Finally, the probability of liquidation over any eight-hour window is very small, so the the liquidation probability is reported as the probability of one (or more) liquidations per year (or $365 \times 3 = 1,095$ eight hour periods in a year).[22]

From Figure 10(a) and (b), for small margin balances, say at 8%, the likelihood of a liquidation over the coming year is large at 10% to 30% depending on contract and position direction. However, with slightly higher margin levels, say 12%, the risk of liquidation in an 8-hour window is small. With higher volatility, Figure 10(c) and

[21]Calibrating using the coin-denominated futures price or the daily spot price from Federal Reserve Bank of St. Louis gives almost identical results.

[22]Mechanically, we scale to the annual equivalent assuming independent Bernoulli events. With probability of liquidation over any 8-hour period denoted p, the probability one or more liquidations happen over a year, p_{annual}, is calculated as $p_{annual} = 1 - (1 - p)^{1095}$.

(d), the 12% margin implies a high liquidation risk. Here, a margin of closer to 20% is needed to make liquidation risk minimal. In both examples, note the impact of contract type. At the same margin, long Tether contract has a lower risk than long a coin contract. In fact, in this example with the assumption that the drift in the underlying Bitcoin price is zero, $\mu = 0$, and that we set the funding rate $r = 0$, the probability of liquidation across contract types is symmetric.

6.2 Exchange Bankruptcy

Cryptocurrency exchange regulation is underdeveloped and ambiguous. Typically, customer margin deposits at a cryptocurrency exchanges are not covered by any program like the Federal Deposit Insurance Corporation (FDIC) or the Securities Investor Protection Corporation (SIPC). In bankruptcy, depositors are treated as unsecured creditors – it is not the case that customer margin balances are considered the "customer's property."[23] This is important since Cryptocurrency exchanges businesses are risky. There is a long list of prominent, high-volume exchanges that have failed: from MtGox in February of 2014 to FTX in November of 2022.[24]

The impact of exchange bankruptcy risk for the crypto carry trade depends on how the trade is executed. Recall, the trade is long a "physical" coin and short an exchange-traded perpetual futures contract. Storing the long coin on the exchange as margin is a convenient method of execution. However, that convenience comes with a large loss if the exchange fails. An execution strategy with less exchange exposure holds the long coin off of the exchange (in a wallet) and keeps the margin balance at the exchange small. To quantify the risk, implement the crypto carry trade so that the margin balance at the beginning of each period to be αF_t, where α is the margin ratio. Table 13 shows returns for a Tether-denominated contract and Table 14 shows returns for coin-denominated contract.[25] The returns depend on whether the exchange is solvent

[23] "Bad News for 500K Crypto Investors: They Don't Own Their Accounts," Slashdot, January 07, 2023, or "FTX's International Customers Lawyer Up, Ask Judge to Rule That Customer Assets Aren't Property of FTX Estate," Coindesk, December 30, 2022.

[24] Even prior to the MtGox failure in 2014, many exchanges failed. See Moore and Christin (2013).

[25] Tables 13 and 14 assume the margin position is sufficient to cover the perpetual position. Recall, that even for a modest level of α, the likelihood the on-exchange margin cannot cover trading losses of the on-exchange perpetual contract, requiring injecting more funds into the exchange, over the 8-hour window is small – see Figure 10(a)).

or bankrupt. As above, it is helpful to abstract from the basis risk and assume $F_t = P_t$ at each date and consider $\log F_{t+1}/F_t \sim N(\mu, \sigma^2)$. The log-approximation of the returns (last line in each Table 13 and 14) helps make things clearer. Letting λ represent the probability that the exchange goes bankrupt over the trading window, we can write the mean and variance of the crypto carry returns (for either the Tether or the coin contract) as

$$E[r_{t+1}] = r + \lambda(\mu - r - \alpha) \tag{14}$$

$$V(r_{t+1}) = \lambda(1-\lambda)(\mu - r - \alpha)^2 + \lambda\sigma^2 \tag{15}$$

The first term in the expected return is the the funding rate. The second term captures that, in exchange bankruptcy, the funding is not paid, the margin (α) is lost, and the off-exchange long position is not hedged (μ is the expected return on the underlying cryptocurrency). The variance of the return reflects two components. The first component reflects the risk from the lost funding and margin. The second term is the risk from the naked long position that occurs when the perpetual futures contract hedge is lost due to the exchange bankruptcy.

To quantify the impact of exchange bankruptcy risk, we calibrate an example where, in the absence of exchange bankruptcy risk, the (annual) Sharpe ratio of the crypto carry trade is approximately the sample average value of 5 for both the Tether and coin denominated contracts. Starting with both contracts at the same value will isolate the impact of exchange risk across the contract types. Set funding to $r = 0.0103\%$ per period (or 11.25%per year). The funding rate calibrates the x component in equation (3). We set the "basis risk," the y component in equation (4) to 0.000604 per period (or 0.0200 per year). In the event of bankruptcy, we assume the long position is exposed for the whole eight-hour period. This is captured as $\log F_{t+1}/F_t \sim N(\mu, \sigma^2)$. We consider a "normal" scenario with $\mu = 0$ and an average volatility of $\sigma = 0.0203$ per period (0.6729 per year). Second we consider a distressed market with higher volatility, $\sigma = 0.0400$ per period (1.3237 per year). This is the 99th percentile from a seven-day rolling volatility calculation. We also assume the market is falling and set $\mu = -0.0649$. That is -6.5% per period (or -7109% per year) and is the first percentile of BTC returns observed in our sample. For example, the return for the eight-hour window 2022-11-09 23:59:00, near to the day FTX declared bankruptcy, was -0.0730.

Figure 11 plots the Sharpe ratio of the crypto carry trade as a function of the bankruptcy likelihood, λ. To facilitate interpretation, λ is stated as an annual rate. That is, a $1 - \lambda$ chance that the exchange survived all $1,095$ eight-hour periods in a year. Figure 11(a) is for the Tether-denominated contact and Figure 11(b) is for the coin-denominated contract.[26] The impact of exchange bankruptcy is slightly smaller for the coin-denominated contract. This is because overall value of the position smaller. In the coin contract, part of the coin is used for margin. But this difference across the contract types is minor. The large impact comes from the lost margin, α, in bankruptcy. The difference in volatility across the two scenarios is minor. Almost all of the difference between the "normal" and "distressed and falling" scenarios is coming from the significant drop in the spot price for the now naked position in the underlying coin.

Empirically, we have documented that the Sharpe ratio for the crypto carry trade is large. How much does the risk of exchange bankruptcy dampen that conclusion? The dashed Figure 11(a) and (b) is at 0.3, roughly the Sharpe ratio on US equities. So if the carry trade is executed with a margin balance of $\alpha = 0.1$ and assumed the market was in the "distressed" market calibration, then a bankruptcy probability of 40% per year would set the carry trade Sharpe ratio to a value in line with US equities. That seems an overly large frequency of bankruptcy. At smaller levels of margin and less pessimistic assumptions for the spot market moments, the implied probability of exchange bankruptcy is much larger.

6.3 Systemic Risk

The previous section looked the likelihood an exchange may fail. But, of course, FTX did fail and file for bankruptcy on 2022-11-11. The collapse of FTX was a large event in cryptocurrency. It was the second largest exchange by volume at the time. However, during this period, there were several large institutional failures. Terra/Luna, a large stable coin, collapsed on 2022-05-09. The large crypto-focused hedge fund Three Arrows Capital filed for bankruptcy on 2022-06-22. Finally, the bankruptcy of Silicon Valley Bank occurred on 2023-03-10. Although Silicon Valley

[26]Calculations in Figure 11 use the "Log-Returns" line in Tables 13 and 14 and not the log-approximation.

Bank (SVB) was not itself a cryptocurrency institution, its collapse had a large impact on the stable coin USDC since the company backing that coin had significant deposits at SVB.

Figure 12 shows spot and derivative volume (across many exchanges) through this period. Each of the four crisis events coincides with an increase in spot and derivative trading volume. In Figure 13 we see the BTC price volatility that co-occurs with these events. The usual asset pricing model would interpret the price changes as changes in the outlook for cryptocurrencies – beliefs are less optimistic or more pessimistic. The crypto carry trade return around these events offers a different insight. Recall, in Section 4, the future's price is pinned to the spot price. At that (say, now lower) price, the demands of long and short traders are equated through the funding rate. That funding rate could be lower or higher. This is analogous to the slope of the futures curve in traditional dated-futures contracts. When the spot oil price falls, the dated-futures price could fall by more or less. As we saw in Tables 4 and 5, the funding rate and the crypto carry trade return are not directly correlated to a falling spot price. So it is interesting we see in Table 5 (Epoch 5) that through this period of systemic crises that indeed the crypto carry trade return is lower.

Figures 14(a) and (b) shows the time series of the funding and basis components of the return (recall equations (3) and (4)). In Section 4 we assumed no basis risk ($F_t = P_t$) and solved for market-clearing funding rate. In practice, the funding rate is set with a mechanical formula that is a rate of 0.01% per eight-hour period plus an adjustment that depends on the traded perpetual futures price F_t through the basis, $\frac{F_t - P_t}{P_t}$. So both the funding and basis will reflect long and short demand in a period. Figure 14(b) shows the basis through this period. There you can see the increased variability of the basis around the listed events. The mean basis is around zero and this is consistent with the whole sample in Table 8. Empirically, $F_t \approx P_t$, and the funding rate drives the crypto carry return. The funding rates in this period are, in general lower. In Figure 14(a) we see that the funding rate (the key component in x_t equation (3)) clusters lower around each of these events. In addition, there were a few very low funding rates that coincide with the FTX and SVB events. On Figure 14(a) note that -0.0010 or negative 0.1% per 8 hours is negative 113% per year. These very low rates were short-lived, but are notable in size.

The smaller funding rates reflect the smaller net-demand for long positions. Presumably some of this is from long-side traders reducing leverage or exiting. In particular, some of the reduction comes from traders being liquidated (margin balance dips to zero) – liquidations are correlated with price drops (Soska, Dong, Khodaverdian, Zetlin-Jones, Routledge, and Christin (2021)). It will be interesting to investigate, perhaps using account-level data, if the few very large negative levels of funding are associated with a few large accounts or if it was more widespread short positions.

7 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 large challenge with both a quickly changing landscape and ambiguity about agency domain.[27]. In addition, and more specifically to exchanges, there is yet little understanding of who is trading in these markets and why. In this paper, use the returns to the crypto carry trade to suggest that, for much of the period we study, there is a large appetite for leverage to be long cryptocurrency exposure. The strength of that demand seems particularly relevant as regulators in the United States and elsewhere consider the role of derivative markets in cryptocurrency.

[27]For example, "Coinbase, Tarred as an Illicit Exchange by the SEC, Quietly Got Regulated Elsewhere in the U.S." Coindesk 2023-08-17 https://www.coindesk.com/policy/2023/08/17/coinbase-tarred-as-an-illicit-exchange-by-the-sec-quietly-got-regulated-elsewhere-in-the-us underscores the difference in regulation from the CFTC and the SEC.

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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	14.26%	1.63%	8.763
Carry Trade - Coin	10.86%	2.20%	4.929
Long Spot (Perpetual Index Price)	32.61%	67.30%	0.485
Long Spot (Coin Index Price)	31.22%	67.57%	0.462
US Equities	6.50%	19.83%	0.328

The Mean and Standard Deviation are for excess returns (the return in excess of the risk-free rate). The Sharpe Ratio is the Mean divided by the Standard Deviation. All moments are converted to be annual rates. 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 – 2023-06-22 (N=3138). US Equities is the excess return over the same period is from Ken French/CRSP.The risk-free rate for calculating excess returns is the one-month U.S. Treasury bond – DGS1MO from FRED.

Table 4: Trading Strategy Returns

8 hour funding window - annualized

Strategy	Mean	Std	Sharpe	n
Up 1: 2021-01-26 – 2021-02-20				
Carry Trade - Tether	86.44%	3.18%	27.147	75
Carry Trade - Coin	62.42%	3.47%	17.979	75
Long Spot	799.90%	103.38%	7.737	75
Down 1: 2021-05-07 – 2021-05-22				
Carry Trade - Tether	50.80%	3.47%	14.624	45
Carry Trade - Coin	43.74%	4.88%	8.967	45
Long Spot	−1,010.63%	120.71%	−8.373	45
Up 2: 2021-09-27 – 2021-10-18				
Carry Trade - Tether	11.27%	1.34%	8.422	63
Carry Trade - Coin	9.76%	1.50%	6.515	63
Long Spot	616.51%	61.19%	10.076	63
Down 2: 2021-11-08 – 2021-12-05				
Carry Trade - Tether	20.07%	1.63%	12.291	81
Carry Trade - Coin	14.06%	1.62%	8.690	81
Long Spot	−340.58%	79.57%	−4.280	81
Down 3: 2022-04-10 – 2022-06-21				
Carry Trade - Tether	4.00%	1.01%	3.946	216
Carry Trade - Coin	0.63%	1.14%	0.556	216
Long Spot	−371.30%	77.05%	−4.819	216

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 – 2023-06-22 (N=3138).

Table 5: Trading Strategy Returns
8 hour funding window - annualized

Strategy	Mean	Std	Sharpe	n
Epoch 1: 2020-08-11 – 2021-04-14				
Carry Trade - Tether	38.93%	2.29%	17.005	738
Carry Trade - Coin	29.82%	3.29%	9.059	738
Long Spot	250.70%	74.73%	3.355	738
Epoch 2: 2021-04-14 – 2021-07-19				
Carry Trade - Tether	19.54%	2.30%	8.489	288
Carry Trade - Coin	15.02%	2.68%	5.613	288
Long Spot	−263.44%	92.26%	−2.855	288
Epoch 3: 2021-07-19 – 2021-11-07				
Carry Trade - Tether	14.64%	1.50%	9.751	333
Carry Trade - Coin	10.61%	2.82%	3.765	333
Long Spot	216.84%	66.14%	3.278	333
Epoch 4: 2021-11-08 – 2022-05-08				
Carry Trade - Tether	7.70%	1.20%	6.420	543
Carry Trade - Coin	7.95%	1.22%	6.526	543
Long Spot	−116.75%	64.10%	−1.821	543
Epoch 5: 2022-05-09 – 2023-06-23				
Carry Trade - Tether	1.03%	0.78%	1.312	1230
Carry Trade - Coin	0.01%	1.05%	0.007	1230
Long Spot	−15.10%	56.18%	−0.269	1230

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 – 2023-06-22 (N=3138).

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

Percentile	Tether	Coin
0.00	−0.119%	−0.300%
0.01	−0.018%	−0.028%
0.02	−0.013%	−0.020%
0.10	−0.002%	−0.006%
0.20	0.002%	0.000%
0.30	0.005%	0.004%
0.40	0.009%	0.008%
0.50	0.010%	0.010%
0.60	0.010%	0.010%
0.70	0.010%	0.010%
0.80	0.010%	0.010%
0.90	0.039%	0.026%
0.98	0.106%	0.093%
0.99	0.128%	0.110%
1.00	0.249%	0.186%

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 – 2023-06-22 (N=3138).

Table 7: Futures to Spot Basis - Deciles

percent of spot

Percentile	Tether	Coin
0.00	−0.961%	−0.961%
0.01	−0.109%	−0.109%
0.02	−0.093%	−0.093%
0.10	−0.066%	−0.066%
0.20	−0.056%	−0.056%
0.30	−0.048%	−0.048%
0.40	−0.040%	−0.040%
0.50	−0.032%	−0.032%
0.60	−0.020%	−0.020%
0.70	−0.001%	−0.001%
0.80	0.032%	0.032%
0.90	0.075%	0.075%
0.98	0.136%	0.136%
0.99	0.170%	0.170%
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 – 2023-06-22 (N=3138).

Table 8: Carry Trade - Decomposition - BTC

Simple returns (Annualized Return is Approximated)

R	Tether Per.Period	Tether Per.Year	Coin Per.Period	Coin Per.Year
Mean				
1. mean x	0.0131%	14.3%	0.0094%	10.3%
2. mean y	−0.0000%	−0.0%	0.0005%	0.5%
3. mean x+y	0.0130%	14.3%	0.0099%	10.9%
St. Deviation				
4. sd x	0.0267%	0.9%	0.0243%	0.8%
5. sd y	0.0389%	1.3%	0.0595%	2.0%
6. sd(x+y)-sd(x)-sd(y)	−0.0164%	−0.5%	−0.0171%	−0.6%
7. sd(x+y)	0.0492%	1.6%	0.0666%	2.2%

The excess return from the crypto-carry trade return $x + y$ is decomposed into the funding x (equation (3)) and the change-in-basis y (equation (4)). 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 – 2023-06-22 (N=3138).

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	14.3%	1.6%	8.76	10.8%	2.2%	4.92	31.3%	67.3%	0.47	3139
LTC	Litecoin	21.2%	2.5%	8.45	15.8%	3.0%	5.33	19.3%	99.5%	0.19	3054
LINK	Chainlink	22.2%	2.8%	7.90	15.2%	4.3%	3.54	−37.7%	113.8%	−0.33	3114
ETH	Ethereum	17.0%	2.3%	7.33	11.8%	2.7%	4.37	50.5%	86.9%	0.58	3118
EOS	EOS	20.6%	3.0%	6.85	16.4%	4.2%	3.92	−52.1%	108.5%	−0.48	3057
ADA	Cardano	18.1%	2.7%	6.58	13.9%	3.8%	3.68	32.6%	104.5%	0.31	3092
DOGE	Dogecoin	18.7%	3.1%	6.10	20.5%	4.2%	4.90	26.8%	130.4%	0.21	2614
DOT	Polkadot	15.1%	3.0%	5.07	18.2%	4.2%	4.37	0.0%	113.5%	0.00	3096
EGLD	Elrond	21.2%	4.3%	4.90	15.2%	6.2%	2.46	6.6%	119.8%	0.06	2737
THETA	THETA	14.6%	3.0%	4.83	10.3%	5.6%	1.83	−132.3%	120.9%	−1.09	2399
UNI	Uniswap	12.3%	2.6%	4.81	6.7%	4.3%	1.58	−92.9%	113.2%	−0.82	2397
XLM	Stellar	8.9%	2.6%	3.44	14.3%	3.8%	3.80	−90.9%	91.4%	−0.99	2394
XRP	XRP (Ripple)	19.8%	6.3%	3.13	14.5%	6.2%	2.33	25.1%	113.2%	0.22	3051
ETC	Ethereum Classic	10.1%	4.1%	2.45	14.3%	4.3%	3.35	42.1%	115.5%	0.36	3052
BCH	Bitcoin Cash	10.3%	4.9%	2.12	9.5%	21.1%	0.45	−18.2%	96.6%	−0.19	3053
TRX	TRON	4.7%	3.3%	1.42	2.5%	5.3%	0.47	29.5%	91.2%	0.32	3058
FIL	Filecoin	9.7%	9.7%	0.99	13.6%	10.4%	1.30	−69.3%	118.7%	−0.58	2913
BNB	Binance Coin	0.2%	3.5%	0.05	0.4%	4.3%	0.10	82.5%	93.9%	0.88	3106

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 – 2023-06-22 (N=3138). The n is the sample for each coin as some were listed during the sample period.

Table 10: Carry Trade - Decomposition - BNB
Simple returns (Annualized Return is Approximated)

R	BTC Coin Per.Year	BTC Tether Per.Year	BNB Coin Per.Year	BNB Tether Per.Year
1. mean x	10.3%	14.3%	−2.4%	−0.7%
2. mean y	0.5%	−0.0%	3.0%	0.9%
3. mean x+y	10.9%	14.3%	0.5%	0.2%
4. sd x	0.8%	0.9%	1.8%	1.8%
5. sd y	2.0%	1.3%	3.6%	2.9%
6. sd(x+y)-sd(x)-sd(y)	−0.6%	−0.5%	−1.1%	−1.2%
7. sd(x+y)	2.2%	1.6%	4.3%	3.5%

The excess return from the crypto-carry trade return $x + y$ is decomposed into the funding x (equation (3)) and the change-in-basis y (equation (4)). 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 – 2023-06-22 (N=3138).

Table 11: Trading Strategy Returns
8 hour funding window - annualized

Tic	Strategy	Mean	Std	Sharpe	n
Higher Leverage Era: 2020-07-23 – 2021-07-23					
BTC	Carry Trade - Tether	32.97%	2.30%	14.328	1038
BTC	Carry Trade - Coin	25.29%	3.38%	7.476	1038
ETH	Carry Trade - Tether	44.55%	3.40%	13.083	1017
ETH	Carry Trade - Coin	32.13%	4.09%	7.849	1017
Lower Leverage Era: 2021-07-24 – 2022-07-23					
BTC	Carry Trade - Tether	8.96%	1.27%	7.049	1092
BTC	Carry Trade - Coin	6.31%	1.35%	4.675	1092
ETH	Carry Trade - Tether	8.33%	1.41%	5.924	1092
ETH	Carry Trade - Coin	6.86%	1.64%	4.176	1092

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: Carry Trade - Correlation

Correlation of Coin and Tether Contract for each Crypto

Tic	correlation
XRP	0.794
FIL	0.767
ETH	0.676
BNB	0.625
BTC	0.573
LTC	0.529
DOT	0.508
DOGE	0.497
TRX	0.480
ADA	0.451
LINK	0.437
ETC	0.425
UNI	0.422
EGLD	0.413
XLM	0.359
EOS	0.333
THETA	0.326
BCH	0.116

Correlations of crypto carry trade returns on a Tether-denominated contract and a coin-denominated contract. The Carry Trade results are for contracts at 8-hour intervals. Data is from Binance Bitcoin (BTC): 2020-08-11 – 2023-06-23 (N=3139).

Table 13: Tether Denominated and Settled - Exchange Risk

(a) Cash-Flows On and Off Exchange (Tether Contract)

	$t=0$		$t=1$		
	Off	On	Off	On Solvent	On Bankrutpt
Buy one "physical" coin	$-F_t$		F_{t+1}		
Exchange Margin (in Tether)		$-\alpha F_t$		αF_t	0
Perpetual Future				$(F_t - F_{t+1}) + rF_t$	0
	$-F_t$	$-\alpha F_t$	F_{t+1}	$(F_t - F_{t+1}) + (r+\alpha)F_t$	0

(b) Combined Cash-Flows (Tether Contract)

	$t=0$	$t=1$	
		Solvent	Bankrupt
Combined Cash Flows	$-(1+\alpha)F_t$	$F_t(1+\alpha+r)$	F_{t+1}
(Log) Returns		$\log(1+\alpha+r)$ $-\log(1+\alpha)$	$\log\frac{F_{t+1}}{F_t}$ $-\log(1+\alpha)$
(Approx Log) Returns		r	$\log\frac{F_{t+1}}{F_t} - \alpha$

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) under the assumption that there is no basis risk ($P_t = F_t$ and $P_{t+1} = F_{t+1}$). The long coin position is held off the exchange. A margin balance with margin rate α, the trading gains and losses on the perpetual future, and the exchange funding rate, r, are held inside the exchange. In the event the exchange is bankrupt at date one, these cash flows are zero. This table abstracts from margin "liquidation" where on-exchange margin is insufficient to cover losses on the perpetual future. Table (b) combines the on and off exchange.

Table 14: Coin Denominated and Settled - Exchange Risk

(a) Cash-Flows On and Off Exchange (Coin-Denominated Contract)

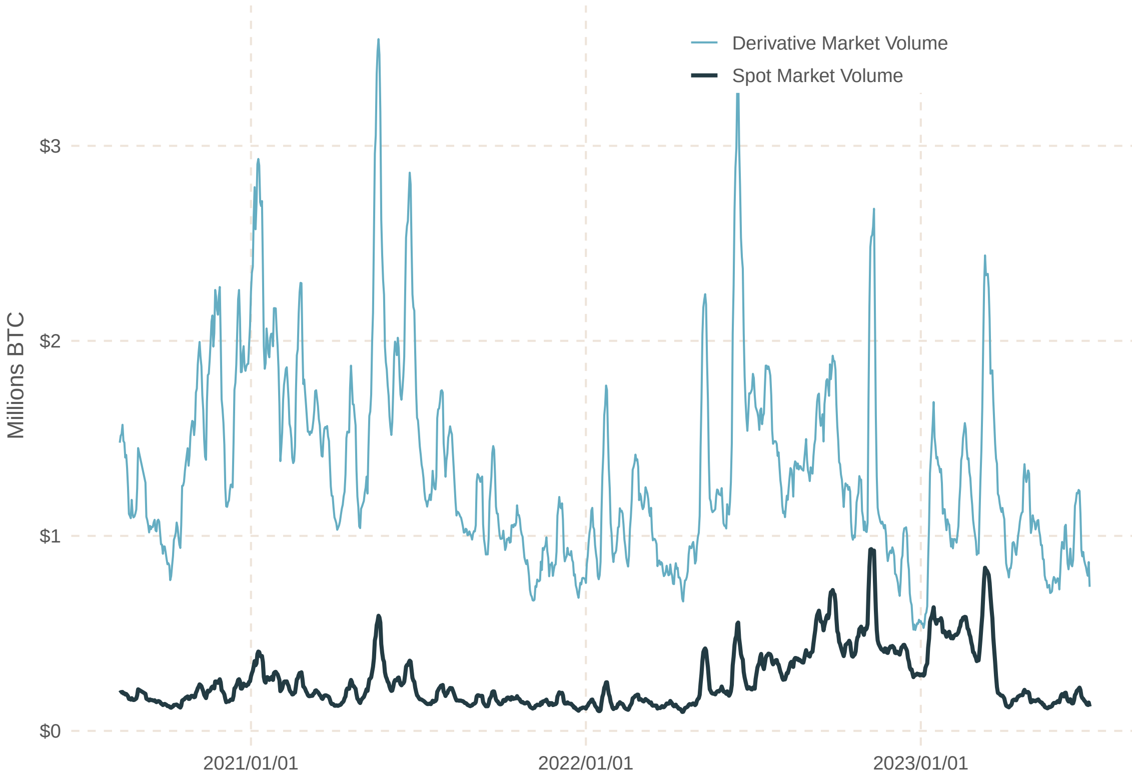
	$t=0$ Off	$t=0$ On	$t=1$ Off	$t=1$ On Solvent	$t=1$ On Bankrupt
Buy $(1-\alpha)$ "physical" coin	$-(1-\alpha)F_t$		$(1-\alpha)F_{t+1}$		
Exchange Margin		$-\alpha F_t$		αF_{t+1}	0
$F_t/(1+r_{t,c})$ Perpetual Future				$\frac{1}{1-r}F_t - F_{t+1}$	0
	$-(1-\alpha)F_t$	$-\alpha F_t$	$(1-\alpha)F_{t+1}$	$\frac{1}{1-r}F_t$ $-(1-\alpha)F_{t+1}$	0

(b) Combined Cash-Flows (Coin-Denominated Contract)

	$t=0$	$t=1$ Solvent	$t=1$ Bankrupt
Combined Cash Flows	$-(1+\alpha)F_t$	$F_t(1+\alpha+r)$	F_{t+1}
(Log) Returns		$\log(1+\alpha+r)$ $-\log(1+\alpha)$	$\log\frac{F_{t+1}}{F_t}$ $-\log(1+\alpha)$
(Approx Log) Returns		r	$\log\frac{F_{t+1}}{F_t}-\alpha$

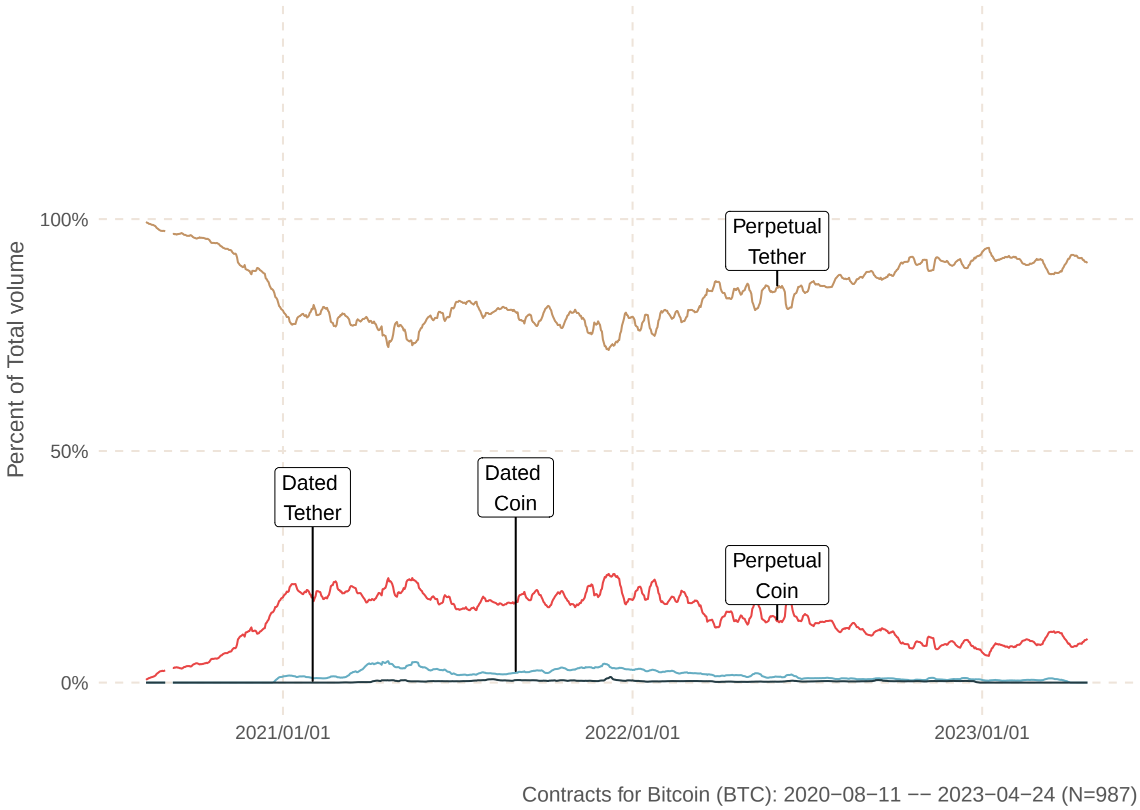
The cash-flows from the positions established at date $t=0$ are realized at date $t=1$ (a period in our empirical analysis is 8 hours) under the assumption that there is no basis risk ($P_t = F_t$ and $P_{t+1} = F_{t+1}$). The long coin position is held off the exchange. A margin balance with margin rate α (held in coin), the trading gains and losses on the perpetual future, and the exchange funding rate, r, are held inside the exchange. In the event the exchange is bankrupt at date one, these cash flows are zero. This table abstracts from margin "liquidation" where on-exchange margin is insufficient to cover losses on the perpetual future. Table (b) combines the on and off exchange.

Figure 1: Spot and Derivative Markets Trading Volume



The trading volume 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 measured in BTC. Data is plotted from 2020-08-11, the start of our crypto carry trade data.

Figure 2: Derivative Markets Trading Volume by Contract Type

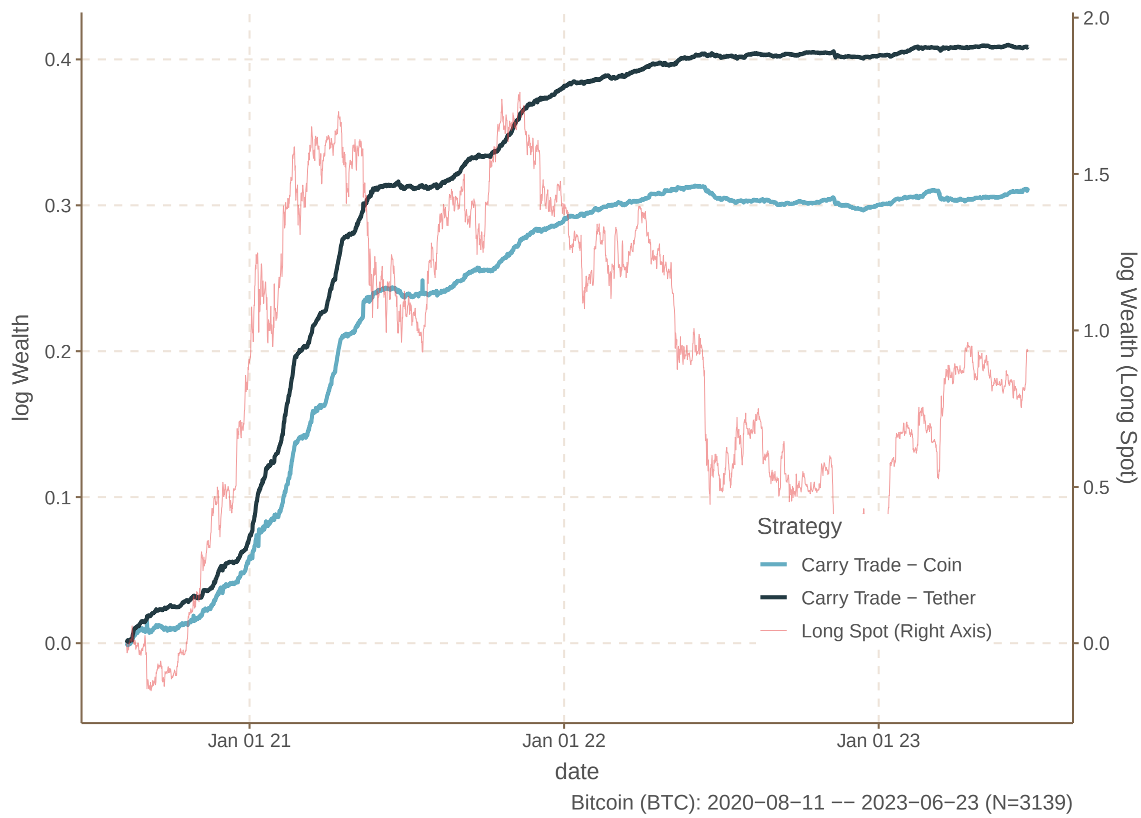


The plots show the daily proportion of the total Bitcoin (BTC) trading volume on Binance by contract type. Volume statistics are 7-day centered moving average measured in BTC. By construction, the sum at each day is 100%. Shown is the perpetual futures contract settled in Tether, and the perpetual futures contract settled in coin (BTC). The finitely-dated futures contracts are aggregated for open contracts (approximately three-month horizon) in both Tether denominated and coin (BTC). Coincidentally, the Perpetual Coin-Settled Bitcoin contract began trading August 10, 2020, one day ahead of our sample start date.

Figure 3: Bitcoin (BTC) Price

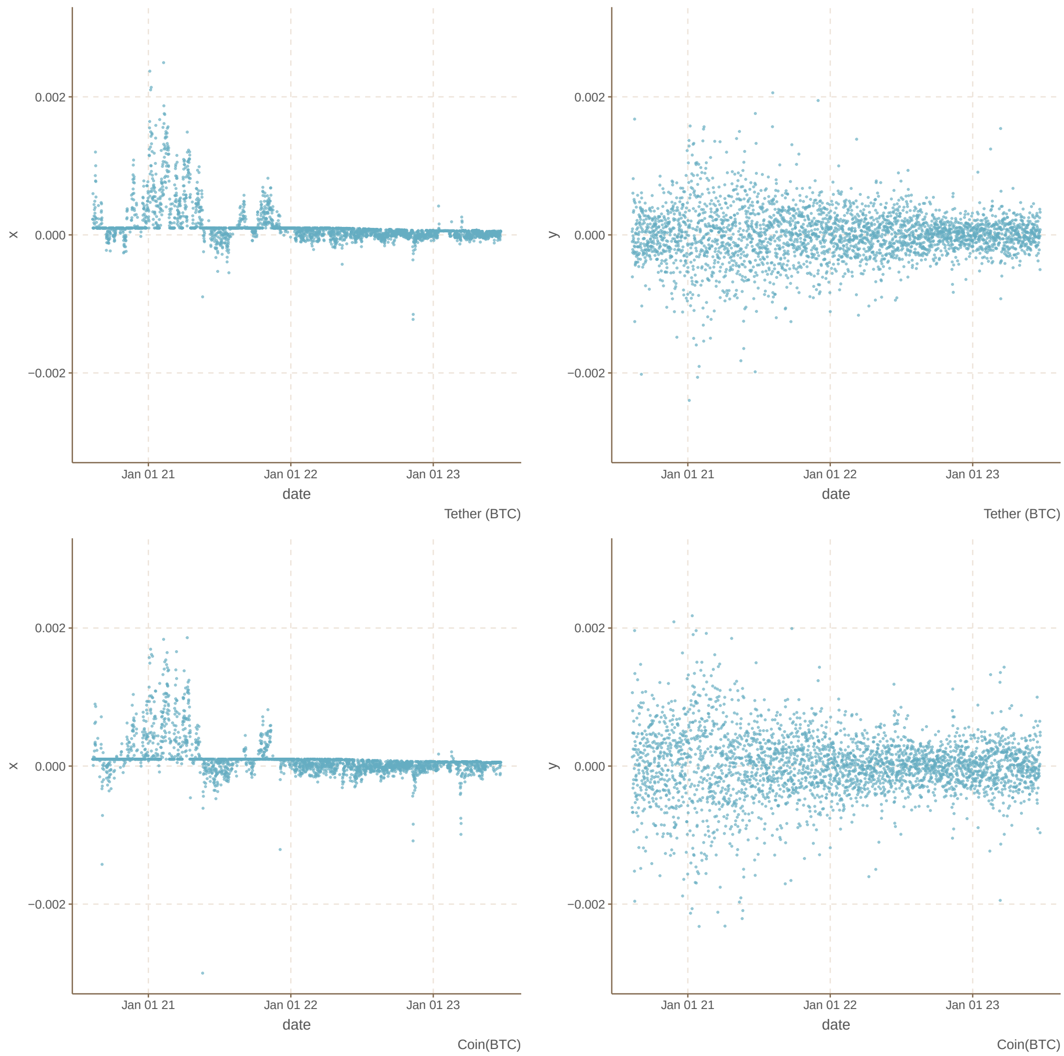
Coinbase Index Price of Bitcoin (BTC). Data is from the Federal Reserve Bank of St. Louis. The shaded regions highlight the subsamples presented in Tables 5.

Figure 4: Carry Trade – Cumulative Returns



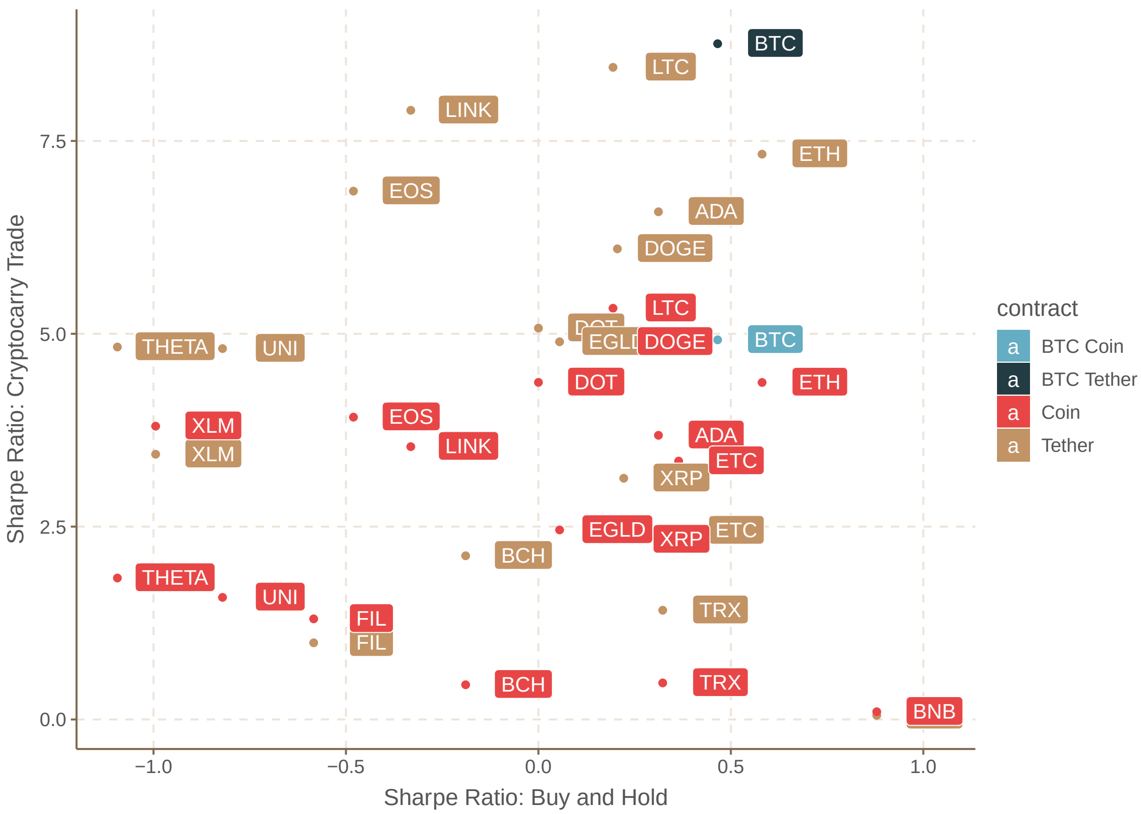
Cumulative Returns from Tether and Coin Carry Trades (i.e., the log wealth from a $1.00 initial investment). The right-scale shows the cumulative returns from an long buy-and-hold investment in Bitcoin. The Carry Trade is defined in Table 1 for "Tether Contract" and in Table 2 for the "Coin Contract."

Figure 5: Carry Trade – Return Components



The excess return from the crypto-carry trade return $x + y$ is decomposed into the funding x (equation (3)) and the change-in-basis y (equation (4)) . Returns in this figure are simple returns. Shown here is the Tether-based contract (top row) and Coin-based contract (bottom row) for BTC. Dates: 2020-08-11 – 2023-06-23.

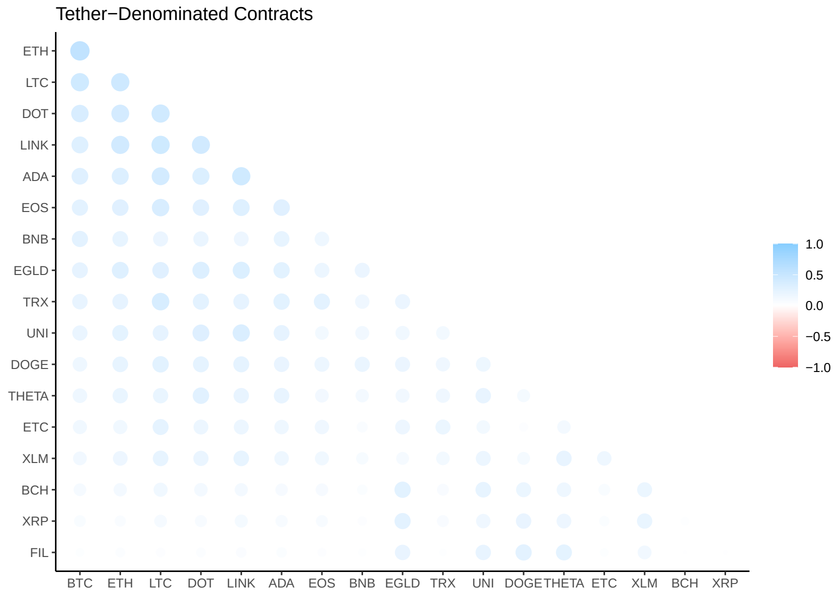
Figure 6: Carry Trade – Sharpe Ratio



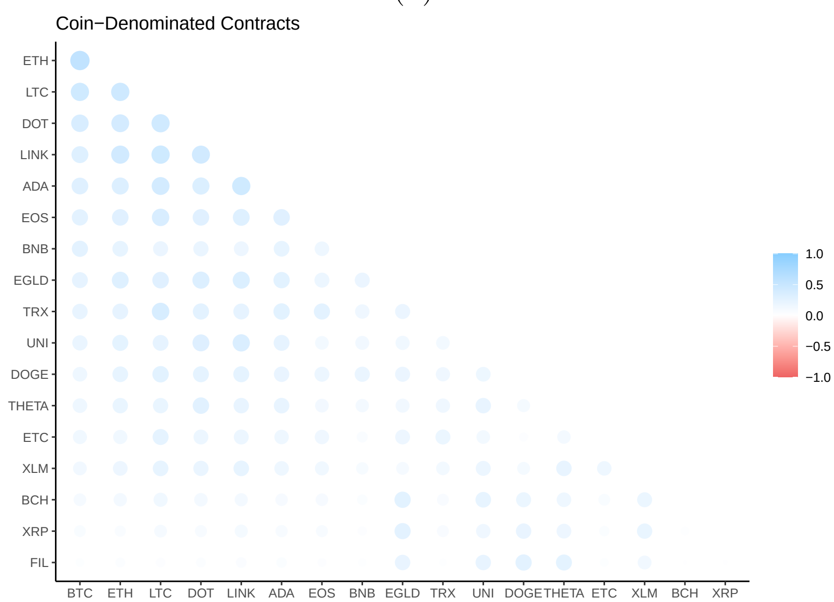
Sharpe Ratio for returns from Tether and Coin Carry Trades versus Sharpe Ration of returns from buy-and-hold the underlying coin. The right-scale shows the cumulative returns from an long buy-and-hold investment in Bitcoin. The Carry Trade is defined in equation (1) for "Tether Contract" and in equation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

Figure 7: Carry Trade Return Correlation

(a)

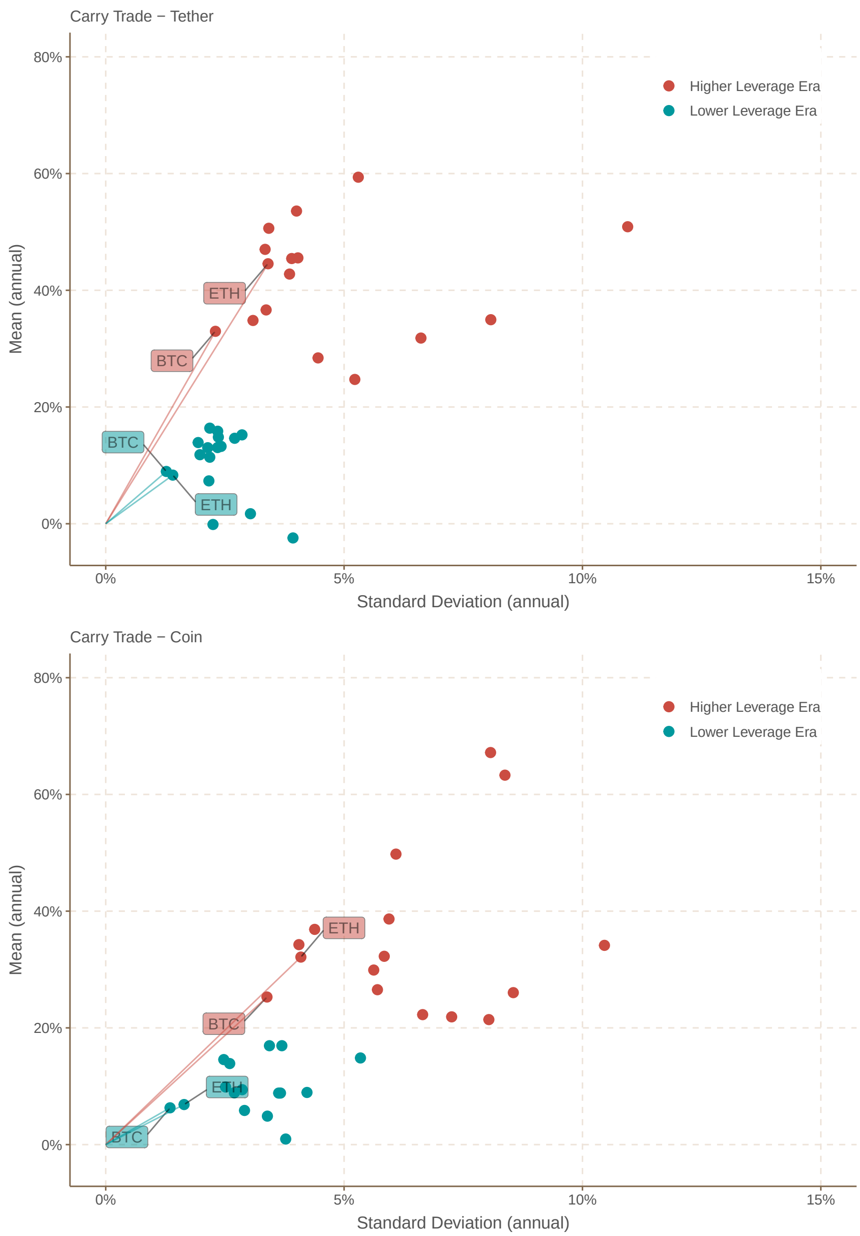


(b)



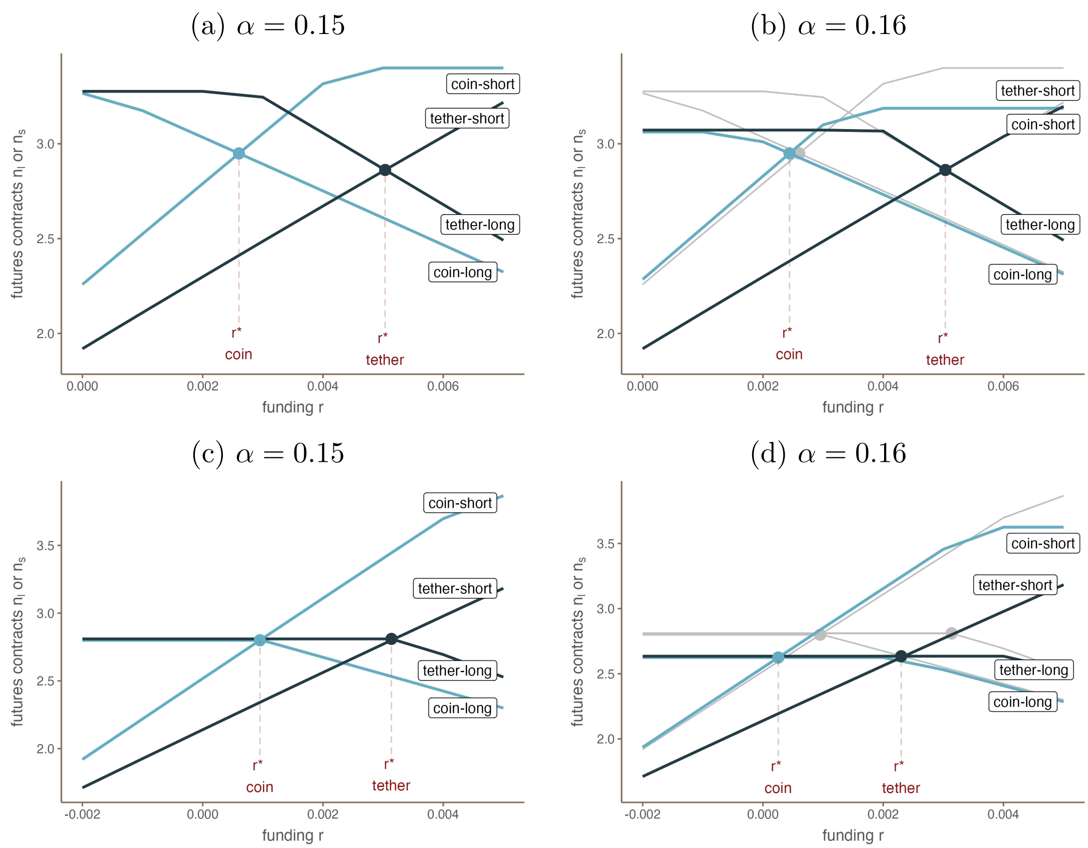
Crypto carry trade return correlations across underlying cryptocurrency. Plot (a) is for Tether-denominated contracts and plot (b) is for coin-denominated contracts. Sharpe Ratio for returns from Tether and Coin Carry Trades versus Sharpe Ration of returns from buy-and-hold the underlying coin. The Carry Trade is defined in equation (1) for "Tether Contract" and in equation (2) for the "Coin Contract." Data range is: 2020-08-11 – 2023-06-23.

Figure 8: Carry Trade – Mean and Standard Deviation – Across Leverage Eras



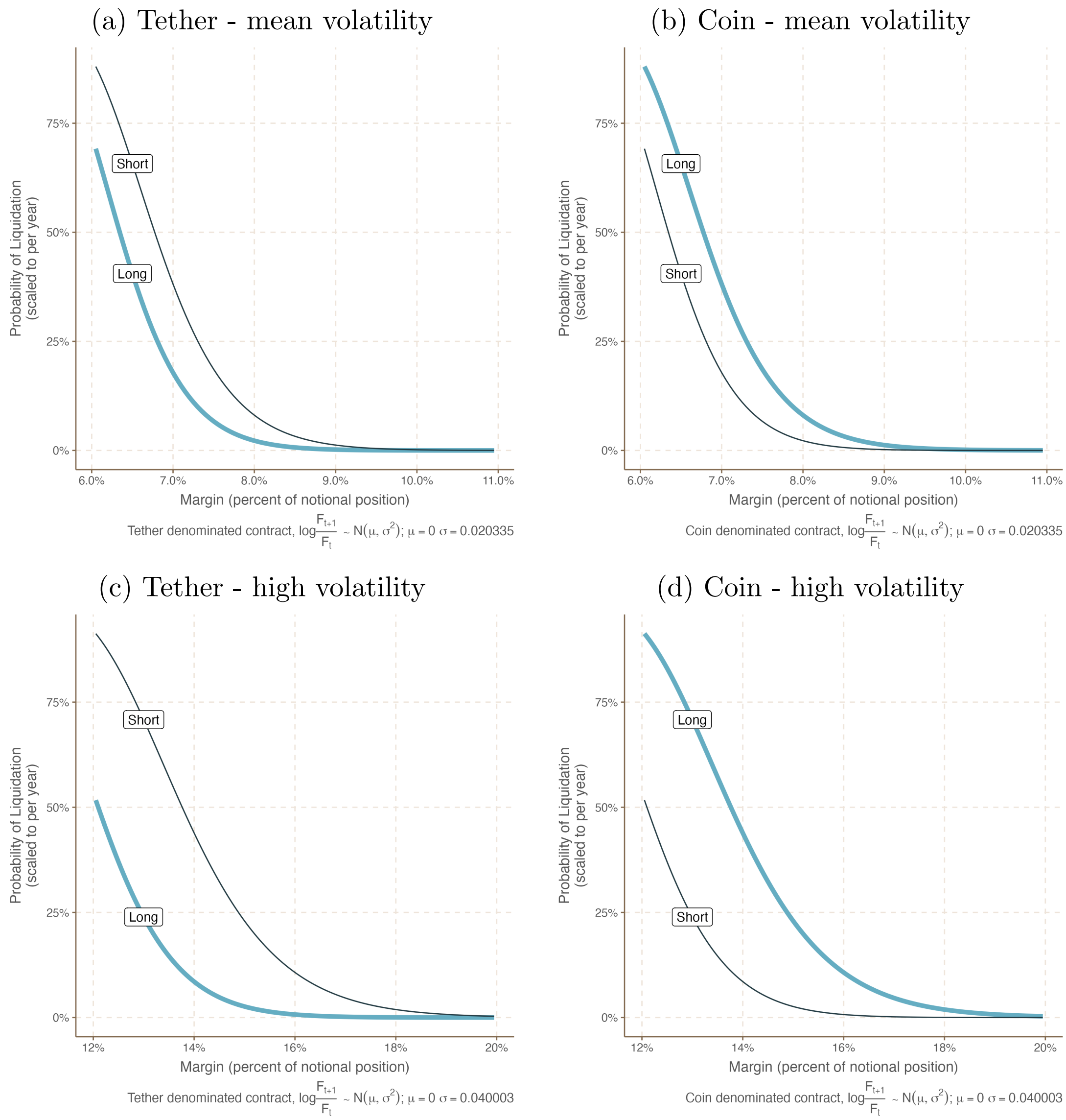
The Higher Leverage Era (125x) is from the start of our sample to 2021-07-23. The Lower Leverage Era (50x) is from 2021-07-24 to the end our our sample. The sample standard deviation and mean for the strategy return for each coin are shown. The ray from the origin for each point is the sample Sharpe 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 – 2023-06-23.

Figure 9: Market-Clearing Funding Rate



The example is parameterized as follows. $\log \frac{F_1}{F_0} \sim N(\mu, \sigma)$ setting and $\sigma = 0.0203$ – an 8-hour volatility (equivalent to a 0.6729 per year). There are two types of traders with $\mu_a = 0.02$ (long) and $\mu_b = -0.01$ (short). In Figurers (a) and (b), the exchange policy minimum margin, α, is not binding, the wealth weights are $w_a = 0.49$ and $w_b = 0.51$. In Figures (c) and (d), the minimum margin, α, is binding for long traders, the wealth weights are $w_a = 0.42$ and $w_b = 0.58$. In Figures (a) and (c), the exchange minimum margin policy is $\alpha = 0.15$. In Figures (b) and (d), the exchange minimum margin policy is $\alpha = 0.16$. Preference of all traders are $u(W_1) = 1/\gamma(c + W_1)^\gamma$ with $\gamma = -6.5$ and $c = 0.1$.

Figure 10: Margin and Liquidation Probability

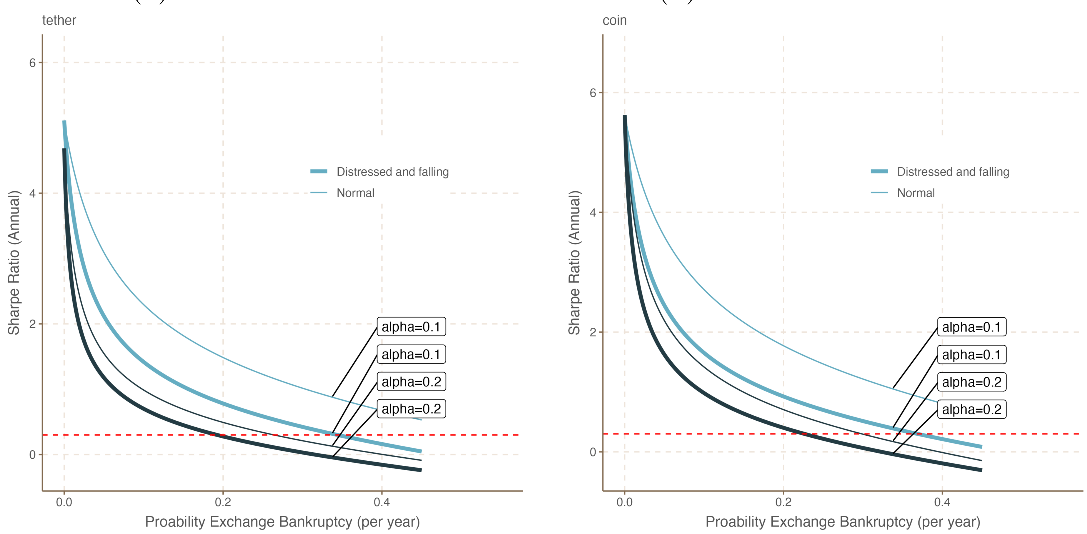


Probability of liquidation is calculated from $\log \frac{F_{t+1}}{F_t} \sim N(\mu, \sigma^2)$ using equations (10), (11) for the Tether denominated contracts in panels (a) and (c) and equations (12) and (13) for the coin denominated contracts in panels (b) and (d). In all cases, the mean spot return is $\mu = 0$. In panels (a) and (b) the volatility is calibrated to the BTC sample mean of $\sigma = 0.0203$ (equivalent to 0.6729 per year). In panels (c) and (d), $\sigma = 0.0400$ (1.3237 per year), the 99th percentile from a rolling seven-day rolling volatility. Funding is set to $r = 0$. The threshold for liquidation is a margin balance of zero. The probability of liquidation per period, p, are converted to an annual equivalent assuming $1095 = 365 \times 3$ independent 8-hour Bernoulli events per year. p_{annual} is calculated as $p_{annual} = 1 - (1 - p)^{1095}$ with p_{annual} representing the probability of one or more liquidations in the next year.

Figure 11: Exchange Bankruptcy Implications

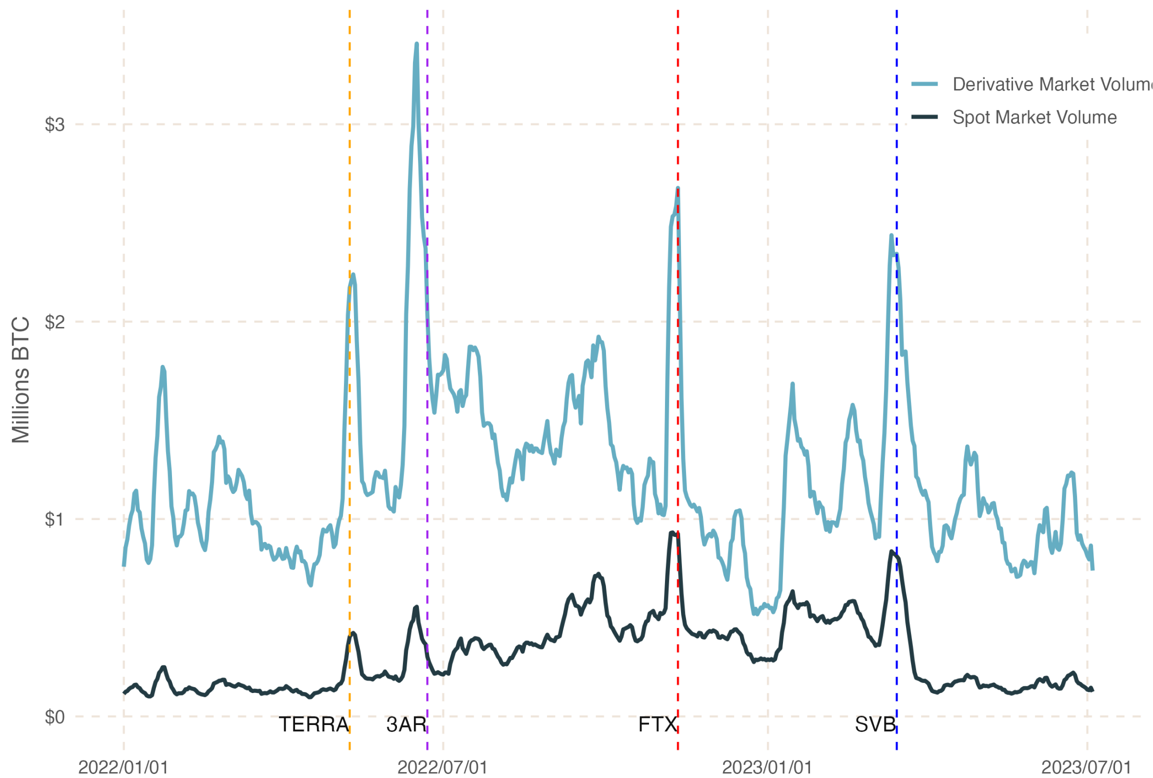
(a) Tether Contract

(b) Coin-Based Contract



The moments of excess returns are calculated from the cash-flows described in Tables 13 and 14. The funding rate (equation (3)) $r = 0.0103\%$ per period (or 11.25%per year). The "basis risk" (equation (4)) is 0.000604 per period (or 0.0200 per year). $\log F_{t+1}/F_t \sim N(\mu, \sigma^2)$. "Normal" scenario has $\mu = 0$ and $\sigma = 0.0203$ per period (0.6729 per year). "Distressed and Falling" has $\mu = -0.0649$ (-71.0865 per year) and $\sigma = 0.0400$ per period (1.3237 per year). The dashed horizontal reference line is at a value of 0.3, the approximate Sharpe ratio of U.S. equities.

Figure 12: Spot and Derivative Markets Trading Volume - Crisis Era



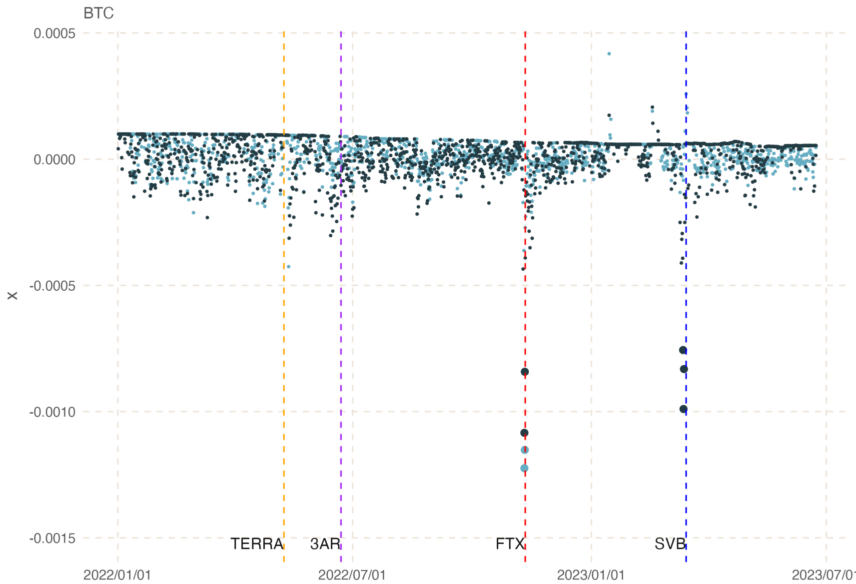
The trading volume is aggregated from the data feeds of exchanges: FTX, Binance, Okex, Huobi, Bitmex, Coinbase, Kraken, Bitstamp, Bybit and Deribit. The derivative volume is the contract's notional value. Volume statistics are 7-day centered moving average measured in BTC. The reference lines shown are for the dates of failure of Terra/Luna, Three Arrows Capital, FTX, and Silicon Valley Bank.

Figure 13: BTC Price - Crisis Era

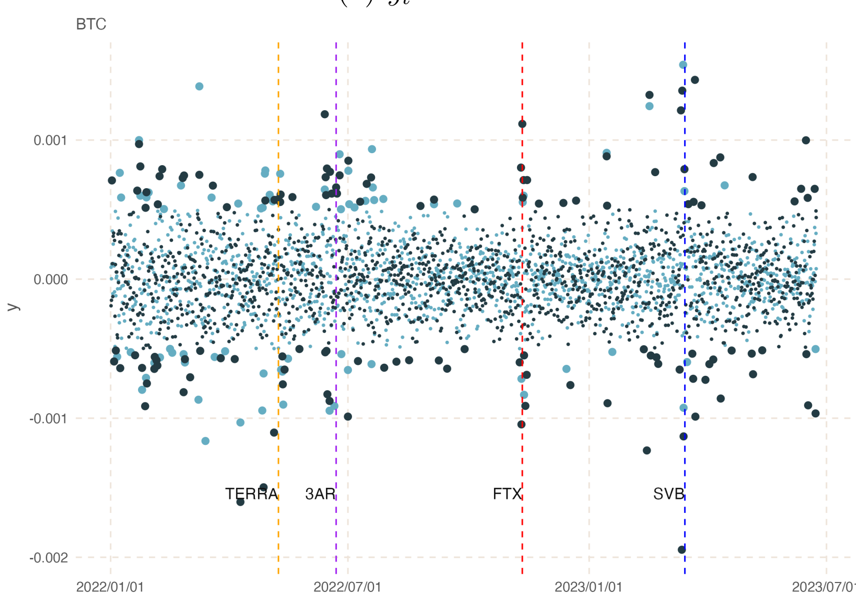
The spot index price for Tether denominated BTC contract at 8-hour intervals. (Virtually identical to index for coin denominated contract or Coinbase index). The reference lines shown are for the dates of failure of Terra/Luna, Three Arrows Capital, FTX, and Silicon Valley Bank.

Figure 14: Carry Trade – Return Components

(a) x_t – Funding



(a) y_t – Basis



The excess return from the crypto-carry trade return for BTC $x + y$ is decomposed into the funding x (equation (3)) and the change-in-basis y (equation (4)). The lighter dots are for Tether-denominated contracts. The darker dots are the coin-denominated contract. Observations that are larger are highlighted with a larger sized dot. The reference lines shown are for the dates of failure of Terra/Luna, Three Arrows Capital, FTX, and Silicon Valley Bank.