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RISKS AND DRAWDOWNS

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ABSTRACT

We examine carry trade returns formed from the G10 currencies. Performance attributes depend on the base currency. Dynamically spread-weighting and risk-rebalancing positions improves performance. Equity, bond, FX, volatility, and downside equity risks cannot explain profitability. Dollar-neutral carry trades exhibit insignificant abnormal returns, while the dollar exposure part of the carry trade earns significant abnormal returns with little skewness. Downside equity market betas of our carry trades are not significantly different from unconditional betas. Hedging with options reduces but does not eliminate abnormal returns. Distributions of drawdowns and maximum losses from daily data indicate the importance of time-varying autocorrelation in determining the negative skewness of longer horizon returns.

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1 Introduction

This paper examines some empirical properties of the carry trade in international currency markets. The carry trade is defined to be an investment in a high interest rate currency that is funded by borrowing a low interest rate currency. The 'carry' is the ex ante observable positive interest differential. The return to the carry trade is uncertain because the exchange rate between the two currencies may change. The carry trade is profitable when the high interest rate currency depreciates relative to the low interest rate currency by less than the interest differential.[1]By interest rate parity, the interest differential is linked to the forward premium or discount. Absence of covered interest arbitrage opportunities implies that high interest rate currencies trade at forward discounts relative to low interest rate currencies, and low interest rate currencies trade at forward premiums. Thus, the carry trade can also be implemented in forward foreign exchange markets by going long in currencies trading at forward discounts and by going short in currencies trading at forward premiums. Such forward market trades are profitable as long as the currency trading at the forward discount depreciates less than the forward discount.

Carry trades are known to have high Sharpe ratios, as emphasized by Burnside, Eichenbaum, Kleschelski, and Rebelo (2011). They are also known to do poorly in highly volatile environments, as emphasized by Bhansali (2007), Clarida, Davis, and Pedersen (2009), and Menkhoff, Sarno, Schmeling, and Schrimpf (2012). Brunnermeirer, Nagel, and Pedersen (2009) document that returns to carry trades have negative skewness. There is a substantive debate about whether carry trades are exposed to risk factors. Burnside, et al. (2011) argue that carry trade returns are not exposed to standard risk factors, in sample. Many others, cited below, find exposures to a variety of risk factors. Burnside (2012) provides a review of the literature.

We contribute to this debate by demonstrating that non-dollar carry trades are exposed to risks, but carry trades versus only the dollar are not, at least not unconditionally in our sample. We also find that downside equity market risk exposure, which has recently been offered as an explanation for the high average carry trade profits by Lettau, Maggiori, and Weber (2014) and Dobrynskaya (2014) or in an alernative version by Jurek (2014), does not explain our carry trade returns.

Finally, we conclude our analysis with a study of the drawdowns to carry trades.[2] We define a drawdown to be the loss that a trader experiences from the peak (or high-water

[1]Koijen, Moskowitz, Pedersen, and Vrugt (2013) explore the properties of 'carry' trades in other asset markets by defining 'carry' as the expected return on an asset assuming that market conditions, including the asset's price, stay the same.

[2]Melvin and Shand (2014) analyze carry trade drawdowns including the dates and durations of the largest drawdowns and the contributions of individual currencies to the portfolio drawdowns.

mark) to the trough in the cumulative return to a trading strategy. We also examine the pure drawdowns, as in Sornette (2003), which are defined to be persistent decreases in an asset price over consecutive days. We document that carry-trade drawdowns are large and occur over substantial time intervals. We contrast these drawdowns with the characterizations of carry trade returns by *The Economist* (2007) as "picking up nickels in front of a steam roller," and by Breedon (2001) who noted that traders view carry-trade returns as arising by "going up the stairs and coming down the elevator." Both of these characterizations suggest that negative skewness in the trades is substantially due to unexpected sharp drops. While we do find negative skewness in daily carry trade returns, the analysis of drawdowns provides a more nuanced view of the losses in carry trades.

2 Background Ideas and Essential Theory

Because the carry trade can be implemented in the forward market, it is intimately connected to the forward premium anomaly – the empirical finding that the forward premium on the foreign currency is not an unbiased forecast of the rate of appreciation of the foreign currency. In fact, expected profits on the carry trade would be zero if the forward premium were an unbiased predictor of the rate of appreciation of the foreign currency. Thus, the finding of apparent non-zero profits on the carry trade can be related to the classic interpretations of the apparent rejection of the unbiasedness hypothesis. The profession has recognized that there are four ways to interpret the rejection of unbiasedness forward rates:

1. First, the forecastability of the difference between forward rates and future spot rates could result from an equilibrium risk premium. Hansen and Hodrick (1983) provide an early econometric analysis of the restrictions that arise from a model of a rational, risk averse, representative investor. Fama (1984) demonstrates that if one interprets the econometric analysis from this efficient markets point of view, the data imply that risk premiums are more variable than expected rates of depreciation.

2. The second interpretation of the data, first offered by Bilson (1981), is that the nature of the predictability of future spot rates implies a market inefficiency. In this view, the profitability of trading strategies appears to be too good to be consistent with rational risk premiums. Froot and Thaler (1990) support this view and argue that the data are consistent with ideas from behavioral finance.

3. The third interpretation of the findings involves relaxation of the assumption that investors have rational expectations. Lewis (1989) proposes that learning by investors could reconcile the econometric findings with equilibrium theory.

4. Finally, Krasker (1980) argues that the interpretation of the econometrics could be flawed because so-called 'peso problems' might be present.[3]

Surveys of the literature by Hodrick (1987) and Engel (1996) provide extensive reviews of the research on these issues as they relate to the forward premium anomaly.

Each of these themes plays out in the recent literature on the carry trade. Bansal and Shaliastovich (2013) argue that an equilibrium long-run risks model is capable of explaining the predictability of returns in bond and currency markets. Lustig, Roussanov, and Verdelhan (2014) develop a theory of countercyclical currency risk premiums. Carr and Wu (2007) and Jurek and Xu (2013) develop formal theoretical models of diffusive and jump currency risk premiums.

Several papers find empirical support for the hypothesis that returns to the carry trade are exposed to risk factors. For example, Lustig, Roussanov, and Verdelhan (2011) argue that common movements in the carry trade across portfolios of currencies indicate rational risk premiums. Rafferty (2012) relates carry trade returns to a skewness risk factor in currency markets. Dobrynskaya (2014) and Lettau, Maggiori, and Weber (2014) argue that large average returns to high interest rate currencies are explained by their high conditional exposures to the market return in the down state. Jurek (2014) demonstrates that the return to selling puts, which has severe downside risk, explains the carry trade. Christiansen, Ranaldo, and Soderlind (2011) note that carry trade returns are more positively related to equity returns and more negatively related to bond risks the more volatile is the foreign exchange market. Ranaldo and Soderlind (2010) argue that the funding currencies have 'safe haven' attributes, which implies that they tend to appreciate during times of crisis. Menkhoff, et al. (2012) argue that carry trades are exposed to a global FX volatility risk. Beber, Breedon, and Buraschi (2010) note that the yen-dollar carry trade performs poorly when differences of opinion are high. Mancini, Ranaldo, and Wrampelmeyer (2013) find that systematic variation in liquidity in the foreign exchange market contributes to the returns to the carry trade. Bakshi and Panayotov (2013) include commodity returns as well as foreign exchange volatility and liquidity in their risk factors. Sarno, Schneider and Wagner (2012) estimate multi-currency affine models with four dimensional latent variables. They find that such variables can explain the predictability of currency returns, but there is a tradeoff between the ability of the models to price the term structure of interest rates and the currency returns. Bakshi, Carr, and Wu (2008) use option prices to infer the dynamics of risk premiums for the dollar, pound and yen pricing kernels.

[3]While peso problems were originally interpreted as large events on which agents placed prior probability and that didn't occur in the sample, Evans (1996) reviews the literature that broadened the definition to be situations in which the ex post realizations of returns do not match the ex ante frequencies from investors' subjective probability distributions.

In contrast to these studies that find substantive financial risks in currency markets, Burnside, et al. (2011) explore whether the carry trade has exposure to a variety of standard sources of risk. Finding none, they conclude that peso problems explain the average returns. By hedging the carry trade with the appropriate option transaction to mitigate downside risk, they determine that the peso state involves a very high value for the stochastic discount factor. Jurek (2014), on the other hand, examines the hedged carry trade and finds positive, statistically significant mean returns indicating that peso states are not driving the average returns. Farhi and Gabaix (2011) and Farhi, Fraiberger, Gabaix, Ranciere, and Verdelhan (2013) argue that the carry trade is exposed to rare crash states in which high interest rate currencies depreciate.

Jordà and Taylor (2012) dismiss the profitability of the naive carry trade based only on interest differentials as poor given its performance in the financial crisis of 2008, but they advocate simple modifications of the positions based on long-run exchange rate fundamentals that enhance its profitability and protect it from downside moves indicating a market inefficiency.

2.1 Implementing the Carry Trade

This section develops notation and provides background theory that is useful in interpreting the empirical analysis. Let the level of the exchange rate of dollars per unit of a foreign currency be S_t, and let the forward exchange rate that is known today for exchange of currencies in one period be F_t. Let the one-period dollar interest rate be $i_t^{\$}$, and let the one-period foreign currency interest rate be i_t^*.[4]

In this paper, we explore several versions of the carry trade. The one most often studied in the literature is equal weighted in that it goes long (short) one dollar in each currency for which the interest rate is higher (lower) than the dollar interest rate. If the carry trade is done by borrowing and lending in the money markets, the dollar payoff to the carry trade without transaction costs can be written as

$$z_{t+1} = [(1 + i_t^*)\frac{S_{t+1}}{S_t} - (1 + i_t^{\$})]y_t \tag{1}$$

where

$$y_t = \left\{ \begin{array}{c} +1 \text{ if } i_t^* > i_t^{\$} \\ -1 \text{ if } i_t^{\$} > i_t^* \end{array} \right\}$$

Equation (1) scales the carry trade either by borrowing one dollar and investing in the

[4]When it is necessary to distinguish between the dollar exchange rate versus various currencies or the various interest rates, we will superscript them with numbers.

foreign currency money market, or by borrowing the appropriate amount of foreign currency to invest one dollar in the dollar money market. When interest rate parity holds, if $i_t^* > i_t^\$$, $F_t < S_t$, the foreign currency is at a discount in the forward market. Conversely, if $i_t^* < i_t^\$$, $F_t > S_t$, and the foreign currency is at a premium in the forward market. Thus, the carry-trade can also be implemented by going long (short) in the foreign currency in the forward market when the foreign currency is at a discount (premium)in terms of the dollar. Let w_t be the amount of foreign currency bought in the forward market. The dollar payoff to this strategy is

$$z_{t+1} = w_t(S_{t+1} - F_t) \tag{2}$$

To scale the forward positions to be either long or short in the forward market an amount of dollars equal to one dollar in the spot market as in equation (1), let

$$w_t = \left\{ \begin{array}{ll} \frac{1}{F_t}(1 + i_t^\$) & \text{if } F_t < S_t \\ -\frac{1}{F_t}(1 + i_t^\$) & \text{if } F_t > S_t \end{array} \right\} \tag{3}$$

When covered interest rate parity holds, and in the absence of transaction costs, the forward market strategy for implementing the carry trade in equation (2) is exactly equivalent to the carry trade strategy in equation (1). Unbiasedness of forward rates and uncovered interest rate parity imply that carry trade profits should average to zero.

Uncovered interest rate parity ignores the possibility that changes in the values of currencies are exposed to risk factors, in which case risk premiums can arise. To incorporate risk aversion, we need to examine pricing kernels.

2.2 Pricing Kernels

One of the fundamentals of no-arbitrage pricing is that there is a dollar pricing kernel or stochastic discount factor, M_{t+1}, that prices all dollar returns, R_{t+1}, from the investment of one dollar:

$$E_t\left[M_{t+1}R_{t+1}\right] = 1 \tag{4}$$

Because implementing the carry trade in the forward market does not require an investment at time t, the no-arbitrage condition is

$$E_t(M_{t+1}z_{t+1}) = 0 \tag{5}$$

Taking the unconditional expectation of equation (5) and rearranging gives

$$E(z_{t+1}) = \frac{-Cov(M_{t+1}, z_{t+1})}{E(M_{t+1})} \tag{6}$$

The expected value of the unconditional return on the carry trade could be non-zero if the dollar payoff on the carry trade covaries negatively with the innovation to the dollar pricing kernel.[5]

2.3 The Hedged Carry Trade

Burnside, et al. (2011), Caballero and Doyle (2012), Farhi, et al. (2013), and Jurek (2014) examine hedging the downside risks of the carry trade by purchasing insurance in the foreign currency option markets. To examine this analysis, let C_t and P_t be the dollar prices of one-period foreign currency call and put options with strike price K on one unit of foreign currency. Buying one unit of foreign currency in the forward market costs F_t dollars in one period, which is an unconditional future cost. One can also unconditionally buy the foreign currency forward by buying a call option with strike price K and selling a put option with the same strike price in which case the future cost is $K + C_t(1 + i_t^{\$}) - P_t(1 + i_t^{\$})$. To prevent arbitrage, these two unconditional future costs of purchasing the foreign currency in one period must be the same. Hence,

$$F_t = K + C_t(1 + i_t^{\$}) - P_t(1 + i_t^{\$}) \tag{7}$$

which is put-call parity for foreign currency options.

Now, suppose a dollar-based speculator wants to be long $w_t = (1 + i_t^{\$})/F_t$ units of foreign currency in the forward market, which, as above, is the foreign currency equivalent of one dollar spot. The payoff is negative if the realized future spot exchange rate of dollars per foreign currency is less than the forward rate. To place a floor on losses from a depreciation of the foreign currency, the speculator can hedge by purchasing out-of-the-money put options on the foreign currency. If the speculator borrows the funds to buy put options on w_t units of foreign currency, the option payoff is $[\max(0, K - S_{t+1}) - P_t(1 + i_t^{\$})]w_t$. The dollar payoff from the hedged long position in the forward market is therefore the sum of the forward purchase

[5] Examples of such models include Nielsen and Saá-Requejo (1993) and Frachot (1996), who develop the first no arbitrage pricing models; Backus, Gavazzoni, Telmer and Zin (2010), who offer an explanation in terms of monetary policy conducted through Taylor Rules; Farhi and Gabaix (2011), who develop a crash risk model; Bansal and Shaliastovich (2013), who develop a long run risks explanation; and Lustig, Roussanov, and Verdelhan (2014), who calibrate a no-arbitrage model of countercyclical currency risks.

of foreign currency and the option payoff:

$$z_{t+1}^{H} = [S_{t+1} - F_t + \max(0, K - S_{t+1}) - P_t(1 + i_t^{\$})]w_t$$

Substituting from put-call parity gives

$$z_{t+1}^{H} = [S_{t+1} - K + \max(0, K - S_{t+1}) - C_t(1 + i_t^{\$})]w_t \tag{8}$$

When $S_{t+1} < K$, $[S_{t+1} - K + \max(0, K - S_{t+1})] = 0$; and if $S_{t+1} > K$, $\max(0, K - S_{t+1}) = 0$. Hence, we can write equation (8) as

$$z_{t+1}^{H} = [\max(0, S_{t+1} - K) - C_t(1 + i_t^{\$})]w_t$$

which is the return to borrowing enough dollars to buy call options on w_t units of foreign currency. Thus, hedging a long forward position by buying out-of-the-money put options with borrowed dollars is equivalent to implementing the trade by directly borrowing dollars to buy the same foreign currency amount of in-the-money call options with the same strike price.

Now, suppose the dollar-based speculator wants to sell w_t units of the foreign currency in the forward market. An analogous argument can be used to demonstrate that hedging a short forward position by buying out-of-the-money call options is equivalent to implementing the trade by directly buying in-the-money foreign currency put options with the same strike price.

When implementing the hedged carry trade, we examine two choices of strike prices corresponding to 10Δ and 25Δ options, where Δ measures the sensitivity of the option price to movements in the underlying exchange rate.[6] Because the hedged carry trades are also zero net investment strategies, they must also satisfy equation (5).

3 Data for the Carry Trades

In constructing our carry trade returns, we only use data on the G-10 currencies: the Australian dollar, AUD; the British pound, GBP; the Canadian dollar, CAD; the euro, EUR, spliced with historical data from the Deutsche mark; the Japanese yen, JPY; the New Zealand dollar, NZD; the Norwegian krone, NOK; the Swedish krona, SEK; the Swiss franc, CHF; and the U.S. dollar, USD. All spot and forward exchange rates are dollar denominated and are from Datastream and IHS Global Insight. For most currencies, the beginning of the sample is

[6]The Δ of an option is the derivative of the value of the option with respect to a change in the underlying spot rate. A 10Δ (25Δ) call option increases in price by 0.10 (0.25) times the small increase in the spot rate. The Δ of a put option is negative.

January 1976, and the end of the sample is August 2013, which provides a total of 451 observations on the carry trade. Data for the AUD and the NZD start in October 1986. Interest rate data are eurocurrency interest rates from Datastream.

We explicitly exclude the European currencies other than the euro (and its precursor, the Deutsche mark), because we know that several of these currencies, such as the Italian lira, the Portuguese escudo, and the Spanish peseta, were relatively high interest rate currencies prior to the creation of the euro. At that time traders engaged in the "convergence trade," which was a form of carry trade predicated on a bet that the euro would be created in which case the interest rates in the high interest rate countries would come down and those currencies would strengthen relative to the Deutsche mark. An obvious peso problem exists in these data because there was uncertainty about whether the euro would indeed be created. If the euro had not succeeded, the lira, escudo, and peseta would have suffered large devaluations relative to the Deutsche mark.

We also avoid emerging market currencies because nominal interest rates denominated in these currencies also incorporate substantive sovereign risk premiums. The essence of the carry trade is that the investor bears pure foreign exchange risk, not sovereign risk. Furthermore, Longstaff, Pan, Pedersen, and Singleton (2011) demonstrate that sovereign risk premiums, as measured by credit default swaps, are not idiosyncratic because they covary with the U.S. stock and high-yield credit markets. Thus, including emerging market currencies could bias the analysis toward finding that the average returns to the broadly defined carry trade are due to exposure to risks.

Our foreign currency options data are from JP Morgan.[7] After evaluating the quality of the data, we decided that high quality, actively traded, data were only available from September 2000 to August 2013. We also only had data for eight currencies versus the USD as option data for the SEK were not available.

We describe the data on various risk factors as they are introduced below. Table A.1 in Appendix A provides distributional information on the risk factors.

4 Unconditional Results on the Carry Trade

Table 1 reports basic unconditional sample statistics for five dollar-based carry trades from the G10 currencies. All of the statistics refer to annualized returns, and all the strategies invest in every currency in each period, if data are available. For the basic carry trade, labeled EQ,

[7]We thank Tracy Johnson at JP Morgan for her assistance in obtaining the data.

the weight on currency j is

$$w_{j,t}^{EQ} = \frac{sign(i_t^j - i_t^{\$})}{N_t}$$

where N_t is the number of currencies. Thus, if the interest rate in currency j is higher (lower) than the dollar interest rate, the dollar-based investor goes long (short) $1/N_t$-th of a dollar in the forward market of currency j. This equal-weight approach is the way most academic articles implement the carry trade.

Our second strategy is 'spread-weighted' and is denoted SPD. The long or short position is again determined by the interest differential versus the dollar, but the fraction of a dollar invested in a particular currency is determined by the interest differential divided by the sum of the absolute values of the interest differentials:

$$w_{j,t}^{SPD} = \frac{i_t^j - i_t^{\$}}{\sum_{j=1}^{N_t} \left| i_t^j - i_t^{\$} \right|}$$

The SPD strategy thus invests more in currencies that have larger interest differentials while retaining the idea that the investment is scaled to have a total of one dollar spread across the absolute values of the long and short positions.

Although it is often said that only one dollar is at risk in such a situation, this is not true when the trader shorts a foreign currency. When a trader borrows a dollar to invest in the foreign currency, the most the trader can lose is the one dollar if the foreign currency becomes worthless, but when a trader borrows the foreign currency equivalent of one dollar to invest in the U.S. money market, the amount of dollars that must be repaid could theoretically go to infinity if the foreign currency strengthens massively versus the dollar, as inspection of equation (1) indicates. Traders would consequently be unlikely to follow the EQ and SPD strategies because they take more risk when the volatility of the foreign exchange market is high than when it is low. In actual markets, traders typically face value-at-risk limits in which the possible loss of a particular amount on their portfolio of positions is calibrated to be a certain probability. For example, a typical value-at-risk model constrains a trader to take positions such that the probability of losing, say more than \$1 million on any given day, is no larger than 1%. Implementing such a strategy requires a conditional covariance matrix of the returns on the nine currencies versus the dollar.

To calculate this conditional covariance matrix, we construct simple IGARCH models from daily data. Let H_t denote the conditional covariance matrix of returns at time t with typical element, h_t^{ij}, which denotes the conditional covariance between the $i-th$ and $j-th$ currency returns realized at time $t+1$. Then, the IGARCH model is

$$h_t^{ij} = \alpha(r_t^i r_t^j) + (1-\alpha)h_{t-1}^{ij} \tag{9}$$

where we treat the product of the returns as equivalent to the product of the innovations in the returns. We set $\alpha = 0.06$, as suggested in RiskMetrics (1996). To obtain the monthly covariance matrixes we multiply the daily IGARCH estimates of H_t by 22.

We use these conditional covariance matrixes in two strategies. In the first strategy, we target a fixed monthly standard deviation of $5\%/\sqrt{12}$, which corresponds to an approximate annualized standard deviation of 5%, and we adjust the dollar scale of the EQ and SPD carry trades accordingly. These strategies are labeled EQ-RR and SPD-RR to indicate risk rebalancing. In the second strategy, we use the conditional covariance matrixes in successive one-month mean-variance maximizations. Beginning with the analysis of Meese and Rogoff (1983), it is often argued that expected rates of currency appreciation are essentially unforecastable. Hence, we take the vector of interest differentials, here labeled μ_t, to be the conditional means of the carry trade returns, and we take positions $w_t^{OPT} = \omega_t H_t^{-1}\mu_t$, where H_t is the conditional covariance matrix, and ω_t is a scaling factor. We label this strategy OPT. As with the risk-rebalanced strategies, we target a constant annualized standard deviation of 5%. Thus, the weights in our portfolio are

$$w_t^{OPT} = \frac{\left(0.05/\sqrt{12}\right)}{\left(\mu_t' H_t^{-1}\mu_t\right)^{0.5}} H_t^{-1}\mu_t \tag{10}$$

If the models of the conditional moments are correct, the conditional Sharpe ratio would equal $\left(\mu_t' H_t^{-1}\mu_t\right)^{0.5}$.[8]

Table 1 reports the first four moments of the various carry trade strategies as well as their Sharpe ratios and first order autocorrelations. Standard errors are in parenthesis and are based on Hansen's (1982) Generalized Method of Moments, as explained in Appendix B.[9]

For the full sample, the carry trades for the USD-based investor have statistically significant average annual returns ranging from 2.10% (0.47) for the *OPT* strategy, to 3.96% (0.91) for the EQ strategy, and to 6.60% (1.31) for the SPD strategy. The strategies also have impressive Sharpe ratios, which range from 0.78 (0.19) for the EQ strategy to 1.02 (0.19) for the SPD-RR strategy. As Brunnermeier, Nagel, and Pedersen (2009) note, each of these strategies is

[8]Ackermann, Pohl, and Schmedders (2012) also use conditional mean variance modeling so their positions are also proportional to $H_t^{-1}\mu_t$, but they target a constant mean return of 5% per annum. Hence, their positions satisfy $w_t^{APS} = \frac{(0.05/12)}{\mu_t' H_t^{-1}\mu_t} H_t^{-1}\mu_t$. While their conditional Sharpe ratio is also $\left(\mu_t' H_t^{-1}\mu_t\right)^{0.5}$, their scaling factor responds more aggressively to perceived changes in the conditional Sharpe ratio than ours.

[9]Throughout the paper, when we discuss estimated parameters, standard errors will be in parentheses and t-statistics will be in square brackets.

significantly negatively skewed, with the OPT strategy having the most negative skewness of -0.89 (0.34). Table 1 also reports positive excess kurtosis that is statistically significant for all strategies. The first order autocorrelations of the strategies are low, as would be expected in currency markets, and only for the EQ-RR strategy can we reject that the first order autocorrelation is zero. Of course, it is well known that this test has very low power against interesting alternatives. The minimum monthly returns for the strategies are all quite large, ranging from -4.01% for the OPT strategy to -7.26% for the SPD. The maximum monthly returns range from 3.21% for the OPT to 8.07% for the SPD. Finally, Table 1 indicates that the carry trade strategies are profitable on between 288 months for the EQ strategy and 303 months for the OPT strategy out of the total of 451 months.[10]

Table 2 presents results for the various equal-weighted carry trades in which each currency is considered to be the base currency and the returns are denominated in that base currency. For each strategy, if the interest rate in currency j is higher (lower) than the interest rate of the base currency, the investor goes long (short) in the forward market of currency j as in the dollar-based EQ strategy. The average annualized profits of these carry trades range from 2.33% (1.02) for the SEK to 3.92% (1.50) for the NZD. These mean returns are all less than the 3.96% (0.88) for the USD although given their standard errors it is unlikely that we would be able to reject equivalence of the means. For all base currencies, the average profitability is statistically significance at the .06 marginal level of significance or smaller. The Sharpe ratios of the alternative base-currency carry trades are also smaller than the USD-based Sharpe ratio of 0.78 (0.19). The lowest Sharpe ratio of the alternative base-currency carry trades is 0.36 (0.19) for the JPY, and the highest is 0.71 (0.18) for the CAD. The point estimates of skewness for the alternative base-currency carry trades are all negative, except for the EUR, and the statistical significance of skewness is high for the JPY, NOK, SEK, NZD, and AUD. All of these alternative-currency-based carry trades have positive, statistically significant, excess kurtosis. Only the GBP-based carry trade shows any sign of first-order autocorrelation. The maximum gains and losses on these strategies generally exceed those of the USD-based strategy. Only the CAD and EUR have smaller maximum monthly losses that the USD-based strategy, and the maximum monthly losses for the JPY, SEK, NZD, and AUD carry trades exceed 10%. The alternative base-currency carry trades are also profitable on slightly fewer days than the USD-based EQ trade, and the percentage of profitable days for the NZD and AUD is slightly smaller than for the USD.

[10] The strategies are all positively correlated. Correlations range from .63 for EQ and OPT to .90 for EQ and SPD. The correlations of EQ and EQ-RR and SPD and SPD-RR are .88 and .89, respectively.

5 Carry-Trade Exposures to Risk Factors

This section examines whether the average returns to the carry trades described above can be explained by exposures to a variety of risk factors. We include equity market, foreign exchange market, bond market, and volatility risk factors. In each case we run a regression of a carry-trade return, R_t, on returns on assets or portfolios, F_t, that represent the sources of risks, as in

$$R_t = \alpha + \beta' F_t + \varepsilon_t \tag{11}$$

Because we use returns as risk factors, the constant term in the regression, α, measures the average performance of the carry trade that is not explained by unconditional exposure of the carry trades to the market traded risks included in the regression.

5.1 Equity Market Risks

Table 3 presents the results of regressions of our carry-trade returns on the three Fama-French (1993) equity market risk factors: the excess market return, $R_{m,t}$, proxied by the return on the value-weighted NYSE, AMEX, and NASDAQ markets over the T-bill return; the return on a portfolio of small market capitalization stocks minus the return on a portfolio of big stocks, $R_{SMB,t}$; and the return on a portfolio of high book-to-market stocks minus the return on a portfolio of low book-to-market stocks, $R_{HML,t}$.[11] Although the Fama-French (1993) factors exhibit some modest explanatory power with nine of the 15 coefficients having t-statistics that are greater than 1.88, the overall impression is that these equity market factors essentially leave most of the average returns of the carry trades unexplained, as the exposures to the risk factors are quite small which allows that constants in the regressions to range from 1.83% with a t-statistic of 3.72 for the OPT strategy, to 5.55% with a t-statistic of 4.84 for the SPD-RR strategy. The largest R^2 is also only .05. These equity market risk factors clearly do not explain the average carry trade returns.

5.2 Pure FX Risks

Table 4 presents the results of regressions of our carry-trade portfolio returns on the two pure foreign exchange market risk factors proposed by Lustig, Roussanov, and Verdelhan (2011) who sort 35 currencies into six portfolios based on their interest rates relative to the dollar interest rate, with portfolio one containing the lowest interest rate currencies and portfolio six containing the highest interest rate currencies. Their two risk factors are the average

[11] The Fama-French risk factors were obtained from Kenneth French's web site which also describes the construction of these portfolios.

return on all six currency portfolios, denoted $R_{FX,t}$, which has a correlation of 0.99 with the first principal component of the six returns, and $R_{HML-FX,t}$, which is the difference in the returns on portfolio 6 and portfolio 1 and has a correlation of 0.94 with the second principal component of the returns. The data are from Adrien Verdelhan's web site, and the sample period is 1983:11-2013:08 for 358 observations. Given its construction as the difference in returns on high and low interest rate portfolios, it is unsurprising that $R_{HML-FX,t}$ has significant explanatory power for our carry-trade returns with robust t-statistics between 6.22 for the OPT portfolio to 8.85 for the EQ-RR portfolio. The R^2's are also higher than with the equity risk factors, ranging between 0.13 and 0.34. Nevertheless, this pure FX risk model does not explain the average returns to our strategies as the constant terms in the regressions remain highly significant and range from a low of 1.29% for the OPT portfolio to 3.60% for the SPD-RR portfolio.

5.3 Bond Market Risks

Because exchange rates are the relative prices of currencies and relative rates of currency depreciation are in theory driven by all sources of aggregate risks in the stochastic discount factors of the two currencies, it is logical that bond market risk factors should have explanatory power for the carry trade as the bond markets must price the important risks of changes in the stochastic discount factor. Table 5 presents the results of regressions of the carry trade returns on the excess equity market return and the excess return on the 10-year bond over the one-month bill rate, which represents the risk arising from changes in the level of interest rates, and the difference in returns between the 10-year bond and the 2-year note, which represents the risk arising from changes in the slope of the term structure of interest rates. The bond market returns are from CRSP. The coefficients on both of the bond market factors are highly significant. Positive returns on the 10-year bond that are matched by the return on the 2-year note, which would be caused by unanticipated decreases in the level of the USD yield curve, are bad for the USD-based carry trades. Notice also that the coefficients on the two excess bond returns are close to being equal and opposite in sign indicating that positive increases the return on the two-year note are bad for the carry trades. Notice, though, that the $R^{2\prime}s$ of the regressions remain between .02 and .05, as in the equity market regressions, and that the constants in the regressions indicate that the means of the carry trade strategies remain statistically significant after these risk adjustment, with values between 2.15% for the OPT strategy to 6.71% for the SPD strategy.

5.4 Volatility Risk

To capture possible exposure of the carry trade to equity market volatility, we introduce the return on a variance swap as a risk factor. This return is calculated as

$$R_{VS,t+1} = \sum_{d=1}^{Ndays} \left(\ln \frac{P_{t+1,d}}{P_{t+1,d-1}} \right)^2 \left(\frac{30}{Ndays} \right) - VIX_t^2$$

where $Ndays$ represents the number of trading days in a month and $P_{t+1,d}$ is the value of the $S\&P$ 500 index on day d of month $t+1$. Data for VIX are obtained from the web site of the CBOE. The availability of data on the VIX limits the sample to 283 observations. The regression results are presented in Tables 6 and 7. Because $R_{VS,t+1}$ is an excess return, we can continue to examine the constant terms in the regressions to assess whether exposure of the carry trade to risks explains the average returns. When we add $R_{VS,t+1}$ to the regressions in Tables 6 to 7, very little changes as the absolute values of the largest t-statistics associated with the coefficients on $R_{VS,t+1}$ are 1.40 for the equity market risks specification and 1.76 for the bond market risks, and the constant terms in these regressions remain highly significant. The coefficients on $R_{VS,t+1}$ are negative in the specifications with the equity and bond market risks indicating that the carry trades do tend to do badly when equity volatility increases, but this exposure is not enough to explain the profitability of the trades.

6 Dollar Neutral and Pure Dollar Carry Trades

In the basic EQ carry trade analysis discussed above, we take equal sized positions in nine currencies versus the dollar, either long or short, depending on whether a currency's interest rate is greater than the dollar interest rate or less than the dollar interest rate. Because there are nine currencies, the EQ portfolio is always either long or short some fraction of a dollar versus some set of currencies. To develop a dollar-neutral carry trade, we exclude the dollar interest rate and calculate the median interest rate of the remaining nine currencies. We then take equal long (short) positions versus the dollar in the four currencies whose interest rates are greater (less) than the median interest rate, and we scale the size of the equal-weighted positions to be the same magnitude as that of EQ. We use EQ0 to denote this portfolio which has zero direct dollar exposure.

The second columns of Panels A and B of Table 8 report the first four moments of the EQ0 carry trade as well as the Sharpe ratio and the first order autocorrelation. Panel A reports the full sample results, and Panel B reports the results over the later part of the sample when VIX data become available (1990:02-2013:08). Heteroskedasticity consistent standard errors are in parenthesis. For ease of comparison, we list the same set of statistics for EQ in Column 1. The EQ0 portfolio has statistically significant average annual returns in both samples, 1.61% (0.58) for the full sample and 1.72% (0.72) for the later sample. While these average returns are lower than that of the EQ strategy, the volatility of the EQ0 strategy is also lower, and its Sharpe ratio is 0.49 (0.19) in the full sample and 0.52 (0.23) in the later sample. These point estimates are about 30% lower than the respective Sharpe ratios of the EQ strategy. The skewness of the EQ0 strategy is -0.47(0.19) and -0.47 (0.28) for the full sample and the later sample, respectively. The autocorrelation of the EQ0 strategy is negligible, and the maximum losses are smaller than those of the EQ strategy. The next question is whether the EQ0 strategy is exposed to risks.

Column 2 of Table 9 presents the results of regressions of the EQ0 returns on the three Fama-French (1993) equity market risk factors. Notice that EQ0 loads significantly on the market return and the HML factor, with t-statistics of 5.29 and 2.83, respectively. The loading on the market return explains approximately 30% of the average return, and the loading on the HML factor explains another 15% of the average return. The resulting constant in the regression has a t-statistic of 1.54, and the R^2 is .10. In comparison, the regression of EQ returns on the same equity risk factors has an estimated constant of 3.39 with a t-statistic of 3.76 and an R^2 of only .04. The Fama-French (1993) three factor model clearly does a better job of explaining the average return of EQ0 strategy.

These results are surprising for two reasons. First, the EQ0 strategy follows the same "carry" strategy using the G10 currencies as in the commonly studied EQ portfolio. The only difference is the dollar exposure, which makes an important difference in abnormal returns and risk factor loadings. Second, the literature currently leans toward the belief that FX carry trades cannot be explained by equity risk factors, but we find that the average returns to a typical FX carry trade can be explained by commonly used equity risk factors, with the caveat that the portfolio has zero direct exposure to the dollar.

6.1 Decomposition of Carry Trade

To understand the difference between EQ and EQ0, we subtract the EQ0 positions from the EQ positions to obtain another portfolio, which we label EQ-minus. The currency positions in the EQ0 portfolio are

$$w_{j,t} = \left\{ \begin{array}{l} +\frac{1}{N_t} \ if \ i_t^j > med\left\{i_t^k\right\} \\ -\frac{1}{N_t} \ if \ i_t^j < med\left\{i_t^k\right\} \end{array} \right\}$$

where $med\left\{i_t^k\right\}$ indicates the median of the interest rates excluding the dollar.

Subtracting the currency positions in the EQ0 strategy from those in EQ strategy gives the positions in EQ-minus, which goes long (short) the dollar when the dollar interest rate is higher (lower) than the median interest rate but only against currencies with interest rates between the median and dollar interest rates. The exact positions of the portfolio are the following:

If $i_t^{\$} < med\left\{i_t^k\right\}$, then

$$y_t^j = \left\{ \begin{array}{c} 0 \; if \; i_t^j > med\left\{i_t^k\right\} \\ \frac{1}{N_t} \; if \; i_t^j = med\left\{i_t^k\right\} \\ \frac{2}{N_t} \; if \; i_t^{\$} < i_t^j < med\left\{i_t^k\right\} \\ 0 \; if \; i_t^j \leq i_t^{\$} \end{array} \right\}$$

If $i_t^{\$} > median\left\{i_t^k\right\}$, then

$$y_t^j = \left\{ \begin{array}{c} 0 \; if \; i_t^j > i_t^{\$} \\ -\frac{1}{N_t} \; if \; i_t^j = med\left\{i_t^k\right\} \\ \frac{-2}{N_t} \; if \; med\left\{i_t^k\right\} < i_t^j \leq i_t^{\$} \\ 0 \; if \; i_t^j \leq med\left\{i_t^k\right\} \end{array} \right\}$$

The EQ0 and EQ-minus portfolios decompose the EQ carry trade into two components: a dollar neutral component and a dollar component.

Column 3 of Panels A and B in Table 8 presents the first four moments of the EQ-minus strategy. which has statistically significant average annual returns in both samples, 2.35 (0.66) for the full sample and 2.11 (0.92) for the later sample. The Sharpe ratio of the EQ-minus strategy is higher than that of the EQ0 strategy in the full sample, 0.61 versus 0.49; but in later half of the sample, the EQ-minus strategy has a slightly lower Sharpe ratio, 0.49 versus 0.52, than the EQ0 strategy. Given the standard errors, one could argue that the Sharpe ratios are the same.

Skewness of EQ-minus is quite negative -0.65 (0.44) and -0.76 (0.45) for the full sample and the later sample, respectively, although we note that the estimates of skewness are actually statistically insignificant due to the large standard error in both samples. In terms of the Sharpe ratio and skewness, the EQ-minus strategy appears no better than the EQ0 strategy. Nevertheless, the EQ-minus strategy has a correlation of -.11 with the EQ0 strategy, and the following results illustrate that the EQ-minus strategy also differs significantly from the EQ0 strategy in its risk exposures.

Column 3 of Table 9 presents the results of regressions of the EQ-minus returns on the three Fama-French (1993) equity market risk factors. Unlike EQ0, only the SMB factor shows any explanatory power for the EQ-minus returns. The constant in the regression is 2.36%

with a t-statistic of 3.60. The R^2 is .04. The equity market risk factors clearly do not explain the average returns to the EQ-minus strategy.

Columns 1 to 3 of Table 10 present regressions of the returns to the EQ strategy and its two components, EQ0 and EQ-minus, on the equity market excess return and two bond market risk factors. Similar to our previous findings, the market excess return and the bond risk factors have significant explanatory power for the returns of EQ0 and a relatively high R^2 of .12. By comparison, none of the risk factors has any significant explanatory power for the returns on the EQ-minus strategy, and the resulting R^2 is only .02.

Finally, Columns 1 to 3 of Table 11 present regressions of the returns of EQ and its two components, EQ0 and EQ-minus, on the two FX risk factors. The two factor FX model completely explains the average returns of the EQ0 strategy while explaining only 25% of the average returns of EQ-minus. The constant term in the EQ-minus regression also is significant with a value of 1.49% and a t-statistic of 1.86 in the FX two factor model.

In summary, these results suggest that for the G10 currencies, conditional dollar exposure contributes more to the carry trade "puzzle" than does the non-dollar component.

6.2 Pure Dollar Factor

As noted above, the EQ-minus strategy goes long (short) the dollar when the dollar interest rate is above (below) the G10 median interest rate. It has the nice property of complementing the EQ0 strategy to become the commonly studied equally weighted carry trade. However, the other leg of the EQ-minus portfolio goes short (long) the currencies with interest rates between the G10 median rate and the dollar interest rate. It takes positions in relatively few currencies and thus seems under-diversified, which could explain its large kurtosis. Since the results just presented indicate that the abnormal returns of EQ hinge on the conditional dollar exposure, which is distinct from "carry", we now expand the other leg of EQ-minus to all foreign currencies. We thus create the following strategy EQ-USD:

$$y_t^j = \left\{ \begin{array}{l} +\frac{1}{N}\ if\ med\left\{i_t^k\right\} > i_t^\$ \\ -\frac{1}{N}\ if\ med\left\{i_t^k\right\} \leq i_t^\$ \end{array} \right\}$$

The EQ-USD strategy focuses on the conditional exposure of the dollar. It goes long (short) the dollar against all nine foreign currencies when the dollar interest rate is higher (lower) than the global median interest rate. The fourth columns of Panels A and B of Table 8 present the first four moments of the returns to the EQ-USD strategy for the full sample and the sample for which equity volatility is available. We find that EQ-USD has statistically significant average annual returns in both samples, 5.54% (1.37) for the full sample and 5.21%

(1.60) for the later sample. Although its volatility is also higher than the EQ strategy, its Sharpe ratio of 0.68 (0.18) in the full sample and 0.66 (0.21) in the later sample are larger although not significantly different from those of the EQ strategy. Skewness of the EQ-USD strategy is insignificant as we find estimates of -0.11(0.17) for the full sample and -0.05 (0.22) for the later sample. Thus, the EQ-USD strategy does not suffer from the extreme negative skewness often mentioned as the hallmark of carry trade. The fourth columns of Tables 9 and 11 report regressions of the returns of EQ-USD on the Fama-French (1993) three factors, the bond factors, and the FX risk factors. The only significant loading is on $R_{FX,t}$, which goes long all foreign currencies. The constants in these regressions range from 5.18% with a t-statistic of 3.40 in the FX market risks regression to 5.82% with a t-statistic of 4.01 for the bond market risks regression. When we use all of the risk factors simultaneously in Table 12 for the shorter sample period, the foreign exchange risk factors and the volatility factor have significant loadings, but the constant in the regression is 4.52% with a a t-statistic of 2.79.

In summary, a large fraction of the premium earned by the EQ carry strategy can be attributed to its conditional dollar exposure. What is more, the EQ-USD portfolio built on this conditional dollar exposure earns a large premium, exhibits small exposures to standard risk factors, which cannot explain its return,and has insignificant negative skewness, indicating that negative skewness is not an explanation for the abnormal excess return of this strategy.

6.3 The Downside Market Risk Explanation

Our last investigation of the potential risks of the carry trade considers two recent studies that offer exposure to downside equity market risk as the explanation of carry trade profitability. The first is by Lettau, Maggiori, and Weber (2014), and the second is by Jurek (2014).

6.3.1 The Lettau, Maggiori, and Weber (2014) Analysis

Lettau, Maggiori, and Weber (2014) first note that although portfolios of high interest rate currencies have higher market betas than portfolios of low interest rate currencies, these market-beta differentials are insufficiently large to explain the magnitude of carry trade returns.[12] To develop a market-return risk based explanation of the average carry trade returns,

[12]Dobrynskaya (2014) uses a slightly different specification than Lettau, Maggiori, and Weber (2014) but reaches similar conclusions. Unfortunately, her GMM system of equations includes redundant orthogonality conditions as she includes the returns on 10 portfolios sorted on the interest differential as well as the 10-1 portfolio return differential. While this should result in a collinear set of orthogonality conditions, the 10 - 1 differential portfolio does not appear to be exactly equal to the difference in the returns on portfolio 10 minus portfolio 1 as the average returns are slightly different. If the covariance matrix of the orthogonality conditions is nearly singular, the resulting standard errors are not reliable. The reported efficient GMM estimates are also likely to be unreliable. Because the approaches are so similar, we focus our discussion on the approach taken by Lettau, Maggiori, and Weber (2014).

Lettau, Maggiori, and Weber (2014) modify the downside market risk model of Ang, Chen, and Xing (2006) and argue that the exposure of the carry trade to the return on the market is larger, conditional on the market return being down. In their empirical analysis, Lettau, Maggiori, and Weber (2014) define the downside market return, which we denote $R^{-}_{m,t}$, as equal to the market return when the market return is one standard deviation below the average market return and zero otherwise.[13] Lettau, Maggiori, and Weber (2014) find that the down-market-beta differential between the high and low interest rate sorted portfolios combined with a high price of down market risk is sufficient to explain the average returns to the carry trade. To examine whether the $R^{-}_{m,t}$ risk factor explains our G10 carry trade strategies, we investigate whether our six currency portfolios have significant betas with respect to $R^{-}_{m,t}$ and whether these downside betas are significantly different from the standard betas We show that our portfolios as well as other currency portfolios more generally, have statistically insignificant beta differentials which invalidates the explanation of Lettau, Maggiori, Weber (2014) for these carry trades.

In their econometric analysis, Lettau, Maggiori, and Weber (2014) run separate univariate OLS regressions of portfolio returns, R_t, on $R_{m,t}$ and $R^{-}_{m,t}$ to define the risk exposures, β and β^{-}. Then, they impose that the price of $R_{m,t}$ risk is the average return on the market, $E\left(R_{m,t}\right)$, and they use a cross-sectional regression to estimate a separate price of risk for $R^{-}_{m,t}$, denoted λ^{-}, which is necessary because $R^{-}_{m,t}$ is not a traded risk factor. The unconditional expected return on an asset is therefore predicted to be

$$E\left(R_t\right) = \beta E\left(R_{m,t}\right) + (\beta^{-} - \beta)\lambda^{-}$$

To test this explanation of our carry trades we first run a bivariate regression of a carry trade return on a constant; an indicator dummy variable, I^{-}, that is one when $R^{-}_{m,t}$ is non-zero and zero otherwise; and the two risk factors, $R_{m,t}$ and $R^{-}_{m,t}$. Thus, we estimate

$$R_t = \alpha_1 + \alpha_2 I^{-} + \beta_1 R_{m,t} + \beta_2 R^{-}_{m,t} + \varepsilon_t \tag{12}$$

In equation (12), β_1 measures the asset's basic exposure to the market excess return given that there is additional adjustment for when the market is in the downstate; and β_2 measures the asset's additional exposure to the market excess return when the market is in the downstate, that is $\beta_2 = (\beta^{-} - \beta_1)$. We then test the significance of β_2 using heteroskedasticity and

[13] Because the definition of $R^{-}_{m,t}$ used by Lettau, Maggiori, and Weber (2014) seemed arbitrary to us, we also considered two alternative more intuitive definitions which are the market return being less than the unconditional average market return and the market return being negative. The results are similar to the reported results and are available in an internet appendix.

autocorrelation consistent standard errors, as in Newey and West (1987) with 3 lags.[14]

Table 13 presents the results of these regressions for our six carry trade portfolios. We first present the estimates of the usual β to establish the unconditional exposures when $R_{m,t}$ is the only risk factor. We find that the five basic carry trade portfolios have small positive $\beta's$, but only the SPD portfolio has a statistically significant β. The EQ-USD strategy, on the other hand, has a slightly negative β. Because the risk factor in these regressions is a return, the constant terms can be interpreted as abnormal returns, and all the constants are highly significant as the smallest t-statistic is 4.01. When we add $R^{-}_{m,t}$ and the downside indicator dummy to the regressions, we find that the $\beta_2's$ for the five basic carry trade portfolios are indeed positive, indicating that the point estimates of β^{-} are indeed slightly larger than those of β_1, but we cannot reject the hypothesis that $\beta_2 = (\beta^{-} - \beta_1) = 0$ as the largest t-statistic is 1.43. Moreover, the estimated β_2 in the EQ-USD regression is actually negative indicating that this currency strategy is less exposed to the market's downside risk than to the upside of market returns.[15]

Because $R^{-}_{m,t}$ is not a return, one cannot interpret the intercepts in these regressions as abnormal returns, which is why Lettau, Maggiori, and Weber (2014) perform the cross-sectional analysis that is required to estimate the price of downside market risk. To determine how much our estimated exposures to downside risk could possibly explain the average returns to the carry trade, we use the estimates of the price of downside risk from Lettau, Maggiori, and Weber (2014) rather than our own cross-sectional analysis.

Lettau, Maggiori, and Weber (2014) include assets other than currencies in their cross-sectional analysis and find a large positive price of downside market risk. When they include currencies and equities with returns measured in percentage points per month, they find an estimate of λ^{-} equal to 1.41%, or 16.92% per annum. When they include only currencies, they find an estimate of λ^{-} equal to 2.18%, or 26.2% per annum. To determine the explanatory power of $(\beta^{-} - \beta)\lambda^{-}$ for our carry trade portfolios, we first add the estimates of β_1 and β_2 to get an estimate of β^{-} from which we subtract the unconditional estimate of β from the first regression. The last two rows of Panel C in Table 13 multiply our estimates of $(\beta^{-} - \beta)$ by 16.92% or 26.2% to provide the explained part of the average carry trade returns that is due to downside risk exposure. Compared to the constant terms in Panel A, the extra return explained by downside risk exposure is minimal for the EQ and EQ-RR strategies.

[14]When there is additional covariance of a return with the market given that the market is down, the standard beta measures a mixture of the basic beta and the downside beta. Thus, $(\beta^{-} - \beta)$ is actually smaller than $(\beta^{-} - \beta_1)$.

[15]Of course, since the EQ-USD strategy takes positions in all foreign currencies relative to the dollar based only on the position of the USD interest rate relative to the median interest rate, it is not strictly a carry trade, and the return on the portfolio when the market is down could be driven by movements in currencies whose interest rates are more extreme relative to the median than the USD interest rate.

The downside risk premium explains between 0% and 5% of the CAPM alphas of these two strategies, respectively. For the SPD and SPD-RR strategies, the downside risk premium explains between 20% and 40% of the CAPM alphas. Notice also that the negative β_2 for the EQ-USD strategy implies that the downside market risk theory cannot explain the excess return of the EQ-USD strategy as the additional expected return from downside risk exposure is actually -2.12% or -3.28%, depending on the value of λ^-.

As a check on the sensitivity of our conclusions about the inability of downside risk to explain the carry trade, we run the same regressions using the six interest rate sorted portfolios of Lustig, Roussanov, and Verdelhan (2011) who place the lowest interest rate currencies in portfolio P1 and the highest interest rate currencies in portfolio P6. The average returns on these portfolios increase monotonically from P1 to P6. Panel A of Table 14 shows the CAPM regression results. The $\beta's$ on $R_{m,t}$ for portfolios P1 to P6 are small but monotonically increasing, and the excess return, P6 - P1, is significantly explained by $R_{m,t}$ with a t-statistic of 5.62. Nevertheless, consistent with our previous results, the market β of the P6 - P1 return is only 0.18, which is too small to explain the average return. The CAPM $\alpha's$ on these portfolios increase monotonically from P1 to P6, and the α of P6 - P1 portfolio is 6.46% with a t-statistic of 3.67.

Panel B of Table 14 presents the regression results in the presence of downside market risk. The slope coefficients on $R_{m,t}$ are close to monotonically increasing; but the slope coefficients on $R_{m,t}^-$ do not increase monotonically. The $\beta_2's$ of portfolios P4 and P5 are smaller than those of portfolios P1 to P3. More importantly, the $\beta_2's$ are all insignificantly different from zero as the largest t-statistic is 0.56 indicating that all the coefficients are smaller than their standard errors. Although the downside risk explanation requires statistical significance of the beta differential implying that insignificance could be taken at face value to indicate that downside risk cannot be the explanation of the carry trade, failure to reject zero is not sufficient to reject the theory. Thus, we also perform the necessary calculations as above to derive the explanatory power of the downside risk premium taking the coefficients at their point estimates. We find that the downside risk effect is not monotonic as portfolios P2, P4 and P5 are predicted to have more negative downside risk premiums than portfolio P1 even though the CAPM $\alpha's$ of P2, P4, and P5 are larger than P1. At the extreme end, the P6 - P1 portfolio has a positive though insignificant β_2. With an annualized downside risk premium of 26.2%, the difference between the downside beta and the unconditional beta helps to explain about a quarter of the CAPM α of the P6 - P1 portfolio.

The fact that the six portfolios of Lustig, Roussanov, and Verdelhan (2011) have $\beta_2 = (\beta^- - \beta_1)$ slope coefficients that are insignificantly different from zero and not monotonic is surprising because Lettau, Maggiori, and Weber (2014) use six similarly constructed currency portfolios from a comparably large number of countries and show that these portfolios have monotonically increasing directly estimated loadings on $R^{-}_{m,t}$. Two things are important to note. First, while the methodologies may seem different because Lettau, Maggiori, and Weber (2014) estimate the $\beta^{-\prime}s$ directly in separate univariate regressions and we add our two slope coefficients, β_1 and β_2, to find estimates of $\beta^{-\prime}s$, the estimated values of β^{-} are the same. The differences arise because Lettau, Maggiori, and Weber (2014) use different currencies in their analysis than Lustig, Roussanov, and Verdelhan (2011) and a different but overlapping time period. For the time period over which the two data sets coincide, the correlation of the returns to the two P6 - P1 portfolios is actually only .4. For the smaller developed currencies sample, both studies sort currencies into five portfolios, and the correlation of the returns to the two P5 - P1 portfolios rises to .8. We therefore further explore our approach with the Lettau, Maggiori, and Weber (2014) developed country portfolios for a sample which starts in 1983:11, when the Lustig, Roussanov, and Verdelhan (2011) sample starts, and ends in 2010:03.

Panel A of Table 15 demonstrates that the CAPM $\alpha' s$ are monotonically increasing from P1 to P5 and the P5-P1 portfolio has a CAPM α of 4.52% with a t-statistic of 2.68. Similar to the previous results, Panel B of Table 15 shows that the point estimates of the $\beta_2' s$ of all the portfolios are insignificantly different from zero as the largest t-statistic is 1.14 indicating that the downside beta is not significantly different from the basic beta. Panel C of Table 15 shows that the predicted downside risk premium is not monotonically increasing from P1 to P5. The P1 portfolio has a larger downside risk premium than the P2 and P3 portfolios, even though the CAPM α of the P1 portfolio is -0.35% and the CAPM α's of the P2 and P3 portfolios are 0.45% and 2.64%, respectively. Nevertheless, we note that 57% of the CAPM α of the P5 - P1 portfolio can be explained by the difference between the downside beta and the unconditional beta using the point estimate of the annualized downside risk premium of 26.2%. Overall, these results highlight our concerns that the downside betas are small and are imprecisely estimated. The relation of the downside betas across the interest rate sorted portfolios is not monotonic in most of the results, which implies that downside market risk cannot explain the average returns to the portfolios, which are monotonically increasing.

6.3.2 The Jurek (2014) Analysis

Jurek (2014) uses the return to selling S&P 500 puts as a downside risk index (DRI) to explain the returns to the carry trade. The DRI is developed and explored in Jurek and Stafford (2014) who argue that it can be thought of as a straightforward way to express downside risk, and that the average return to the DRI can therefore be considered to be a risk premium.[16] Jurek and Stafford (2014) show that an appropriately levered investment in the DRI accurately matches the pre-fee risks and returns of broad hedge fund indices such as the HFRI Fund-Weighted Composite and the Credit Suisse Broad Hedge Fund Index.

We follow Jurek's description of the development of the DRI to obtain a sample from January 1990 to August 2013.[17] The last column of Table A.1 shows summary statistics for the DRI. The mean return is an annualized 9.42%, which is highly statistically significant given its standard error of 1.43. The DRI is also highly non-normally distributed as evidenced by its skewness of -2.92 and its excess kurtosis of 13.57. The returns are mostly positive as losses occur in less than 18% of the months.

Jurek (2014) examines a sample from 1990:1 to 2012:06 and reports that the slope coefficients [t-statistics] from regressions of spread-weighted and dollar-neutral, spread-weighted carry trades on the DRI are 0.3514 [6.41] and 0.3250 [5.85], respectively, and the constant terms in the regressions are 0.0019 [0.14] and -0.0032 [-0.22], respectively. Jurek (2014) interprets the strong significance of the slopes and the fact that the intercepts are smaller than their standard errors as evidence that this measure of downside risk explains the average returns of the carry trades quite well.

Table 16 presents our analysis using the DRI index. In regressions that just include the DRI as an explanatory variable, the slope coefficients are generally significant, except for the EQ-USD portfolio for which the DRI has no explanatory power. The estimated constant terms with heteroskedasticity consistent t-statistics in brackets range from 1.26 [2.17] for the OPT portfolio to 5.37 [2.83] for the EQ-USD portfolio. The constant terms for the EQ-RR and SPD-RR portfolios also have t-statistics greater than 2.6. Returns to the pure dollar portfolio, which was demonstrated above to be unrelated to general market risk, is again shown to be immune to downside market risk proxied by the return from selling put options. We consequently conclude that while our carry trade portfolios, other than the pure dollar portfolio, have some exposure to the downside risk index of Jurek and Stafford (2014), such exposures are insufficient to explain the returns to the carry trades. When we include the

[16] Caballero and Doyle (2014) use the return from shorting VIX futures as an indicator of systemic risk to explain the carry trade. Because VIX futures only began trading in 2004, we prefer the Jurek and Stafford (2013) downside risk index, as we can construct returns for a much longer sample.

[17] Jurek and Stafford (2013) note that the maximum loss from selling a put is the strike price. They investigate strategies in which the seller of the put places capital equal to $X\%$ of the maximum loss in the bank in addition to the capital from the funds obtained from the sale of the put. The return from selling puts is then the capital gain or loss on the puts plus the accrued interest on the invested capital divided by the invested capital. We follow Jurek (2014) in using options that have strike prices one standard deviation below the current index value, and we place 50% of the maximum loss in the bank. Jurek and Stafford (2013) use the OptionMetrics database which begins in 1996. Jurek (2014) extends the data back to 1990 by using the Berkeley Options Database. We are grateful to Jurek for providing his data, and we updated the series to August 2013.

DRI with the three Fama-French (1993) risk factors in Panel B, we find that none of the slope coefficients on DRI is significantly different from zero, and the intercepts all retain their magnitude and statistical significance.

7 Results for the Hedged Carry Trade

This section considers results for hedged carry trades. As noted in the Data section, our foreign currency options sample is for the much shorter period from September 2000 to August 2013, for which we have high quality options data. We also only employ USD-denominated foreign currency options. Jurek (2014) is able to utilize a full set of 45 bilateral put and call currency options for the G10 currencies, and he notes correctly that using only put and call options versus the USD overstates the cost of hedging because it does not take advantage of the offsetting exposures that arise from being long some currencies other than the USD, short other currencies, and directly hedging this non-USD exposure with the appropriate bilateral option for which both the volatility of the cross-rate and hence the cost of the options are lower. We simply do not have the data to implement this more efficient approach to hedging. Thus, the changes in profitability from our hedged strategies overstate the reductions in profitability that traders would actually have experienced.

Table 17 reports the results for the hedged carry trades. We consider the equal weighted hedged carry trade and the spread weighted hedged carry trade as well as the EQ-USD trade. For comparison, the statistics for the corresponding unhedged carry trades over the same sample are also reported. The first thing to notice is that the profitability of the unhedged carry trades in the shorter sample is not as large as in the full sample. The average returns (standard errors) are only 2.22% (1.43) for the EQ strategy, 5.55% (2.50) for the SPD strategy, and 4.58% (2.27) for the EQ-USD strategy. The Sharpe ratios are also slightly lower at 0.47 (0.31), 0.66 (0.31), and 0.53 (0.26), respectively, and they are less precisely estimated given the shorter sample. While the point estimates of unconditional skewness of the unhedged EQ and SPD strategies remain negative, they are insignificantly different from zero. Skewness of the EQ-USD strategy is positive but insignificantly different from zero.

The average returns for the hedged carry trades are reported for 10Δ and 25Δ option strategies. In each case, the average hedged returns are lower than the corresponding unhedged returns. For the 10Δ strategies, the average profitability of the hedged EQ trade is 38 basis points less than its unhedged counterpart, the average profitability of the hedged SPD trade is 34 basis points less than its unhedged counterpart, and the average profitability of the EQ-USD trade is 61 basis points less than its unhedged counterpart. For the 25Δ strategies, the average profitabilities of the hedged EQ trade is 87 basis points less, that of the hedged SPD trade is 129 basis points less, and that of the EQ-USD trade is 145 basis points less than their respective unhedged counterparts. The statistical significance of the average returns of the hedged EQ strategies are questionable as the p-values of the hedged EQ strategies increase from .12 for the unhedged to .132 and .198 for the 10Δ and 25Δ trades, respectively. On the other hand, the p-values of the 10Δ and 25Δ hedged SPD strategies remain quite low, at .017 and .022, respectively. Hedging the EQ-USD strategy causes a slight deterioration in the statistical significance of the mean return as the p-values of the hedged EQ-USD strategies rise from the .043 of the unhedged to .055 and .083 for the 10Δ and 25Δ trades, respectively.

In comparing the maximum losses across the unhedged and hedged strategies, one sees that hedging only provides limited protection against substantive losses for the EQ and SPD strategies since the maximum losses of the hedged trades are similar to the maximum losses from the respective unhedged trades. The maximum monthly loss for the EQ strategy is 4.12%, and the maximum losses for the EQ hedged 10Δ and 25Δ strategies are 2.93% and 3.52%, respectively. Similarly, the maximum monthly unhedged loss for the SPD strategy is 7.44%, and the maximum losses for the SPD hedged 10Δ and 25Δ strategies are 6.30% and 4.75%, respectively. Hedging the EQ-USD strategy with the 25Δ strategy did help to avoid a substantive loss as the maximum losses for this strategy are 7.15% for the unhedged strategy and 5.30% and 3.68% for the 10Δ and 25Δ strategies, respectively.

7.1 Risk Exposures of the Hedged Carry Trades

We begin the examination of the exposures of the hedged carry trades to risk factors in Panel A of Table 18 where we consider the basic equity market risk exposures to the three Fama-French (1993) factors. For the shorter sample, the unhedged EQ strategy has an insignificant constant term and statistically significant exposure to the market return with an R^2 of .20. The corresponding results for the SPD strategy also indicate stronger and statistically more significant exposures to the market return and the HML factor than in the full sample, as well as a higher R^2 of .26. Nevertheless, the constant term in the SPD regression remains important and statistically significant at 4.23% [2.13] . Hedging these carry trades has very little influence on the results as the constant terms in the EQ-10Δ and EQ-25Δ strategies are both smaller with smaller t-statistics while the constant terms in the SPD-10Δ and SPD-25Δ strategies are also both slightly smaller but with statistically significant t-statistics. The statistically significant exposures to the market return and HML remain in the hedged SPD regressions.

The unhedged EQ-USD strategy has no exposure to the Fama-French (1993) factors in the shorter sample and the constant term is 3.88% with a t-statistic of 1.72. Hedging the

EQ-USD trades results in insignificant exposures to the Fama-French (2013) risk factors, and the constant terms in the regressions remain relatively large in magnitude but with reduced statistical significance. Panel B of Table 18 adds the return to the variance swap as a risk factor to the equity risks. With the equity market factors, the return to the variance swap only has explanatory power for the EQ-USD strategy where it is statistically significant for both the unhedged and hedged returns. The constant terms in these regressions remain statistically significantly different from zero.

Panel A of Table 19 considers exposures to the equity market excess return and the two bond market excess returns as in Table 6. We see significant differences between the shorter sample results and the full sample results for both the EQ and SPD strategies. For the EQ carry trade, the significance of the bond market factors is now gone, while the return on the equity market is strong, as was just reported. For the SPD trade, the bond market factors are now statistically significant as before, but with the opposite signs of the full sample results.

Hedging these carry trades causes very little change in the slope coefficients or the t-statistics but reduces the magnitude of constant terms in the regressions. None of the constants has a t-statistic larger than 1.57. For the EQ-USD strategy, the bond market risk factors are statistically significant and nearly equal and opposite in sign indicating that an innovation in the two-year return is associated with a decrease in the return to the trade. Panel B of Table 19 adds the return to the variance swap as a risk factor to the bond risks. In conjunction with the bond market factors, the return to the variance swap only has explanatory power for the hedged EQ-USD strategies, and the constant terms in these regressions have reduced statistical significance.

Table 20 demonstrates that the downside risk indicator (DRI) of Jurek and Stafford (2014) has strong significance for the EQ and SPD strategies, both in their unhedged and hedged forms, for the shorter sample. The constant terms in these regressions are also insignificantly different from zero indicating that the DRI alone has the power to explain these carry trades. In contrast, the DRI has no ability to explain the unhedged EQ-USD strategy leaving an intercept of 4.58%, albeit with a t-statistic that has a p-value of .10. The DRI has no ability to explain the return to the hedged EQ-USD strategy, and the t-statistics for the constant terms remain marginally significant.

8 Drawdown Analysis Using the Daily Frequency

Carry trades are generally found to have negative skewness. The literature has associated this negative skewness with crash risk. However, negative skewness at the monthly level can stem from extreme negatively skewed daily returns or from a sequence of persistent, negative daily returns that are not negatively skewed. These two cases have different implications for risk management and for theoretical explanations of the carry trade. If persistent negative returns are the explanation, the detection of increased serial dependence could potentially be used to limit losses. While the literature has almost exclusively focused on the characteristics of carry trade returns at the monthly frequency, we now characterize the downside risks of carry trade returns at the daily frequency while retaining the monthly decision interval.[18]

To calculate daily returns for a carry trade strategy, we consider that a trader has one dollar of capital that is deposited in the bank at the end of month $t-1$. The trader earns the one-month dollar interest rate, $i_t^{\$}$, prorated per day. We use the one month euro-currency interest rates as the interest rates at which traders borrow and lend, and we infer the foreign interest rates from the USD interest rate and covered interest rate parity. At time $t-1$, the trader also enters one of the four carry trade strategies, EQ, EQ-RR, SPD, or SPD-RR, which are rebalanced at the end of month t. Let $P_{t,\tau}$ represent the cumulative dollar carry trade profit realized on day τ during month t. The accrued interest on the one dollar of committed capital is $\left(1+i_t^{\$}\right)^{\frac{\tau}{D_t}}$ by the τ^{th} trading day of month t with D_t being the number of trading days within the month. Then, the excess daily return can then be calculated as follows:

$$rx_{t,\tau} = \frac{\left(P_{t,\tau} + \left(1+i_t^{\$}\right)^{\frac{\tau}{D_t}}\right)}{P_{t,\tau-1} + \left(1+i_t^{\$}\right)^{\frac{\tau-1}{D_t}}} - \left(1+i_t^{\$}\right)^{\frac{1}{D_t}}$$

Panel A of Table 21 shows the summary statistics of these daily returns from our four carry trade strategies annualized for ease of comparison to the corresponding annualized monthly returns in Panel B. If the daily returns of a portfolio were independently and identically distributed, the annualized moments at the daily and monthly levels would scale such that with 21 trading days in a month, the means and standard deviations would be the same. Standardized daily skewness would equal $\sqrt{21}$ times standardized monthly skewness, and standardized daily kurtosis would equal 21 times standardized monthly kurtosis.For ease of comparison, Panel C takes ratios of monthly central moments to the daily central moments and normalize them by the corresponding ratios under the I.I.D assumption. If the daily returns independently and identically distributed, the normalized ratios would equal 1.

Table 21 shows that the annualized average returns for the daily carry trades and their corresponding monthly counterparts are almost identical. The annualized daily standard deviations of the four strategies are all slightly below the annualized monthly standard deviations,

[18]While traders in foreign exchange markets can easily adjust their carry trade strategies at the daily frequency if not intradaily with minimal transaction costs, we choose to examine the daily returns to carry trades that are rebalanced monthly to maintain consistency with the academic literature and because we do not have quotes on forward rates for arbitrary maturities that are necessary to close out positions within the month.

which is consistent with small positive autocorrelations at the daily frequency. Ratios of standardized monthly skewness relative to daily skewness vary considerably across the portfolios. For the EQ and SPD portfolios, the normalized ratios are 7.1 and 2.4, indicating that the monthly skewness are well above the value if the daily returns were *i.i.d.*. On the other hand, the same ratios for the risk rebalancing portfolios are markedly closer to 1, 1.7 for EQ-RR and 1.3 for SPD-RR. This is not surprising because risk rebalancing targets a constant IGARCH predicted variance over time, thereby reducing the serial dependence in the conditional variance of the return. As a result, the data generating process of the risk rebalancing portfolios conforms better to the *i.i.d.* assumption. Similarly, normalized ratios between monthly and daily kurtosis are far above the value implied by the *i.i.d.* assumption for the EQ and SPD portfolios whereas the same ratios for the EQ-RR and SPD-RR portfolios are again much closer to 1. Risk rebalancing tilts the data generating process towards the *i.i.d.* distribution, and it reveals substantial negative skewness at the daily level. The daily skewness of the EQ-RR and SPD-RR strategies is -1.01 and -1.62, respectively. Lastly, the minimum (actual, not annualized) daily returns are of similar size to the minimum (actual, not annualized) monthly returns for all four strategies. In this sense, it may seem that much of the risk of the carry trade is realized at the daily level, yet the months with the largest daily losses are not the months with the largest monthly losses.

We use three measures to capture the downside risks of carry trade portfolios. The first is its drawdown, which is defined as the percentage loss from the previous high-water mark to the following lowest point. The second is its pure drawdown, which is defined as the percentage loss from consecutive daily negative returns. The third is its maximum loss, which is defined as the minimum cumulative return over a given period of time. We calculate the distributions of drawdowns and pure drawdowns, which are defined as the number of drawdowns (pure drawdowns) more severe than a certain value. For maximum losses, we calculate the distribution as the maximum loss versus a particular time horizon.

We compare these distributions to counterfactual models under the assumption that the returns are independent across time by simulating daily excess returns of the four strategies. This first model assumes a normal distribution with the corresponding unconditional mean and standard deviation of the data.[19] The second model captures non-normalities while retaining the independence assumption by simulating the daily excess returns using independent bootstrapping with replacement. We simulate 10,000 trials of the same size as the data, and we calculate the probability of observing the observed empirical patterns under these two simulation methods, which we report as p-values.

[19] Chernov, Graveline, and Zviadadze (2013) use historical currency return processes and option data to estimate stochastic volatility jump-diffusion models. We have not attempted to simulate from these more complex and realistic models to generate distributions of drawdowns and maximum losses.

8.0.1 Drawdowns

Table 22 reports the magnitudes of the 20 worst drawdowns, their p-values under the simulations from the normal distribution (labeled as "p_n") and from the bootstrap (labeled as "p_b") as well as the number of days it took to experience that particular drawdown. The worst drawdown from the EQ strategy is 12.0%, which corresponds to a p-value of .13 under either the normal or the bootstrap distribution. Because these values exceed the .05 threshold, the probability of observing one drawdown worse than 12.0% is not inconsistent with those statistical models. This large drawdown was not a crash, though. It took 94 days to go from the peak to trough. The second worst EQ drawdown is 10.8%, which took 107 days from peak to trough. The p-values for this drawdown indicate that the probability of observing two drawdowns worse than 10.8% is .016 under the normal distribution and .018 under the bootstrap. Therefore, while a single worst drawdown of 12.0% is not uncommon under the assumption of either of the simulated distributions, for less extreme but still severe drawdowns, the EQ strategy suffers such drawdowns more frequently than the *i.i.d.* distributions suggest. Examining the remaining 18 worst drawdowns indicates that almost all of them took more than a month to experience.

For the SPD strategy, the worst drawdown is 21.5%, which has p-values of .017 for the normal distribution and .023 for the bootstrap distribution. This worst drawdown was experienced over 163 days. Drawdowns for the SPD strategy with magnitudes between 8.2% and 8.9% happen more frequently in the data than both simulation models would suggest with p-values of .05. The number of days it took to experience the 10 worst drawdowns also exceeds 50. The effect of risk-rebalancing on the drawdowns of the EQ strategy is minimal, while risk rebalancing the SPD strategy cuts the largest drawdown in half. The distributions of drawdowns for the risk rebalanced strategies, EQ-RR and SPD-RR, often reach p-values below .05 under both simulation methods. Risk rebalancing also tends to lengthen the period over which the maximum drawdowns are experienced.

8.0.2 Maximum Losses

Table 23 reports the magnitudes of the maximum losses and their p-values under the two simulations. For the EQ strategy, the maximum one-day loss is 2.7%. The p-value for the one-day loss clearly rejects the assumption of a normal distribution, which is not surprising because the portfolio has significant negative skewness and excess kurtosis. In fact the simulations under a normal distribution fail to match the empirical distribution of maximum losses over all horizons for all four strategies, indicating the limitations of using the normal distribution when studying the most extreme tail events. Thus, we focus our discussion on the bootstrapping results. Bootstrapping captures these higher moments, and using this simulation method, the maximum daily loss of 2.7% has a p-value of .594 indicating that across the 10,000 simulations this loss was drawn at least once in over half of the simulations. As we move towards longer horizons, the maximum loss in the data increases steadily until 180 days. After that, the maximum losses generally decrease because even though longer horizons mean the losing streak could be longer, the tendency for larger losses is offset by the positive average returns.[20]

For the EQ strategy, the maximum losses within periods shorter than one, two, and three days obtain p-values larger than .05 for the bootstrap simulation. For longer horizons, the maximum losses usually are much more severe than what the .05 bootstrapping bound suggests. Maximum losses for SPD over periods shorter than 35 days are well within the .05 bound of the bootstrap distribution. But, for periods longer than 40 days, the maximum losses for SPD start to exceed the .05 bound. This suggests that even taking account of the daily skewness and kurtosis, the distributions of maximum losses for EQ and SPD at longer horizons reject the independence assumption underlying the bootstrapping. The rejection could come from serial dependence of a variety of moments. We know that volatility of daily returns is quite persistent, and thus controlling for serial dependency in the second moment seems to be a natural, first step to determining why the *i.i.d.* bootstrapping fails to match the empirical maximum loss.[21] The EQ-RR and SPD-RR strategies should avoid some of these problems as they are rebalanced monthly to achieve a constant IGARCH predicted volatility and hence have less serial dependence in their second moments. Table 23 demonstrates that once we take account of stochastic volatility in this way, the maximum losses observed in the data largely lie within the .05 bounds of the bootstrap distributions. Therefore, even though the drawdown analysis shows that risk rebalancing is not effective at regulating the distribution of drawdowns to what would be implied by an *i.i.d.* assumption, risk-rebalancing certainly helps to align the maximum losses with what is implied by an *i.i.d.* return.

8.0.3 Pure Drawdown

Table 24 reports statistics for the 20 worst pure drawdowns, their p-values under the two simulations, and the number of days over which the pure drawdown occurred. The *i.i.d.* normal distribution fails to match the empirical distributions of the pure drawdowns for virtually all magnitudes and frequencies, where frequency k means that there are at least k pure drawdowns greater than or equal to a particular magnitude. We thus focus on the p-values from the bootstrap distributions. For the EQ strategy, the worst pure drawdown is 5.2% with a p-value

[20] The maximum drawdown for the EQ strategy is 12% which took 94 days. This is not reported as a maximum loss because 94 days is not reported in Table 23.

[21] Bootstrapping a block of returns to better capture the conditional heteroskedasticity in the data would potentially improve our approach.

of .014, and it was experienced over 7 trading days. For less severe pure drawdowns, we see that the bootstrap simulations also fail to match the frequencies at these thresholds. For example, there are 10 pure drawdowns greater than or equal in magnitude to 3% which never occurs in the simulations. The pure drawdowns occur between 3 and 12 business days.

Similar observations can be made for the SPD strategy. Observing pure drawdowns greater than or equal to 4.4% never occurs in either simulation. In results available in the online appendix, we observe that the durations of the pure drawdowns, that is, the number of days with consecutive negative returns, are well within the .05 bounds implied by two simulations. These results suggest that the low p-values of the empirical distributions of the magnitudes of pure drawdowns stem mainly from the fact that the consecutive negative returns tend to have larger variances than the typical returns.[22]

When we apply the risk-rebalancing strategies in EQ-RR and SPD-RR, we find that the worst five pure drawdowns lie well within the .05 bounds, while less extreme pure drawdowns happen more frequently than is implied by the bootstrap's .05 bound. For example, the fifth worst pure drawdown of the SPD-RR strategy is 4.2%, and we observed five pure drawdowns of this magnitude or larger in 22.1% of the bootstrap simulations. Recall that the distribution of maximum losses of EQ-RR and SPD-RR lie within the bootstrap's .05 bound also, while the distributions of drawdowns of the two EQ and SPD strategies do not. These results together suggest that controlling for serial dependence in volatility greatly improves the accuracy of an *i.i.d.* approximation for studying the extreme downside risks, but to fully match the frequencies of less extreme but still severe downside events, we need a richer model to capture the serial dependence in the data.

To sum up, studying these four carry trade strategies at the daily level conveys rich information regarding downside risks. Although the minimum daily returns are of similar size to the minimum monthly returns, they do not occur in the same months. Maximum drawdowns occur over substantial periods of time, often in highly volatile environments, suggesting that extreme negative returns do not happen suddenly and could possibly be avoided by traders who can re-balance daily. Drawdowns are much larger than the daily losses, and simulations using a normal distribution fail to match the empirical frequencies of downside events in most cases. This is consistent with the significant, negative skewness at the daily frequency. Bootstrapping helps to capture the negative skewness and excess kurtosis of the empirical distributions, and bootstrapping with a volatility forecasting model helps to match the frequencies of the most extreme tail events in the data, but it fails to match the frequencies of less extreme but still severe tail events.

[22]Similarly, we find larger values of pure run-ups than is implied by the simulations.

9 Conclusions

This paper provides some perspectives on the risks of currency carry trades that differ from the conventional wisdom in the literature. First, it is generally argued that exposure to the three Fama-French (1993) equity market risk factors cannot explain the returns to the carry trade. We find that these equity market risks do significantly explain the returns to an equally weighted carry trade that has no direct exposure to the dollar. Our second finding is also at variance with the literature. We find that our carry trade strategies with alternative weighting schemes are not fully priced by the HML_{FX} risk factor proposed by Lustig, Roussanov, and Verdelhan (2011), which is basically a carry trade return across a broader set of currencies. Third, we argue that the time varying dollar exposure of the carry trade is at the core of carry trade puzzle. A dollar carry factor earns a significant abnormal return in the presence of equity market risks, bond market risks, FX risks, and a volatility risk factor. The dollar carry factor also has insignificant skewness, indicating crash risk cannot explain its abnormal return. Our fourth finding that is inconsistent with the literature is that the exposure of our carry trades to downside market risk is not statistically significantly different from the unconditional exposure. Thus, the downside risk explanation of Dobrynskaya (2014) and Lettau, Maggiori, and Weber (2014) does not explain the average returns to our strategies. We do find that the downside risk explanation of Jurek (2014) explains the non-dollar carry trade, but it also fails to explain our dollar carry factor.

We also show that spread-weighting and risk-rebalancing the currency positions improve the Sharpe ratios of the carry trades, and the returns to these strategies earn significant abnormal returns in presence of the HML_{FX} risk factor proposed by Lustig, Roussanov, and Verdelhan (2011). The choice of benchmark currency also matters. We show that equally weighted carry trades can have a Sharpe ratio as low as 0.36 when the JPY is chosen as the benchmark currency and as high as 0.78 when the USD is chosen as the benchmark currency. Currency exposure explains the difference between these carry trade strategies. We thus decompose the equally weighted USD based carry trade into two components: one has zero direct exposure to the dollar and the other contains the strategy's dollar exposure. We find that the dollar-neutral part of carry trade exhibits an insignificant alpha in the Fama-French (1993) three-factor model. On the other hand, a USD carry factor based on the carry trade's time varying exposure to the dollar cannot be priced by a combination of equity, bond, FX, and volatility risk factors, commanding insignificant loadings on these risk factors and a significant alpha.

We also initiate a discussion of the attributes of the distributions of the drawdowns of different strategies using daily data while maintaining at a monthly rebalancing strategy.

We do so in an intuitive way using simulations, as the statistical properties of drawdowns are less developed than other measures of risk, such as standard deviation and skewness. Although we correct for time varying heteroskedasticity with our risk rebalancing model, we still find that most of the time the empirical distributions of the drawdowns of our carry trade strategies lie outside of the 95% confidence band based on a normal distribution that matches the unconditional mean and standard deviation of the strategy. Simulating from an *i.i.d.* bootstrap does a much better job of predicting the distributions of carry trade drawdowns, but it cannot fully capture the severity of the drawdowns. Adding conditional autocorrelation, especially in down states, seems necessary to fully characterize the distributions of drawdowns and the negative skewness that characterizes the monthly data.

We began the paper by noting the parallels between the returns to the carry trade and the rejections of the unbiasedness hypothesis. As with any study of market efficiency, there are four possible explanations. We do find that the profitability of the basic carry trade has decreased over time, which suggests the possibility that market inefficiency explains the relatively larger early period returns that are not associated with exposures to risks. But, we also find significant risk exposures which suggests a role for risk aversion. The risks may change over time in which case there is room for learning as a possible explanation requiring a deviation from the basic rational expectations econometric paradigm. The performance of the hedged carry trade suggests that a single unrealized peso state is probably not the explanation of the data, although generalized peso problems in which the *ex post* distribution of returns differs for the *ex ante* distribution that rational investors perceived certainly cannot be ruled out.

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Table 1: Summary Statistics of USD Carry Trade Returns

This table presents summary statistics on the monthly zero-investment portfolio returns for five carry-trade strategies. The strategies are the basic equal-weighted (EQ) and spread-weighted (SPD) strategies, and their risk-rebalanced versions (labeled "-*RR*") as well as a mean-variance optimized strategy (OPT). The weights in the basic strategies are calibrated to have one dollar at risk each month. The risk-rebalanced strategies rescale the basic weights by IGARCH estimates of a covariance matrix to target an annualized 5% standard deviation. The OPT strategy is a conditional mean-variance efficient strategy at the beginning of each month, based on the IGARCH conditional covariance matrix and the assumption that the expected future excess currency return equals the interest rate differential.
The sample period is 1976:02-2013:08 except for the AUD and the NZD, which start in October 1986. The reported parameters, (mean, standard deviation, skewness, excess kurtosis, and autocorrelation coefficient) and their associated standard errors are simultaneous GMM estimates. The Sharpe ratio is the ratio of the annualized mean and standard deviation, and its standard error is calculated using the delta method (see Appendix B).

	Carry Trade Weighting Method				
	EQ	EQ-RR	SPD	SPD-RR	OPT
Ave Ret (% p.a.)	3.96	5.44	6.60	6.18	2.10
(std. err.)	(0.91)	(1.13)	(1.31)	(1.09)	(0.47)
Standard Deviation	5.06	5.90	7.62	6.08	2.62
(std. err.)	(0.28)	(0.22)	(0.41)	(0.24)	(0.17)
Sharpe Ratio	0.78	0.92	0.87	1.02	0.80
(std. err.)	(0.19)	(0.20)	(0.19)	(0.19)	(0.20)
Skewness	-0.49	-0.37	-0.31	-0.44	-0.89
(std. err.)	(0.21)	(0.11)	(0.19)	(0.14)	(0.34)
Excess Kurtosis	2.01	0.40	1.78	0.90	3.91
(std. err.)	(0.53)	(0.21)	(0.35)	(0.29)	(1.22)
Autocorrelation	0.08	0.16	0.02	0.09	0.06
(std. err.)	(0.07)	(0.05)	(0.07)	(0.05)	(0.07)
Max (% per month)	4.78	5.71	8.07	5.96	3.21
Min (% per month)	-6.01	-4.90	-7.26	-5.88	-4.01
No. Positive	288	288	297	297	303
No. Negative	163	163	154	154	148

Table 2: Summary Statistics of the Carry Trade by Currency of Investor

This table presents summary statistics on the monthly zero-investment portfolio returns to the equal weight strategy with each currency as the base. The sample period is 1976:02-2013:08 except for the AUD and the NZD, which start in October 1986. The reported parameters, (mean, standard deviation, skewness, excess kurtosis, and autocorrelation coefficient) and their associated standard errors are simultaneous GMM estimates. The Sharpe ratio is the ratio of the annualized mean and standard deviation, and its standard error is calculated using the delta method (see Appendix B).

	Carry Trade Base Currency									
	CAD	EUR	JPY	NOK	SEK	CHF	GBP	NZD	AUD	USD
Average Return	3.02	2.69	3.40	2.67	2.33	3.05	3.09	3.92	3.23	3.96
(std. err.)	(0.73)	(0.90)	(1.70)	(0.84)	(1.02)	(1.21)	(0.97)	(1.50)	(1.41)	(0.88)
Standard Deviation	4.26	5.33	9.58	5.09	5.97	7.20	5.60	8.47	7.61	5.06
(std. err.)	(0.21)	(0.26)	(0.61)	(0.31)	(0.80)	(0.40)	(0.37)	(0.80)	(0.63)	(0.27)
Sharpe Ratio	0.71	0.50	0.36	0.52	0.39	0.42	0.55	0.46	0.42	0.78
(std. err.)	(0.18)	(0.17)	(0.19)	(0.18)	(0.21)	(0.17)	(0.18)	(0.19)	(0.20)	(0.19)
Skewness	-0.11	0.14	-0.79	-0.64	-3.77	-0.34	-0.26	-0.90	-0.97	-0.49
(std. err.)	(0.20)	(0.19)	(0.38)	(0.38)	(0.92)	(0.31)	(0.45)	(0.36)	(0.32)	(0.21)
Excess Kurtosis	1.53	1.43	3.68	3.71	30.24	2.41	4.41	5.57	4.15	2.01
(std. err.)	(0.36)	(0.46)	(1.64)	(1.24)	(7.37)	(0.87)	(1.48)	(1.58)	(1.87)	(0.53)
Autocorrelation	0.03	0.02	0.07	0.01	0.07	-0.02	0.10	-0.11	-0.07	0.08
(std. err.)	(0.07)	(0.06)	(0.08)	(0.06)	(0.05)	(0.06)	(0.06)	(0.10)	(0.11)	(0.06)
Max % per month	4.71	6.61	9.09	6.95	5.04	9.85	8.53	9.28	7.55	4.78
Min % per month	-4.24	-4.87	-16.02	-7.74	-16.47	-9.69	-8.69	-13.55	-12.28	-6.01
No. Positive	283	274	268	274	285	258	276	192	194	288
No. Negative	168	177	183	177	166	193	175	130	128	163

Table 3: Carry Trade Exposures to Basic Equity Risks

This table presents regressions of the carry trade returns of five different strategies on three equity market risk factors postulated by Fama and French (1993): the excess return on the market portfolio; the excess return on small market capitalization stocks over big capitalization stocks; and the excess return of high book-to-market stocks over low book-to-market stocks as in the following. The regression specification is

$$R_t = \alpha + \beta_{MKT} \cdot R_{m,t} + \beta_{HML} \cdot R_{HML,t} + \beta_{SMB} \cdot R_{SMB,t} + \varepsilon_t$$

The Fama-French factors are from Ken French's data library. The sample period is 1976:02-2013:08 (451 observations) except for the AUD and the NZD, which start in October 1986. The reported alphas are annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

	EQ	SPD	EQ-RR	SPD-RR	OPT
α	3.39	5.34	4.95	5.55	1.83
t-stat	[3.76]	[4.00]	[4.27]	[4.84]	[3.72]
β_{MKT}	0.05	0.10	0.05	0.06	0.02
t-stat	[2.46]	[2.88]	[2.25]	[2.33]	[1.88]
β_{SMB}	-0.03	0.00	-0.03	-0.01	0.01
t-stat	[-0.90]	[0.06]	[-0.89]	[-0.18]	[0.96]
β_{HML}	0.07	0.13	0.05	0.07	0.03
t-stat	[2.21]	[2.93]	[1.62]	[2.27]	[1.98]
R^2	0.04	0.05	0.02	0.02	0.02

Table 4: Carry Trade Exposures to FX Risks

This table presents regressions of the carry trade returns of five different strategies on the two pure foreign exchange risk factors constructed by Lustig, Roussanov, and Verdelhan (2011): the average return on six carry trade portfolios sorted by currency interest differential versus the dollar, R_{RX}; and the excess return of the highest interest differential portfolio over the lowest interest differential portfolio, R_{HML-FX}. The regression specification is

$$R_t = \alpha + \beta_{RX} \cdot R_{RX,t} + \beta_{HML-FX} \cdot R_{HML-FX,t} + \varepsilon_t$$

The RX and HML-FX factor return data are from Adrien Verdelhan's web site, and the sample period is 1983:11-2013:08 (358 observations). The reported alphas are in annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

	EQ	SPD	EQ-RR	SPD-RR	OPT
α	1.47	2.86	2.86	3.60	1.29
t-stat	[1.73]	[2.34]	[2.81]	[3.44]	[2.87]
β_{RX}	0.14	0.31	0.01	0.11	0.01
t-stat	[2.27]	[3.33]	[0.24]	[1.56]	[0.45]
$\beta_{\text{HML}-\text{FX}}$	0.28	0.39	0.34	0.32	0.09
t-stat	[8.24]	[7.04]	[8.85]	[6.57]	[6.22]
R^2	0.31	0.34	0.29	0.28	0.13

Table 5: Carry Trade Exposures to Bond Risks

This table presents regressions of the carry trade returns of five different strategies on the excess return on the U.S. equity market and two USD bond market risk factors: the excess return on the 10-year Treasury bond, R_{10y}; and the excess return of the 10-year bond over the two-year Treasury note, R_{10y-2y}. The regression specification is

$$R_t = \alpha + \beta_{MKT} \cdot R_{m,t} + \beta_{10y} \cdot R_{10y,t} + \beta_{10y-2y} \cdot (R_{10y,t} - R_{2y,t}) + \varepsilon_t$$

The reported alphas are in annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets. The sample period is 1976:01-2013:08 (451 observations).

	EQ	SPD	EQ-RR	SPD-RR	OPT
α	4.19	6.71	5.74	6.43	2.15
t-stat	[4.51]	[4.97]	[5.03]	[5.74]	[4.65]
β_{MKT}	0.04	0.08	0.04	0.04	0.02
t-stat	[1.81]	[2.36]	[1.92]	[2.01]	[1.74]
β_{10y}	-0.39	-0.51	-0.44	-0.41	-0.12
t-stat	[-2.97]	[-2.72]	[-4.25]	[-3.74]	[-2.97]
$\beta_{\text{10y}-\text{2y}}$	0.46	0.59	0.50	0.47	0.14
t-stat	[2.46]	[2.21]	[3.26]	[2.93]	[2.30]
R^2	0.05	0.05	0.05	0.04	0.02

Table 6: Carry Trades Exposures to Equity and Volatility Risks

This table includes the return on a variance swap as a risk factor. This return is calculated as

$$R_{VS,t+1} = \sum_{d=1}^{Ndays} \left(\ln \frac{P_{t+1,d}}{P_{t+1,d-1}} \right)^2 \left(\frac{30}{Ndays} \right) - VIX_t^2$$

where $Ndays$ represents the number of trading days in a month and $P_{t+1,d}$ is the value of the $S\&P$ 500 index on day d of month $t+1$. Data for VIX are obtained from the web site of the CBOE. For explanations of equity risk factors, pleaser refer to Table 3.
The sample period is 1990:02-2013:08 (283 observations). The reported alphas are annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

	EQ	*EQ-RR*	SPD	SPD-RR	*OPT*	EQ	EQ-RR	SPD	SPD-RR	OPT
α	3.11	4.15	4.51	4.54	1.38	2.87	3.76	4.22	4.20	1.32
t-stat	[2.76]	[2.50]	[3.58]	[3.34]	[2.65]	[2.56]	[2.32]	[3.41]	[3.14]	[2.40]
β_{MKT}	0.09	0.16	0.06	0.07	0.03	0.08	0.15	0.05	0.06	0.02
t-stat	[3.03]	[3.66]	[2.42]	[2.66]	[2.58]	[2.42]	[2.92]	[1.81]	[1.96]	[1.98]
β_{SMB}	-0.04	-0.01	-0.04	-0.02	0.01	-0.04	-0.01	-0.04	-0.02	0.01
t-stat	[-0.92]	[-0.15]	[-1.00]	[-0.36]	[1.01]	[-0.97]	[-0.22]	[-1.08]	[-0.45]	[0.94]
β_{HML}	0.06	0.14	0.04	0.07	0.03	0.06	0.13	0.04	0.06	0.03
t-stat	[1.75]	[2.77]	[1.25]	[1.99]	[2.48]	[1.60]	[2.52]	[1.11]	[1.81]	[2.37]
β_{VS}						-0.02	-0.03	-0.02	-0.03	-0.01
t-stat						[-0.94]	[-0.90]	[-1.24]	[-1.40]	[-0.41]
R^2	0.07	0.10	0.04	0.04	0.04	0.07	0.11	0.04	0.05	0.04

Table 7: Carry Trades Exposures to Bond and Volatility Risks

This table includes the return on a variance swap as a risk factor. This return is calculated as

$$R_{VS,t+1} = \sum_{d=1}^{Ndays} \left(\ln \frac{P_{t+1,d}}{P_{t+1,d-1}} \right)^2 \left(\frac{30}{Ndays} \right) - VIX_t^2$$

where $Ndays$ represents the number of trading days in a month and $P_{t+1,d}$ is the value of the $S\&P$ 500 index on day d of month $t+1$. Data for VIX are obtained from the web site of the CBOE. For explanations of bond risk factors, pleaser refer to Table 5.
The sample period is 1990:02-2013:08 (283 observations). The reported alphas are annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

	EQ	EQ-RR	SPD	SPD-RR	OPT	EQ	EQ-RR	SPD	SPD-RR	OPT
α	2.83	3.77	4.75	4.71	1.60	2.32	2.79	4.38	4.13	1.45
t-stat	[2.19]	[2.08]	[3.69]	[3.43]	[2.98]	[1.72]	[1.55]	[3.40]	[3.06]	[2.61]
β_{MKT}	0.07	0.15	0.05	0.06	0.02	0.06	0.12	0.04	0.04	0.02
t-stat	[2.38]	[3.05]	[1.73]	[2.11]	[2.26]	[1.85]	[2.32]	[1.27]	[1.43]	[1.59]
β_{10y}	0.31	0.63	-0.07	0.08	-0.02	0.39	0.78	-0.01	0.16	0.01
t-stat	[1.05]	[1.57]	[-0.26]	[0.28]	[-0.15]	[1.26]	[1.85]	[-0.05]	[0.58]	[0.04]
$\beta_{\text{10y}-\text{2y}}$	-0.35	-0.73	0.08	-0.10	0.01	-0.44	-0.91	0.01	-0.20	-0.02
t-stat	[-0.97]	[-1.48]	[0.24]	[-0.29]	[0.06]	[-1.17]	[-1.74]	[0.03]	[-0.59]	[-0.13]
β_{VS}						-0.03	-0.06	-0.02	-0.04	-0.01
t-stat						[-1.39]	[-1.69]	[-1.25]	[-1.76]	[-0.70]
R^2	0.04	0.08	0.02	0.02	0.02	0.05	0.09	0.02	0.03	0.02

Table 8: Summary Statistics of Dollar-Neutral and Pure-Dollar Trades

This table presents summary statistics on the monthly zero-investment portfolio returns for four carry-trade strategies. The strategies are the basic equal-weighted (EQ) and dollar-neutral (EQ0) strategies, as well as the strategy (EQ-minus) which is the difference between EQ and EQ0. The fourth portfolio is pure dollar carry (EQ-USD). The weights in the strategies are discussed in the main text.

The sample period is 1976:02-2013:08 except for the AUD and the NZD, which start in October 1986. The reported parameters, (mean, standard deviation, skewness, excess kurtosis, and autocorrelation coefficient) and their associated standard errors are simultaneous GMM estimates. The Sharpe ratio is the ratio of the annualized mean and standard deviation, and its standard error is calculated using the delta method (see Appendix B.) Panel A reports the results for the full sample, while Panel B reports results for the later half of the sample 1990:02-2013:08 when variance swap data become available.

	Panel A: 1976/02-2013/08				Panel B: 1990/2-2013/8			
	EQ	EQ0	EQ-minus	EQ-USD	EQ	EQ0	EQ-minus	EQ-USD
Ave Ret (% p.a.)	3.96	1.61	2.35	5.54	3.83	1.72	2.11	5.21
(std. err.)	(0.91)	(0.58)	(0.66)	(1.37)	(1.17)	(0.72)	(0.92)	(1.60)
Standard Deviation	5.06	3.28	3.85	8.18	5.43	3.30	4.31	7.89
(std. err.)	(0.28)	(0.16)	(0.28)	(0.38)	(0.36)	(0.21)	(0.35)	(0.47)
Sharpe Ratio	0.78	0.49	0.61	0.68	0.70	0.52	0.49	0.66
(std. err.)	(0.19)	(0.19)	(0.18)	(0.18)	(0.24)	(0.23)	(0.23)	(0.21)
Skewness	-0.49	-0.47	-0.65	-0.11	-0.60	-0.47	-0.76	-0.05
(std. err.)	(0.21)	(0.19)	(0.44)	(0.17)	(0.22)	(0.28)	(0.45)	(0.22)
Excess Kurtosis	2.01	1.34	4.84	0.86	1.68	1.66	3.87	1.04
(std. err.)	(0.53)	(0.51)	(2.00)	(0.31)	(0.57)	(0.71)	(1.86)	(0.38)
Autocorrelation	0.08	0.05	0.05	0.00	0.05	0.05	0.05	-0.03
(std. err.)	(0.07)	(0.06)	(0.06)	(0.06)	(0.08)	(0.07)	(0.06)	(0.07)
Max (% per month)	4.78	3.28	3.83	9.03	4.60	3.28	3.80	9.03
Min (% per month)	-6.01	-3.92	-6.69	-8.27	-6.01	-3.92	-6.69	-7.22
No. Positive	288	275	264	273	182	179	164	168
No. Negative	163	176	187	178	101	104	119	115

Table 9: Dollar Neutral and Pure Dollar Carry Trades Exposures to Basic Equity Risks

This table presents regressions of the carry trade returns of four different strategies on three equity market risk factors postulated by Fama and French (1993): the excess return on the market portfolio; the excess return on small market capitalization stocks over big capitalization stocks; and the excess return of high book-to-market stocks over low book-to-market stocks as in the following. The regression specification is

$$R_t = \alpha + \beta_{MKT} \cdot R_{m,t} + \beta_{HML} \cdot R_{HML,t} + \beta_{SMB} \cdot R_{SMB,t} + \varepsilon_t$$

The Fama-French factors are from Ken French's data library. The sample period is 1976:02-2013:08 (451 observations). The reported alphas are annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

	EQ	EQ0	EQ-minus	EQ-USD
α	3.39	1.03	2.36	5.41
t-stat	[3.76]	[1.54]	[3.60]	[3.70]
β_{MKT}	0.05	0.08	-0.02	0.01
t-stat	[2.46]	[5.29]	[-1.24]	[0.21]
β_{SMB}	-0.03	0.02	-0.05	-0.05
t-stat	[-0.90]	[1.00]	[-1.84]	[-1.04]
β_{HML}	0.07	0.05	0.02	0.06
t-stat	[2.21]	[2.83]	[0.84]	[1.08]
R^2	0.04	0.10	0.04	0.01

Table 10: Dollar Neutral and Pure Dollar Carry Trades Exposures to Basic Bond Risks

This table presents regressions of the carry trade returns of four different strategies on the excess return on the U.S. equity market and two USD bond market risk factors: the excess return on the 10-year Treasury bond, R_{10y}; and the excess return of the 10-year bond over the two-year Treasury note, R_{10y-2y}. The regression specification is

$$R_t = \alpha + \beta_{MKT} \cdot R_{m,t} + \beta_{10y} \cdot R_{10y,t} + \beta_{10y-2y} \cdot (R_{10y,t} - R_{2y,t}) + \varepsilon_t$$

The reported alphas are in annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets. The sample period is 1976:01-2013:08 (451 observations). Data for AUD and the NZD start in October 1986.

	EQ	EQ0	EQ-minus	EQ-USD
α	4.19	1.50	2.69	5.82
t-stat	[4.51]	[2.77]	[3.88]	[4.01]
β_{MKT}	0.04	0.06	-0.03	-0.01
t-stat	[1.81]	[5.48]	[-1.60]	[-0.35]
β_{10y}	-0.39	-0.25	-0.14	-0.22
t-stat	[-2.97]	[-4.42]	[-1.16]	[-0.92]
$\beta_{\mathrm{10y-2y}}$	0.46	0.29	0.17	0.32
t-stat	[2.46]	[3.52]	[1.02]	[0.93]
R^2	0.05	0.12	0.02	0.01

Table 11: Dollar Neutral and Pure Dollar Carry Trades Exposures to FX Risks

This table presents regressions of the carry trade returns of five different strategies on the two pure foreign exchange risk factors constructed by Lustig, Roussanov, and Verdelhan (2011]: the average return on six carry trade portfolios sorted by currency interest differential versus the dollar, R_{RX}; and the excess return of the highest interest differential portfolio over the lowest interest differential portfolio, R_{HML-FX}. The regression specification is

$$R_t = \alpha + \beta_{RX} \cdot R_{RX,t} + \beta_{HML-FX} \cdot R_{HML-FX,t} + \varepsilon_t$$

The R_{RX} and R_{HML-FX} factor return data are from Adrien Verdelhan's web site, and the sample period is 1983:11-2013:08 (358 observations). The reported alphas are in annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

	EQ	EQ0	EQ-minus	EQ-USD
α	1.47	-0.03	1.49	5.18
t-stat	[1.73]	[-0.06]	[1.86]	[3.40]
β_{RX}	0.14	-0.02	0.15	0.52
t-stat	[2.27]	[-0.50]	[2.80]	[4.31]
$\beta_{\mathrm{HML-FX}}$	0.28	0.24	0.04	0.00
t-stat	[8.24]	[11.03]	[1.58]	[-0.01]
R^2	0.31	0.41	0.09	0.20

Table 12: All Risk Factors

This table presents regressions of the EQ-USD returns on the Fama-French three factors, two pure foreign exchange risk factors constructed by Lustig, Roussanov, and Verdelhan (2011), and two USD bond market risk factors. The regression specification is

$$R_t = \alpha + \beta_{MKT} \cdot R_{m,t} + \beta_{HML} \cdot R_{HML,t} + \beta_{SMB} \cdot R_{SMB,t} + \beta_{10y} \cdot R_{10y,t} + \beta_{10y-2y} \cdot (R_{10y,t} - R_{2y,t}) + \beta_{RX} \cdot R_{RX,t} + \beta_{HML-FX} \cdot R_{HML-FX,t} + \beta_{VS} R_{VS,t} + \varepsilon_t$$

The sample period is 1990:02-2013:08 (283 observations). The reported alphas are in annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

	EQ-USD
α	4.52
t-stat	[2.79]
β_{MKT}	0.02
t-stat	[0.62]
β_{SMB}	-0.02
t-stat	[-0.36]
β_{HML}	0.06
t-stat	[1.15]
β_{10y}	0.43
t-stat	[1.47]
$\beta_{\text{10y}-\text{2y}}$	-0.57
t-stat	[-1.53]
β_{RX}	0.44
t-stat	[3.14]
$\beta_{\text{HML}-\text{FX}}$	0.14
t-stat	[2.03]
β_{vs}	0.13
t-stat	[2.67]
R^2	0.19

Table 13: Carry Trade Exposures to Downside Market Risk

This table presents regressions of the carry trade returns of six different strategies on the market return and the downside market return defined by Lettau, Maggiori, and Weber (2014). The market return $R_{m,t}$ is the excess return on the market, the value-weight excess return of all CRSP firms incorporated in the US and listed on the NYSE, AMEX, or NASDAQ; the downside market return $R^-_{m,t} = R_{m,t} \times I^-$ where $I^- = I\left(R_{m,t} < \overline{R_{m,t}} - std\left(R_{m,t}\right)\right)$ is the indicator function equal to 1 when the market return is one standard deviation below the average market return and zero elsewhere. The regression specification is

$$R_t = \alpha_1 + \alpha_2 I^- + \beta_1 \cdot R_{m,t} + \beta_2 \cdot R^-_{m,t} + \varepsilon_t$$

in which $\beta_2 = \beta^- - \beta_1$ and $\beta^- = \frac{Cov\left(R_{m,t},\ R_t|I^-=1\right)}{Var(R_{m,t}|I^-=1)}$. We define $\beta = \frac{Cov(R_{m,t},\ R_t)}{Var(R_{m,t})}$.
The sample period is 1976:02-2013:08 (451 observations). Excess returns are annualized. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Panel A:	EQ	SPD	EQ-RR	SPD-RR	OPT	EQ-USD
α	3.72	6.08	5.17	5.91	1.99	5.63
t-stat	[4.01]	[4.55]	[4.49]	[5.28]	[4.16]	[4.03]
β	0.03	0.07	0.04	0.04	0.02	-0.01
t-stat	[1.55]	[2.13]	[1.59]	[1.71]	[1.51]	[-0.36]
R^2	0.01	0.02	0.01	0.01	0.01	0.00

Panel B:	EQ	SPD	EQ-RR	SPD-RR	OPT	EQ-USD
α	4.08	6.19	5.94	6.38	2.22	4.86
t-stat	[3.86]	[4.13]	[4.50]	[4.82]	[4.69]	[3.13]
$\alpha-$	-1.26	7.02	-1.74	7.67	-0.73	-9.36
t-stat	[-0.20]	[0.91]	[-0.19]	[1.12]	[-0.21]	[-0.89]
β_1	0.02	0.06	0.01	0.02	0.01	0.02
t-stat	[0.87]	[1.51]	[0.57]	[0.73]	[0.66]	[0.45]
β_2	0.01	0.09	0.03	0.12	0.01	-0.16
t-stat	[0.15]	[0.98]	[0.28]	[1.43]	[0.17]	[-1.31]
R^2	0.01	0.02	0.01	0.02	0.01	0.01

Panel C:	EQ	SPD	EQ-RR	SPD-RR	OPT	EQ-USD
$\beta^- - \beta$	0.00	0.08	0.01	0.10	0.00	-0.13
		Downside Risk Premium$(\beta^- - \beta) \times \lambda^-$				
$\lambda^- = 16.9$	0.00	1.31	0.16	1.63	0.01	-2.12
$\lambda^- = 26.2$	0.00	2.02	0.25	2.53	0.02	-3.28

Table 14: Carry Trade Exposures to Downside Market Risk- LRV Six Portfolios

This table presents regressions of Lustig, Roussanov, and Verdelhan (2011) six interest rate sorted portfolios returns on the market return and the downside market return defined by Lettau, Maggiori, and Weber (2014). The market return $R_{m,t}$ is the excess return on the market, the value-weight excess return of all CRSP firms incorporated in the US and listed on the NYSE, AMEX, or NASDAQ; the downside market return $R^-_{m,t} = R_{m,t} \times I^-$ where $I^- = I\left(R_{m,t} < \overline{R_{m,t}} - std\left(R_{m,t}\right)\right)$ is the indicator function equal to 1 when the market return is one standard deviation below the average market return and zero elsewhere. The regression specification is

$$R_t = \alpha_1 + \alpha_2 I^- + \beta_1 \cdot R_{m,t} + \beta_2 \cdot R^-_{m,t} + \varepsilon_t$$

in which $\beta_2 = \beta^- - \beta_1$ and $\beta^- = \frac{Cov\left(R_{m,t},\ R_t | I^-=1\right)}{Var(R_{m,t}|I^-=1)}$. We define $\beta = \frac{Cov(R_{m,t},\ R_t)}{Var(R_{m,t})}$.
The sample period is 1983:11-2013:08 (358 observations). Excess returns are annualized. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Panel A:	P1	P2	P3	P4	P5	P6	P6-P1
α	-1.59	-0.32	0.99	2.97	3.25	4.88	6.46
t-stat	[-1.00]	[-0.22]	[0.66]	[1.79]	[1.75]	[2.39]	[3.67]
β	0.02	0.04	0.05	0.07	0.12	0.20	0.18
t-stat	[0.42]	[1.09]	[1.49]	[1.73]	[2.45]	[4.39]	[5.62]
R^2	0.00	0.01	0.01	0.02	0.04	0.10	0.10

Panel B:	P1	P2	P3	P4	P5	P6	P6-P1
α	-2.83	-0.44	0.72	2.50	3.49	4.09	6.92
t-stat	[-1.55]	[-0.26]	[0.44]	[1.47]	[1.68]	[1.87]	[3.50]
$\alpha-$	6.16	-0.87	3.86	-4.52	-7.78	10.70	4.55
t-stat	[0.49]	[-0.06]	[0.28]	[-0.44]	[-0.55]	[0.73]	[0.38]
β_1	0.05	0.04	0.06	0.09	0.11	0.21	0.17
t-stat	[1.21]	[1.16]	[1.43]	[2.09]	[2.15]	[4.34]	[3.76]
β_2	-0.01	-0.02	0.02	-0.08	-0.07	0.06	0.08
t-stat	[-0.08]	[-0.09]	[0.14]	[-0.55]	[-0.35]	[0.34]	[0.56]
R^2	0.01	0.01	0.01	0.02	0.05	0.10	0.10

Panel C:	P1	P2	P3	P4	P5	P6	P6-P1
$\beta^- - \beta$	0.02	-0.01	0.03	-0.06	-0.07	0.08	0.06
		Downside Risk Premium$(\beta^- - \beta) \times \lambda^-$					
$\lambda^- = 16.9$	0.33	-0.21	0.50	-1.04	-1.19	1.37	1.04
$\lambda^- = 26.2$	0.51	-0.33	0.78	-1.61	-1.83	2.12	1.61

Table 15: Carry Trade Exposures to Downside Market Risk-LMW Five Portfolios

This table presents regressions of Lettau, Maggiori, and Weber (2014) five interest rate sorted portfolios returns on the market return and the downside market return. The market return $R_{m,t}$ is the excess return on the market, the value-weight excess return of all CRSP firms incorporated in the US and listed on the NYSE, AMEX, or NASDAQ; the downside market return $R^-_{m,t} = R_{m,t} \times I^-$ where $I^- = I\left(R_{m,t} < \overline{R_{m,t}} - std\left(R_{m,t}\right)\right)$ is the indicator function equal to 1 when the market return is one standard deviation below the average market return and zero elsewhere. The regression specification is

$$R_t = \alpha_1 + \alpha_2 I^- + \beta_1 \cdot R_{m,t} + \beta_2 \cdot R^-_{m,t} + \varepsilon_t$$

in which $\beta_2 = \beta^- - \beta_1$ and $\beta^- = \frac{Cov\left(R_{m,t},\ R_t|I^-=1\right)}{Var(R_{m,t}|I^-=1)}$. We define $\beta = \frac{Cov(R_{m,t},\ R_t)}{Var(R_{m,t})}$. The sample period is 1983:11-2010:03 (317 observations). Excess returns are annualized. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Panel A:	P1	P2	P3	P4	P5	P5-P1
α	-0.35	0.45	2.64	3.48	4.17	4.52
t-stat	[-0.21]	[0.22]	[1.29]	[1.80]	[1.75]	[2.68]
β	-0.03	0.02	0.03	0.06	0.12	0.15
t-stat	[-0.87]	[0.60]	[0.59]	[1.44]	[1.90]	[3.85]
R^2	0.00	0.00	0.00	0.01	0.04	0.10
NOBS	317	317	317	317	317	317

Panel B:	P1	P2	P3	P4	P5	P5-P1
α	-1.34	1.22	2.31	3.66	5.36	6.70
t-stat	[-0.72]	[0.54]	[1.03]	[1.71]	[2.36]	[4.19]
$\alpha-$	5.64	-4.62	1.39	10.12	8.07	2.44
t-stat	[0.44]	[-0.33]	[0.09]	[0.79]	[0.41]	[0.23]
β_1	0.00	0.00	0.04	0.05	0.08	0.08
t-stat	[-0.12]	[0.07]	[0.72]	[0.97]	[1.39]	[2.00]
β_2	-0.01	0.00	-0.01	0.12	0.16	0.17
t-stat	[-0.03]	[0.01]	[-0.03]	[0.81]	[0.58]	[1.14]
R^2	0.01	0.00	0.00	0.02	0.04	0.12
NOBS	317	317	317	317	317	317

Panel C:	P1	P2	P3	P4	P5	P5-P1
$\beta^- - \beta$	0.02	-0.02	0.00	0.11	0.12	0.10
	Downside Risk Premium$(\beta^- - \beta) \times \lambda^-$					
$\lambda^- = 16.9$	0.36	-0.33	0.04	1.78	2.03	1.66
$\lambda^- = 26.2$	0.56	-0.50	0.06	2.75	3.13	2.57

Table 16: Carry Trade Exposures to Downside Risk Index

Panel A of this table presents regressions of the carry trade returns of five different strategies, the pure dollar carry trade, the non-dollar and dollar components of equally weighted carry trade on downside risk index (DRI) reported by Jurek and Stafford (2013). The regression specification is

$$R_t = \alpha + \beta_{DRI} \cdot R_{DRI,t} + \varepsilon_t$$

.
Panel B augments the DRI with Fama-French three factors. The regression specification is

$$R_t = \alpha + \beta_{MKT} \cdot R_{m,t} + \beta_{HML} \cdot R_{HML,t} + \beta_{SMB} \cdot R_{SMB,t} + \beta_{DRI} \cdot R_{DRI,t} + \varepsilon_t$$

.
The sample period is 1990:01-2013:07 (283 observations). Jurek provides us with the DRI return from 1990:01 to 2012:06. We use Option Metrics data to construct the DRI returns from 2012:07 to 2013:07 using the methodology reported in Jurek and Stafford (2013). The reported alphas are annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Panel A:	EQ	SPD	EQ-RR	SPD-RR	OPT	EQ-USD	EQ0	EQ-minus
α	2.59	3.22	4.18	4.07	1.26	5.37	0.10	2.49
t-stat	[2.05]	[1.74]	[2.99]	[2.67]	[2.17]	[2.83]	[0.13]	[2.39]
β_{DRI}	0.14	0.28	0.10	0.13	0.05	-0.01	0.18	-0.04
t-stat	[2.45]	[2.90]	[1.89]	[2.36]	[2.26]	[-0.11]	[5.14]	[-0.76]
R^2	0.03	0.06	0.02	0.03	0.02	0.00	0.14	0.00

Panel B:	EQ	SPD	EQ-RR	SPD-RR	OPT	EQ-USD	EQ0	EQ-minus
α	2.90	3.70	4.33	4.09	1.22	6.07	0.45	2.45
t-stat	[2.31]	[1.98]	[3.04]	[2.60]	[2.08]	[3.05]	[0.51]	[2.33]
β_{DRI}	0.05	0.09	0.05	0.08	0.03	-0.19	0.09	-0.04
t-stat	[0.64]	[0.79]	[0.73]	[1.08]	[0.85]	[-1.33]	[1.49]	[-0.53]
β_{MKT}	0.07	0.13	0.04	0.04	0.02	0.11	0.05	0.01
t-stat	[1.63]	[2.07]	[1.04]	[1.01]	[0.99]	[1.86]	[2.54]	[0.41]
β_{SMB}	-0.04	-0.01	-0.04	-0.01	0.01	-0.04	0.01	-0.05
t-stat	[-0.90]	[-0.13]	[-0.99]	[-0.33]	[1.05]	[-0.71]	[0.74]	[-1.48]
β_{HML}	0.06	0.13	0.04	0.06	0.03	0.07	0.03	0.03
t-stat	[1.68]	[2.65]	[1.16]	[1.89]	[2.41]	[1.18]	[1.85]	[0.96]
R^2	0.06	0.10	0.03	0.04	0.04	0.02	0.17	0.03

Table 17: Hedged Carry Trade Performance

This table presents summary statistics for the currency-hedged carry trades for the EQ, SPD, EQ-USD strategies. The currency return data are monthly from 2000:10-2013:08. The sample includes G10 currencies other than Swedish Krona, for which we don't have option data. The reported parameters (mean, standard deviation, skewness, excess kurtosis, and autocorrelation coefficient) and their associated standard errors are simultaneous GMM estimates. The Sharpe ratio is the ratio of the annualized mean and standard deviation, and its standard error is calculated using the delta method (see Appendix B.) The hedging strategy is described in Section 2.3.

	Unhedged			Hedged					
	EQ	SPD	EQ-USD	EQ-10Δ	EQ-25Δ	SPD-10Δ	SPD-25Δ	USD-10Δ	USD-25Δ
Ave Ret (% p.a.)	2.22	5.55	4.58	1.84	1.35	5.21	4.26	3.97	3.13
(std. err.)	(1.43)	(2.50)	(2.27)	(1.22)	(1.05)	(2.19)	(1.87)	(2.07)	(1.81)
Standard Dev,	4.75	8.39	8.59	4.32	3.96	7.53	6.65	7.95	7.07
(std. err.)	(0.38)	(0.79)	(0.66)	(0.32)	(0.31)	(0.69)	(0.62)	(0.61)	(0.61)
Sharpe Ratio	0.47	0.66	0.20	0.42	0.34	0.69	0.64	0.54	0.93
(std. err.)	(0.31)	(0.31)	(0.26)	(0.29)	(0.26)	(0.29)	(0.27)	(0.23)	(0.23)
Skewness	-0.32	-0.23	0.84	0.02	0.27	0.28	0.70	0.65	1.22
(std. err.)	(0.20)	(0.28)	(0.42)	(0.19)	(0.27)	(0.25)	(0.26)	(0.53)	(0.87)
Excess Kurtosis	0.71	1.88	-0.11	0.36	0.65	1.40	1.54	-0.13	-0.16
(std. err.)	(0.43)	(0.60)	(0.08)	(0.33)	(0.40)	(0.57)	(0.60)	(0.09)	(0.10)
Autocorrelation	0.01	0.02	0.53	-0.07	-0.13	-0.02	-0.07	0.50	0.44
(std. err.)	(0.12)	(0.11)	(0.26)	(0.10)	(0.10)	(0.10)	(0.09)	(0.25)	(0.24)
Max (%)	4.04	8.01	0.09	3.75	3.48	7.67	7.01	0.09	0.08
Min (%)	-4.12	-7.44	-0.07	-2.93	-3.52	-6.30	-4.75	-0.05	-0.04
No. Positive	93	99	85	94	86	97	91	84	76
No. Negative	62	56	70	61	69	58	64	71	79

Table 18: Hedged Carry Trades Exposures to Equity Risks

This table presents regressions of the hedged carry trade returns of EQ, SPD, and EQ-USD strategies on three equity market risk factors postulated by Fama and French (1993). The regression specification is

$$R_t = \alpha + \beta_{MKT} \cdot R_{m,t} + \beta_{HML} \cdot R_{HML,t} + \beta_{SMB} \cdot R_{SMB,t} + \varepsilon_t.$$

The second specification includes the return on a variance swap.

$$R_t = \alpha + \beta_{MKT} \cdot R_{m,t} + \beta_{HML} \cdot R_{HML,t} + \beta_{SMB} \cdot R_{SMB,t} + \beta_{VS} VS_t + \varepsilon_t.$$

The Fama-French factors are from Ken French's data library. The sample period is 2000:10-2013:08 (155 observations) and includes G10 currencies other than Swedish Krona, for which we don't have option data. Results for unhedged returns over the same sample are reported for the ease of comparison. The reported alphas are annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Panel A:	EQ	SPD	EQ-USD	EQ-10Δ	EQ-25Δ	SPD-10Δ	SPD-25Δ	USD-10Δ	USD-25Δ
α	1.80	4.23	3.88	1.45	1.01	3.95	3.18	3.29	2.54
t-stat	[1.55]	[2.13]	[1.72]	[1.43]	[1.10]	[2.23]	[2.04]	[1.60]	[1.41]
β_{MKT}	0.13	0.26	0.07	0.11	0.09	0.23	0.18	0.07	0.05
t-stat	[5.26]	[4.99]	[1.05]	[5.00]	[3.71]	[4.92]	[4.20]	[1.00]	[0.81]
β_{SMB}	0.00	-0.02	0.04	0.01	0.01	-0.01	0.00	0.04	0.04
t-stat	[-0.00]	[-0.35]	[0.57]	[0.15]	[0.25]	[-0.12]	[0.01]	[0.57]	[0.59]
β_{HML}	0.03	0.14	0.08	0.03	0.03	0.13	0.11	0.08	0.07
t-stat	[1.17]	[3.14]	[1.18]	[1.11]	[1.17]	[3.19]	[3.27]	[1.27]	[1.32]
R^2	0.20	0.26	0.03	0.18	0.13	0.26	0.22	0.03	0.03

Panel B:	EQ	SPD	EQ-USD	EQ-10Δ	EQ-25Δ	SPD-10Δ	SPD-25Δ	USD-10Δ	USD-25Δ
α	1.58	4.07	4.76	1.43	1.15	3.92	3.30	4.17	3.39
t-stat	[1.42]	[2.07]	[2.10]	[1.42]	[1.24]	[2.22]	[2.08]	[2.02]	[1.89]
β_{MKT}	0.12	0.25	0.14	0.11	0.10	0.22	0.19	0.13	0.11
t-stat	[3.74]	[3.96]	[2.20]	[3.95]	[3.72]	[4.08]	[3.85]	[2.24]	[2.21]
β_{SMB}	-0.01	-0.03	0.06	0.01	0.01	-0.01	0.00	0.06	0.06
t-stat	[-0.12]	[-0.41]	[0.80]	[0.13]	[0.34]	[-0.14]	[0.07]	[0.82]	[0.88]
β_{HML}	0.03	0.14	0.10	0.03	0.03	0.13	0.12	0.10	0.09
t-stat	[0.99]	[3.01]	[1.56]	[1.08]	[1.32]	[3.13]	[3.39]	[1.69]	[1.80]
β_{VS}	-0.03	-0.02	0.11	0.00	0.02	0.00	0.01	0.11	0.10
t-stat	[-1.30]	[-0.45]	[2.10]	[-0.11]	[0.74]	[-0.09]	[0.37]	[2.18]	[2.29]
R^2	0.21	0.26	0.07	0.18	0.14	0.26	0.22	0.08	0.08

Table 19: Hedged Carry Trades Exposures to Bond Risks

This table presents regressions of the hedged carry trade returns of EQ, SPD, and EQ-USD strategies on on the excess return on the U.S. equity market and two USD bond market risk factors: the excess return on the 10-year Treasury bond; and the excess return of the 10-year bond over the two-year Treasury note. The regression specification is

$$R_t = \alpha + \beta_{MKT} \cdot R_{m,t} + \beta_{10y} \cdot R_{10y,t} + \beta_{10y-2y} \cdot (R_{10y,t} - R_{2y,t}) + \varepsilon_t$$

The second specification includes the return on a variance swap.

$$R_t = \alpha + \beta_{MKT} \cdot R_{m,t} + \beta_{10y} \cdot R_{10y,t} + \beta_{10y-2y} \cdot (R_{10y,t} - R_{2y,t}) + \beta_{VS} VS_t + \varepsilon_t.$$

The sample period is 2000:10-2013:08 (155 observations) and includes G10 currencies other than Swedish Krona, for which we don't have option data. Results for unhedged returns over the same sample are reported for the ease of comparison. The reported alphas are annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Panel A:	EQ	SPD	EQ-USD	EQ-10Δ	EQ-25Δ	SPD-10Δ	SPD-25Δ	USD-10Δ	USD-25Δ
α	1.51	3.00	2.13	1.09	0.60	2.80	2.11	1.67	1.15
t-stat	[1.22]	[1.44]	[0.95]	[1.03]	[0.66]	[1.57]	[1.42]	[0.82]	[0.66]
β_{MKT}	0.14	0.30	0.13	0.13	0.10	0.27	0.22	0.12	0.09
t-stat	[4.85]	[5.14]	[1.89]	[4.71]	[4.07]	[5.13]	[4.74]	[1.84]	[1.64]
β_{10y}	0.16	0.99	1.47	0.24	0.36	0.96	0.99	1.39	1.27
t-stat	[0.56]	[2.12]	[2.36]	[0.90]	[1.47]	[2.23]	[2.66]	[2.39]	[2.49]
$\beta_{\text{10y}-\text{2y}}$	-0.10	-0.96	-1.61	-0.21	-0.38	-0.94	-1.04	-1.52	-1.43
t-stat	[-0.30]	[-1.76]	[-2.11]	[-0.66]	[-1.24]	[-1.87]	[-2.29]	[-2.12]	[-2.20]
R^2	0.21	0.27	0.08	0.19	0.14	0.27	0.24	0.08	0.08

Panel B:	EQ	SPD	EQ-USD	EQ-10Δ	EQ-25Δ	SPD-10Δ	SPD-25Δ	USD-10Δ	USD-25Δ
α	1.15	2.46	3.14	1.01	0.71	2.48	1.98	2.68	2.14
t-stat	[0.97]	[1.27]	[1.39]	[0.97]	[0.79]	[1.49]	[1.39]	[1.32]	[1.23]
β_{MKT}	0.13	0.27	0.18	0.12	0.11	0.25	0.21	0.17	0.14
t-stat	[3.71]	[3.92]	[2.55]	[4.01]	[3.86]	[4.01]	[3.82]	[2.56]	[2.51]
β_{10y}	0.24	1.11	1.25	0.26	0.33	1.03	1.02	1.17	1.05
t-stat	[0.83]	[2.39]	[2.29]	[0.95]	[1.39]	[2.39]	[2.75]	[2.36]	[2.51]
$\beta_{\text{10y}-\text{2y}}$	-0.21	-1.11	-1.32	-0.23	-0.34	-1.03	-1.08	-1.23	-1.15
t-stat	[-0.60]	[-2.04]	[-2.04]	[-0.71]	[-1.17]	[-2.03]	[-2.39]	[-2.10]	[-2.26]
β_{VS}	-0.03	-0.04	0.08	-0.01	0.01	-0.02	-0.01	0.08	0.08
t-stat	[-1.45]	[-0.97]	[1.53]	[-0.27]	[0.40]	[-0.61]	[-0.26]	[1.59]	[1.70]
R^2	0.22	0.27	0.10	0.19	0.14	0.27	0.24	0.10	0.10

Table 20: Hedged Carry Trades Exposures to Downside Risk Index

This table presents regressions of the hedged carry trade returns of EQ, SPD, and EQ-USD strategies on downside risk index (DRI) reported by Jurek and Stafford (2013). The regression specification is

$$R_t = \alpha + \beta_{DRI} \cdot R_{DRI,t} + \varepsilon_t$$

The sample period is 2000:10-2013:08 (155 observations) and includes G10 currencies other than Swedish Krona, for which we don't have option data. Results for unhedged returns over the same sample are reported for the ease of comparison. The reported alphas are annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

	EQ	SPD	EQ-USD	EQ-10Δ	EQ-25Δ	SPD-10Δ	SPD-25Δ	USD-10Δ	USD-25Δ
α	0.12	1.73	4.58	0.31	0.51	2.15	2.18	4.21	3.72
t-stat	[0.10]	[0.75]	[1.66]	[0.28]	[0.48]	[1.09]	[1.28]	[1.66]	[1.65]
β_{DRI}	0.25	0.45	0.03	0.19	0.11	0.37	0.26	0.01	-0.03
t-stat	[4.97]	[3.40]	[0.20]	[3.54]	[1.94]	[3.17]	[2.41]	[0.04]	[-0.25]
R^2	0.16	0.16	0.00	0.11	0.05	0.14	0.09	0.00	0.00

Table 21: Summary Statistics of Daily Carry Trade Returns

Panels A and B present summary statistics on the daily zero-investment portfolio returns for five carry-trade strategies. The sample period is 1976:02-2013:08. The reported parameters, (mean, standard deviation, skewness, excess kurtosis, and autocorrelation coefficient) and their associated standard errors are simultaneous GMM estimates. The Sharpe ratio is the ratio of the annualized mean and standard deviation, and its standard error is calculated using the delta method (see Appendix B).
Panel C takes the ratios of the monthly central moments to the daily central moments and normalize these ratios by the expected ratios if daily returns were I.I.D. Therefore, if daily returns are indeed I.I.D., the normalized ratios should be 1.

	Panel A: Daily Carry Trade Returns				Panel B: Monthly Carry Trade Returns			
	EQ	EQ-RR	SPD	SPD-RR	EQ	EQ-RR	SPD	SPD-RR
Ave Ret (% p.a.)	3.92	5.38	6.53	6.13	3.96	5.44	6.60	6.18
(std. err.)	(0.82)	(0.91)	(1.18)	(0.93)	(0.91)	(1.13)	(1.31)	(1.09)
Standard Dev.	5.06	5.54	7.25	5.65	5.06	5.90	7.62	6.08
(std. err.)	(0.10)	(0.11)	(0.15)	(0.15)	(0.28)	(0.22)	(0.41)	(0.24)
Sharpe Ratio	0.77	0.97	0.90	1.08	0.78	0.92	0.87	1.02
(std. err.)	(0.17)	(0.17)	(0.17)	(0.18)	(0.19)	(0.20)	(0.19)	(0.19)
Skewness	-0.32	-1.01	-0.59	-1.62	-0.49	-0.37	-0.31	-0.44
(std. err.)	(0.17)	(0.43)	(0.33)	(0.71)	(0.21)	(0.11)	(0.19)	(0.14)
Excess Kurt.	7.46	11.90	10.25	24.43	2.01	0.40	1.78	0.90
(std. err.)	(1.16)	(6.61)	(4.05)	(12.02)	(0.53)	(0.21)	(0.35)	(0.29)
Autocorr.	0.03	0.02	0.02	0.02	0.08	0.16	0.02	0.09
(std. err.)	(0.02)	(0.01)	(0.01)	(0.01)	(0.07)	(0.05)	(0.07)	(0.05)
Max (%)	3.12	2.13	4.52	2.58	4.78	5.71	8.07	5.96
Min (%)	-2.78	-5.64	-6.57	-6.61	-6.01	-4.90	-7.26	-5.88
No. Positive	5230	5230	5223	5223	288	288	297	297
No. Negative	4342	4342	4349	4349	163	163	154	154

Panel C: Normalized Ratios of Higher Central Moments

	EQ	EQ-RR	SPD	SPD-RR
Ave Ret (% p.a.)	1.0	1.0	1.0	1.0
Standard Deviation	1.0	0.9	1.0	0.9
Sharpe Ratio	1.0	1.1	1.0	1.1
Skewness	7.1	1.7	2.4	1.3
Kurtosis	5.7	0.7	3.7	0.8

Table 22: Drawdowns

This table presents p-value of the cumulative distribution of Drawdowns of the monthly zero-investment portfolio returns for four carry-trade strategies under two simulation methods. The p-value under simulations of a normal distribution is labeled "p_n" and the p-value under simulations of bootstrapping method is labeled "p_b". "days" indicates how many days the n^{th} worst drawdown lasts. The strategies are the basic equal-weighted (*EQ*) and spread-weighted (*SPD*) strategies, and their risk-rebalanced versions (labeled "*-RR*"). The weights in the basic strategies are calibrated to have one dollar at risk each month. The risk-rebalanced strategies rescale the basic weights by IGARCH estimates of a covariance matrix to target a 5% volatility. The sample period is 1976:02-2013:08 except for the AUD and the NZD, which start in October 1986.

Worst 20 Drawdowns

	EQ				SPD				EQ-RR				SPD-RR			
Freq	Mag.	p-n	p-b	days	Mag.	p-n	p-b	days	Mag.	p-n	p-b	days	Mag.	p-n	p-b	days
1	12.0%	12.6%	13.0%	94	21.5%	1.7%	2.3%	163	14.1%	4.2%	6.4%	353	10.2%	25.8%	40.3%	69
2	10.8%	1.6%	1.8%	107	13.2%	7.4%	9.8%	60	10.5%	2.4%	4.9%	340	9.7%	5.2%	14.3%	340
3	9.6%	0.3%	0.5%	98	9.5%	39.4%	46.0%	134	9.0%	1.5%	3.6%	69	8.4%	3.4%	13.4%	80
4	7.8%	1.1%	1.4%	112	9.4%	16.4%	21.8%	96	8.6%	0.3%	0.9%	305	7.6%	2.8%	13.4%	68
5	5.8%	21.9%	24.0%	37	9.4%	6.1%	8.9%	51	7.8%	0.3%	1.1%	68	7.2%	1.5%	8.8%	62
6	5.2%	34.1%	36.0%	22	9.0%	3.4%	5.1%	62	6.6%	1.7%	5.3%	53	7.1%	0.3%	3.2%	114
7	5.2%	17.8%	19.6%	49	8.9%	1.2%	1.9%	38	6.5%	0.5%	2.6%	98	6.7%	0.2%	2.6%	96
8	4.9%	20.4%	22.3%	32	8.4%	1.0%	2.0%	305	5.6%	5.6%	13.5%	60	6.4%	0.2%	2.1%	18
9	4.8%	10.5%	12.0%	78	8.2%	0.5%	0.9%	67	5.5%	2.2%	6.9%	37	5.8%	0.6%	3.8%	6
10	4.7%	6.9%	8.1%	136	8.2%	0.1%	0.2%	65	5.5%	0.7%	2.9%	6	5.6%	0.3%	2.5%	2
11	4.7%	4.3%	4.9%	59	6.4%	17.5%	20.4%	23	5.5%	0.2%	1.1%	128	5.6%	0.1%	1.0%	220
12	4.5%	4.9%	5.4%	62	6.3%	15.3%	17.5%	80	5.5%	0.1%	0.4%	17	5.4%	0.1%	0.7%	38
13	4.4%	3.0%	3.3%	23	6.1%	12.8%	14.4%	113	5.1%	0.2%	0.8%	67	5.3%	0.1%	0.4%	113
14	3.8%	25.8%	25.9%	19	5.8%	17.5%	17.9%	47	4.6%	2.2%	4.6%	112	5.2%	0.0%	0.2%	56
15	3.8%	20.3%	20.6%	6	5.8%	11.0%	11.5%	70	4.6%	1.0%	2.2%	32	5.0%	0.0%	0.2%	17
16	3.8%	12.6%	12.8%	13	5.5%	15.5%	14.7%	111	4.0%	17.0%	21.8%	85	4.4%	1.4%	2.0%	70
17	3.7%	12.5%	12.9%	86	5.5%	8.9%	8.5%	18	3.8%	28.9%	33.0%	17	4.2%	2.8%	3.4%	14
18	3.5%	16.8%	16.3%	52	4.8%	63.7%	55.5%	69	3.7%	26.7%	29.8%	23	4.0%	4.6%	4.9%	60
19	3.2%	52.5%	49.9%	28	4.7%	56.7%	47.5%	33	3.6%	34.5%	35.2%	33	3.7%	27.2%	19.9%	36
20	3.1%	54.0%	50.2%	23	4.5%	70.9%	61.3%	17	3.5%	35.4%	35.1%	23	3.6%	28.7%	20.2%	67

Table 23: Maximum Losses

This table presents p-value of maximum losses over a certain number of days of the monthly zero-investment portfolio returns for four carry-trade strategies under two simulation methods. The p-value under simulations of a normal distribution is labeled "p_n" and the p-value under simulations of bootstrapping method is labeled "p_b". The strategies are the basic equal-weighted (*EQ*) and spread-weighted (*SPD*) strategies, and their risk-rebalanced versions (labeled "-*RR*"). The weights in the basic strategies are calibrated to have one dollar at risk each month. The risk-rebalanced strategies rescale the basic weights by IGARCH estimates of a covariance matrix to target a 5% volatility. The sample period is 1976:02-2013:08 except for the AUD and the NZD, which start in October 1986.

Maximum Losses

	EQ			SPD			EQ-RR			SPD-RR		
Horizon (days)	Mag.	p-n	p-b	Mag.	p-n	p-b	Mag.	p-n	p-b	Mag.	p-n	p-b
1	-2.7%	0.0%	59.4%	-6.5%	0.0%	44.6%	-5.6%	0.0%	43.5%	-6.6%	0.0%	43.5%
2	-3.5%	0.0%	8.1%	-6.4%	0.0%	56.9%	-5.5%	0.0%	55.6%	-6.5%	0.0%	57.2%
3	-4.0%	0.0%	5.4%	-6.6%	0.0%	48.0%	-6.0%	0.0%	23.9%	-6.6%	0.0%	48.7%
4	-4.4%	0.0%	2.9%	-6.5%	0.0%	54.3%	-5.8%	0.0%	42.3%	-6.5%	0.0%	58.4%
5	-5.0%	0.0%	1.2%	-6.8%	0.0%	43.3%	-5.8%	0.0%	45.1%	-6.5%	0.0%	62.2%
6	-5.2%	0.0%	1.3%	-7.3%	0.0%	28.9%	-5.9%	0.0%	41.9%	-6.5%	0.0%	62.4%
7	-4.9%	0.0%	3.9%	-6.7%	0.0%	50.4%	-5.9%	0.0%	41.2%	-6.4%	0.0%	65.7%
8	-5.2%	0.0%	2.7%	-7.2%	0.0%	37.0%	-6.1%	0.0%	36.7%	-6.4%	0.0%	67.3%
9	-5.5%	0.0%	1.7%	-7.7%	0.0%	27.2%	-6.3%	0.0%	30.2%	-6.3%	0.0%	69.1%
10	-6.0%	0.0%	0.8%	-8.1%	0.0%	18.6%	-6.4%	0.0%	29.0%	-6.3%	0.0%	69.8%
11	-6.7%	0.0%	0.2%	-8.8%	0.0%	10.3%	-6.2%	0.0%	38.0%	-6.3%	0.0%	70.6%
12	-7.0%	0.0%	0.1%	-9.2%	0.0%	6.8%	-6.2%	0.0%	39.7%	-6.3%	0.0%	71.0%
13	-7.0%	0.0%	0.2%	-9.2%	0.0%	8.4%	-6.3%	0.0%	38.0%	-6.3%	0.1%	71.5%
14	-5.5%	0.1%	6.6%	-8.4%	0.0%	19.4%	-6.1%	0.1%	44.5%	-6.3%	0.1%	72.1%
15	-5.1%	0.9%	18.2%	-8.0%	0.1%	28.8%	-6.1%	0.2%	45.1%	-6.2%	0.1%	73.5%
20	-5.9%	0.5%	9.0%	-8.7%	0.3%	22.9%	-6.0%	2.1%	53.7%	-6.2%	1.3%	74.9%
25	-6.7%	0.4%	4.8%	-8.7%	1.7%	28.4%	-6.0%	8.2%	59.3%	-6.6%	2.1%	67.2%
30	-7.6%	0.1%	1.6%	-10.2%	0.3%	10.9%	-7.3%	1.0%	25.6%	-6.7%	4.6%	66.1%
35	-8.2%	0.0%	1.1%	-10.7%	0.4%	9.3%	-7.6%	1.3%	22.0%	-7.1%	4.4%	57.4%
40	-8.4%	0.0%	1.3%	-12.1%	0.1%	3.6%	-8.4%	0.5%	11.9%	-8.1%	1.1%	32.6%
45	-8.9%	0.0%	0.8%	-12.2%	0.3%	4.3%	-8.3%	1.2%	14.3%	-8.2%	1.8%	33.0%
50	-9.2%	0.1%	0.8%	-11.8%	0.8%	7.1%	-9.0%	0.8%	9.5%	-8.0%	4.7%	39.3%
60	-10.0%	0.0%	0.5%	-13.3%	0.3%	3.3%	-9.6%	0.6%	6.7%	-9.1%	1.8%	21.1%
120	-11.0%	1.0%	1.6%	-17.4%	0.1%	0.8%	-10.2%	4.3%	9.8%	-8.3%	23.7%	40.7%
180	-11.3%	2.8%	3.3%	-20.2%	0.1%	0.4%	-10.3%	8.1%	12.7%	-8.4%	24.8%	34.7%

Table 24: Pure Drawdowns

This table presents p-value of the cumulative distribution of Pure Drawdowns of the monthly zero-investment portfolio returns for four carry-trade strategies under two simulation methods. The p-value under simulations of a normal distribution is labeled "p_n" and the p-value under simulations of bootstrapping method is labeled "p_b". "days" indicates how many days the n^{th} worst pure drawdown lasts. The strategies are the basic equal-weighted (*EQ*) and spread-weighted (*SPD*) strategies, and their risk-rebalanced versions (labeled "-*RR*"). The weights in the basic strategies are calibrated to have one dollar at risk each month. The risk-rebalanced strategies rescale the basic weights by IGARCH estimates of a covariance matrix to target a 5% volatility. The sample period is 1976:02-2013:08 except for the AUD and the NZD, which start in October 1986.

Worst 20 Pure Drawdowns

	EQ				SPD				EQ-RR				SPD-RR			
Freq	Mag.	p-n	p-b	days	Mag.	p-n	p-b	days	Mag.	p-n	p-b	days	Mag.	p-n	p-b	days
1	5.2%	0.3%	1.4%	7	7.3%	0.2%	19.1%	7	5.6%	0.3%	57.9%	2	6.6%	0.0%	61.3%	2
2	4.4%	0.1%	0.5%	12	6.9%	0.0%	6.4%	7	5.5%	0.0%	28.3%	6	5.8%	0.0%	44.0%	6
3	3.8%	0.0%	0.5%	5	6.5%	0.0%	5.9%	2	4.6%	0.0%	14.4%	8	5.6%	0.0%	29.0%	2
4	3.8%	0.0%	0.1%	6	6.2%	0.0%	2.4%	6	4.1%	0.0%	13.1%	8	4.5%	0.0%	27.3%	6
5	3.5%	0.0%	0.1%	5	5.8%	0.0%	0.7%	8	3.7%	0.0%	14.3%	8	4.2%	0.0%	22.1%	8
6	3.5%	0.0%	0.0%	3	4.8%	0.0%	0.8%	9	3.7%	0.0%	6.6%	6	3.7%	0.0%	14.7%	6
7	3.3%	0.0%	0.0%	4	4.7%	0.0%	0.3%	6	3.3%	0.0%	9.3%	2	3.6%	0.0%	8.2%	7
8	3.2%	0.0%	0.0%	8	4.6%	0.0%	0.1%	4	3.3%	0.0%	4.6%	7	3.5%	0.0%	4.5%	10
9	3.2%	0.0%	0.0%	7	4.4%	0.0%	0.1%	8	3.1%	0.0%	4.9%	5	3.4%	0.0%	2.3%	8
10	3.1%	0.0%	0.0%	8	4.4%	0.0%	0.0%	4	3.0%	0.0%	4.3%	5	3.2%	0.0%	1.8%	7
11	3.0%	0.0%	0.0%	6	4.4%	0.0%	0.0%	4	2.8%	0.1%	8.1%	5	3.1%	0.0%	1.4%	5
12	3.0%	0.0%	0.0%	3	4.3%	0.0%	0.0%	7	2.8%	0.0%	4.4%	12	2.9%	0.0%	3.2%	5
13	2.9%	0.0%	0.0%	6	4.2%	0.0%	0.0%	7	2.8%	0.0%	2.3%	4	2.9%	0.0%	1.8%	5
14	2.9%	0.0%	0.0%	8	4.1%	0.0%	0.0%	8	2.7%	0.0%	1.3%	5	2.8%	0.0%	1.3%	5
15	2.8%	0.0%	0.0%	5	3.9%	0.0%	0.0%	6	2.7%	0.0%	1.4%	5	2.7%	0.0%	1.6%	5
16	2.8%	0.0%	0.0%	3	3.8%	0.0%	0.0%	8	2.7%	0.0%	0.7%	8	2.7%	0.0%	0.9%	6
17	2.8%	0.0%	0.0%	4	3.7%	0.0%	0.0%	6	2.6%	0.0%	0.5%	4	2.7%	0.0%	0.7%	5
18	2.8%	0.0%	0.0%	4	3.7%	0.0%	0.0%	3	2.5%	0.0%	1.1%	4	2.6%	0.0%	0.5%	4
19	2.8%	0.0%	0.0%	6	3.7%	0.0%	0.0%	5	2.5%	0.0%	0.8%	7	2.6%	0.0%	0.3%	4
20	2.7%	0.0%	0.0%	4	3.6%	0.0%	0.0%	6	2.5%	0.0%	0.6%	5	2.6%	0.0%	0.2%	7

A Appendix Tables

Table A.1: Summary Statistics of Factors (Monthly Returns)

This table reports the summary statistics of the risk factors used in this study. That includes Fama-French three factors, two pure foreign exchange risk factors constructed by Lustig, Roussanov, and Verdelhan (2011), and two USD bond market risk factors, the return on variance swap, as well as the downside risk return constructed by Jurek and Stafford (2013).

The reported parameters, (mean, standard deviation, skewness, excess kurtosis, and autocorrelation coefficient) and their associated standard errors are simultaneous GMM estimates. The Sharpe ratio is the ratio of the annualized mean and standard deviation, and its standard error is calculated using the delta method (see Appendix B.) Variance swap data and option data used to calculate the DRI return become available since 1990.

	1976/02-2013/08					1990/2-2013/8						1983/11-2013/8		1990/1-2013/7
	Mkt	SMB	HML	10y-1M	10y-2y	Mkt	SMB	HML	10y-1M	10y-2y	V Swap	RX	HML_FX	DRI
Ave Ret (% p.a.)	7.01	3.04	3.75	3.08	1.49	7.20	2.51	2.95	3.92	2.14	-17.24	2.47	7.85	9.42
(std. err.)	(2.62)	(1.70)	(1.91)	(1.37)	(0.96)	(3.37)	(2.25)	(2.60)	(1.44)	(1.13)	(3.93)	(1.42)	(1.82)	(1.43)
Standard Dev.	15.54	10.49	10.25	8.11	6.04	15.29	11.55	11.04	6.95	5.70	12.15	7.02	8.97	6.70
(std. err.)	(0.84)	(1.08)	(0.74)	(0.41)	(0.32)	(0.98)	(1.53)	(1.04)	(0.42)	(0.42)	(5.37)	(0.35)	(0.50)	(0.94)
Sharpe Ratio	0.45	0.29	0.37	0.38	0.25	0.47	0.22	0.27	0.56	0.38	-1.42	0.35	0.88	1.41
(std. err.)	(0.18)	(0.16)	(0.19)	(0.17)	(0.16)	(0.24)	(0.19)	(0.23)	(0.21)	(0.20)	(0.92)	(0.21)	(0.23)	(0.38)
Skewness	-0.73	0.55	0.02	0.18	0.23	-0.65	0.82	0.08	0.03	0.05	8.63	-0.25	-0.59	-2.92
(std. err.)	(0.27)	(0.47)	(0.33)	(0.18)	(0.19)	(0.21)	(0.48)	(0.40)	(0.26)	(0.30)	(9.98)	(0.14)	(0.21)	(0.48)
Excess Kurt.	2.20	8.00	2.72	1.07	1.29	1.11	8.17	2.86	1.06	1.72	117.16	0.69	1.29	13.57
(std. err.)	(1.14)	(3.73)	(0.68)	(0.36)	(0.46)	(0.62)	(3.21)	(0.70)	(0.59)	(0.74)	(212.58)	(0.28)	(0.59)	(3.79)
Autocorr.	0.08	0.00	0.16	0.08	0.01	0.09	-0.04	0.15	0.08	0.04	0.44	0.00	0.11	0.12
(std. err.)	(0.05)	(0.06)	(0.06)	(0.05)	(0.05)	(0.07)	(0.07)	(0.08)	(0.05)	(0.06)	(0.27)	(0.06)	(0.07)	(0.08)
Max (%)	12.5	22.0	13.9	9.5	7.3	11.3	22.0	13.9	8.5	7.3	48.1	5.8	8.8	5.2
Min (%)	-23.2	-16.4	-12.7	-7.6	-6.0	-17.2	-16.4	-12.7	-6.7	-6.0	-10.8	-6.9	-10.4	-13.0
No. Positive	270	239	248	243	236	176	144	149	158	157	42	200	236	239
No. Negative	181	212	203	208	215	107	139	134	125	126	241	158	122	44

Table A.2: Carry Trade Exposures to Downside Market Risk (Alternative Cutoff Value in the Definition of Downside)

This table presents regressions of the carry trade returns of six different strategies on the market return and the downside market return defined by Lettau, Maggiori, and Weber (2014). The market return $R_{m,t}$ is the excess return on the market, the value-weight excess return of all CRSP firms incorporated in the US and listed on the NYSE, AMEX, or NASDAQ; the downside market return $R^{-}_{m,t} = R_{m,t} \times I^{-}$ where I^{-} is the indicator function. The regression specification is

$$R_t = \alpha_1 + \alpha_2 I^{-} + \beta_1 \cdot R_{m,t} + \beta_2 \cdot R^{-}_{m,t} + \varepsilon_t$$

in which $\beta_2 = \beta^{-} - \beta_1$ and$\beta^{-} = \frac{Cov\left(R_{m,t},\ R_t | I^{-}=1\right)}{Var(R_{m,t}|I^{-}=1)}$. We define $\beta = \frac{Cov(R_{m,t},\ R_t)}{Var(R_{m,t})}$.
The sample period is 1976:02-2013:08 (451 observations). Excess returns are annualized. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.[23]

Panel A: $I^{-} = I\left(R_{m,t} < \overline{R_{m,t}}\right)$

	EQ	SPD	EQ-RR	SPD-RR	OPT	EQ-USD
α	-1.83	-2.47	0.90	1.09	3.07	-9.03
t-stat	[-0.85]	[-0.81]	[0.39]	[0.47]	[2.89]	[-2.93]
$\alpha-$	8.36	13.23	7.98	9.91	-1.12	17.44
t-stat	[2.98]	[3.46]	[2.40]	[3.10]	[-0.83]	[4.24]
β_1	0.13	0.22	0.10	0.11	-0.01	0.26
t-stat	[2.79]	[3.01]	[2.40]	[2.44]	[-0.21]	[4.39]
β_2	-0.07	-0.09	-0.01	0.01	0.02	-0.28
t-stat	[-1.27]	[-1.13]	[-0.23]	[0.10]	[0.73]	[-3.56]
R^2	0.03	0.05	0.02	0.03	0.01	0.05

Panel B: $I^{-} = I\left(R_{m,t} < 0\right)$

	EQ	SPD	EQ-RR	SPD-RR	OPT	EQ-USD
α	-0.08	0.40	2.89	4.10	2.97	-5.87
t-stat	[-0.04]	[0.15]	[1.36]	[1.85]	[3.23]	[-2.12]
$\alpha-$	6.57	10.22	5.52	5.73	-1.20	14.79
t-stat	[2.58]	[2.82]	[1.67]	[1.74]	[-0.92]	[3.57]
β_1	0.10	0.17	0.07	0.06	0.00	0.21
t-stat	[2.39]	[2.59]	[1.84]	[1.44]	[-0.16]	[3.70]
β_2	-0.04	-0.05	0.01	0.04	0.02	-0.23
t-stat	[-0.77]	[-0.63]	[0.15]	[0.57]	[0.61]	[-2.72]
R^2	0.03	0.04	0.02	0.02	0.01	0.04

B GMM Standard Errors

Table 1 reports the first four unconditional moments of the basic carry trades as well as their Sharpe ratios. This Appendix explains the construction of the standard errors. Let μ denote the sample mean, σ denote the standard deviation, γ_3 denote sample standardized skewness, and γ_4 denote sample standardized kurtosis. The orthogonality conditions are

$$\begin{aligned} E\left(r_t\right) - \mu &= 0 \\ E\left[(r_t-\mu)^2\right] - \sigma^2 &= 0 \\ \frac{E\left[(r_t-\mu)^3\right]}{\sigma^3} - \gamma_3 &= 0 \\ \frac{E\left[(r_t-\mu)^4\right]}{\sigma^4} - \gamma_4 - 3 &= 0 \end{aligned}$$

Let $\theta = (\mu, \sigma, \gamma_3, \gamma_4)^\intercal$, let $g_T(\theta)$ denote the sample mean of the orthogonality conditions for a sample of size T, and let S_T denote an estimate of the variance of the sample moments. We estimate S_T using the Newey-West (1987) approach with three leads and lags. Hansen (1982) demonstrates that choosing the parameter estimates to minimize $g_T(\theta)^\intercal S_T^{-1} g_T(\theta)$ produces asymptotically unbiased estimates with asymptotic variance $\frac{1}{T}(D_T^\intercal S_T^{-1} D_T)^{-1}$ where D_T is the gradient of $g_T(\theta)$ with respect to θ. The Sharpe ratio is defined to be $SR = \frac{\mu}{\sigma}$, and the variance of SR is found by the delta method:

$$var(SR) = \frac{1}{T} \begin{bmatrix} \frac{1}{\sigma} & \frac{-\mu}{\sigma^2} & 0 & 0 \end{bmatrix} (D_T^\intercal S_T^{-1} D_T)^{-1} \begin{bmatrix} \frac{1}{\sigma} & \frac{-\mu}{\sigma^2} & 0 & 0 \end{bmatrix}^\intercal$$