June 29, 2015 Comments Welcome

The Carry Trade: Risks and Drawdowns

Kent Daniel, Robert J. Hodrick, and Zhongjin Lu*

- Abstract -

We examine carry trade returns of G10 currencies. Performance depends strongly on the base currency. Dollar-neutral carry trades exhibit insignificant abnormal returns, while the dollar-exposure component of the carry trade earns significant abnormal returns with little skewness. Spread-weighting and risk-rebalancing of positions improves performance. Equity, bond, FX, volatility, and downside equity risks cannot explain profitability. Downside equity 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 a role for time-varying autocorrelation in determining negative skewness at longer horizons.

*Daniel: Graduate School of Business, Columbia University, and NBER, kd2371@columbia.edu; Hodrick: Graduate School of Business, Columbia University, and the NBER, rh169@columbia.edu; Lu: Terry College of Business, University of Georgia, zlu15@uga.edu. This research was supported by a grant from the Network for Study on Pensions, Aging, and Retirement to the Columbia Business School. We thank Craig Burnside, Mike Chernov, Victoria Dobrynskaya, and Hanno Lustig for helpful comments. We especially thank Pierre Collin-Dufresne for many substantive early discussions that were fundamental to the development of the paper. We also thank Elessar Chen for his research assistance. We are grateful to Lucio Sarno and Maik Schmeling for providing their data.

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 standard carry trades have negative skewness, but Bekaert and Panayotov (2015) develop 'good' carry trades that do not have significantly negative skewness. High Sharpe ratios could be due to risk exposures, and 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 literature in a number of ways. In addition to the usual equally weighted carry trade considered in much of the literature, we examine spread-weighted trades that conditionally invest more in the currencies with the highest interest differentials. We also employ a simple covariance matrix of the currency returns that allows us to reduce the overall risk of our carry trade portfolios in recognition that traders face limits on losses that require reductions in the sizes of trades when volatility increases. The covariance matrix is also used in a sequential mean-variance optimization. Spread-weighting and risk-rebalancing enhance the performance of the carry trade.

For the equal-weighted carry trade, we show that returns are dependent on the base

[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.

currency in which the carry trade is implemented with the dollar base providing the largest average return. Both this finding and the fact that Lustig, Roussanov, and Verdelhan (2014) find that the average forward discount of currencies relative to the U.S. dollar is a particularly strong predictor of excess currency returns suggest that common movements of the dollar relative to all currencies are a primary driver of carry trade returns. We therefore we decompose standard carry-trade returns into two components: a "dollar-neutral" carry trade return that has no net dollar exposure, and what we call "dollar-carry." We show that while dollar-neutral carry trades are unconditionally exposed to standard risks in our sample, dollar-carry is not. Based on this analysis, we show that dollar-neutral carry has insignificant abnormal returns after risk adjustment, and strong negative skewness. In contrast, dollar-carry continues to earn significant abnormal returns with little skewness.

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 alternative version by Jurek (2014), does not explain our carry trade returns.

Our investigation of hedged carry trade returns largely supports the findings of Jurek (2014). For the shorter sample over which high quality date are available, we find that hedging reduces but does not eliminate the high Sharpe ratios of the carry trade, especially for the spread-weighted ones.

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 mark) to the trough in the cumulative return to a trading strategy. We also examine 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. In contrast to these characterizations, our analysis of daily returns suggests that a large fraction of the documented negative return skewness of carry trades results from the time varying return autocorrelations of daily carry returns: the large drawdowns in carry returns result from sequences of losses rather that large single-day drops.

[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.

I. 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.[3] Thus, the finding of 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.[4]

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.

---

[3]Hassan and Mano (2014) find that 70differentials,while Bekaert and Panayotov (2015) develop static trades that are 50% as profitable as their more dynamic ones. Because the forward premium puzzle is dynamic, Hassan and Mano (2014) argue that reconciling carry trade profitability and the forward premium puzzle requires separate explanations.

[4]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.

Each of these themes plays out in the recent literature on the carry trade. Lustig and Verdelhan (2007) show that high interest rate currencies are more exposed to aggregate consumption growth risk than low interest rate currencies using 81 currencies and 50 years of data. 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, Sarno, Schmeling, and Schrimpf (2012) argue that carry trades are exposed to 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.

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.

A. 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^*.[5]

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) an equal amount of 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 for a single foreign currency – ignoring transaction costs – is:

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

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 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

[5] 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.

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

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

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.

B. 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 gross-returns R_{t+1} (*i.e.*, time-$t+1$ payoffs that result from the investment of one dollar at time t):

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

Because carry trades implemented in the forward market are zero-investment portfolios, 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

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

That is, the (unconditional) expected return to the carry trade will positive if the (unconditional) covariation with the stochastic discount factor is negative.[6]

[6]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

C. 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 a unconditional future (time $t+1$) cost. One can also 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 (unconditional future) costs must be equal. Hence,

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

This is the put-call parity relationship 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. As above, this is the foreign currency equivalent of one dollar spot. The payoff is negative if the realized future spot exchange rate – expressed in dollars per unit 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 payoffs resulting from the forward purchase of the foreign currency and the option:

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

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

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

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.

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.[7] Because the hedged carry trades are also zero net investment strategies, they must also satisfy equation (5).

II. Data

In constructing our carry trade returns, we only use data on the G10 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 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

[7] 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.

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.[8] 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 the online appendix provides distributional information on the risk factors.

III. Returns and Risks of the Carry Trade

Table I reports basic unconditional sample statistics for the annualized returns of our five dollar-based carry trade strategies. At each point in time, the strategies are constructed using all G10 currencies for which exchange rate data is available.

A. Baseline Carry Strategy Characteristics

Our basic carry strategy, which we designate *EQ*, is the way most academic articles implement the carry trade. The EQ strategy has a weight on currency j of:

$$w_{j,t}^{EQ} = \frac{sign(i_t^j - i_t^\$)}{N_t} \tag{9}$$

where N_t is the number of currencies in our universe at time t. Thus, if the interest rate in currency j is higher (lower) than the dollar interest rate, the dollar-based investor goes long (short) $\$(1/N_t)$ in the forward market of currency j. The return to the EQ strategy from

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

time t to time $t+1$ is then the sum of the weighted returns:

$$R_{EQ,t+1} = \sum_{j=1}^{N_t} w_{j,t}^{EQ} z_{j,t+1}$$

where $z_{j,t+1}$ is the time $t+1$ payoff to investing \$1 in the money market for foreign currency j, and borrowing \$1 at time t, or using the equivalent forward market transactions per the discussion in Section I.A

Most long-short strategies implemented in academic studies of the equity market are \$1-long/\$1-short. This is convenient in that the long-short "return" can then be interpreted as the difference in returns between the long and the short sides of the portfolio. While EQ is a zero-investment strategy, it is a *\$1-at-risk* strategy rather than a \$1-long-\$1-short strategy. That is, the sum of the absolute values of the investments in the non-US currencies is always \$1. However, in a setting where there are eight foreign currencies, and the dollar interest rate $i_t^{\$}$ is the median interest rate, the strategy will be long \$0.5 of high interest rate currencies and short \$0.5 of low interest rate currencies. In contrast, were the USD the lowest interest rate, the EQ strategy would be long \$1 of foreign currencies, and short 1 USD.[9]

The second strategy, labeled SPD, is 'spread-weighted.' Like the EQ portfolio, it is long (short) currencies that have a positive (negative) interest differential relative to the the dollar. However, the size of the investment in a particular currency is determined by the magnitude of the interest-rate differential:

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

The SPD strategy thus invests more in currencies that have larger interest differentials. Because the sum of the absolute values of the interest differentials is in the denominator the SPD portfolio is also \$1-at-risk.

The *\$1-at-risk* characteristic of the EQ and SPD strategies means that the volatility of the EQ and SPD strategies rise and fall with exchange rate volatilities. As a result, such strategies would not generally be employed by actual traders in FX markets. Such traders are generally required to constrain their *value-at-risk*, defined as the maximum loss that will

[9]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.

be sustained with a given 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%.

As a result, traders will generally scale-up or down their investment based on some estimate of risk. To evaluate the efficacy of such scaling we construct "risk-rebalanced" versions of the EQ and SPD strategies, labeled "EQ-RR" and "SPD-RR."

Constructing these strategies requires a conditional covariance matrix of the returns on the nine currencies versus the dollar. To calculate this, 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 ith and jth currency returns realized at time $t+1$. Then, the IGARCH model is

$$h_t^{ij} = \alpha(r_t^i r_t^j) + (1-\alpha)h_{t-1}^{ij} \tag{10}$$

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 matrix we multiply the daily IGARCH estimates of H_t by 21.

For the EQ-RR and SPD-RR strategies, we target a constant monthly standard deviation of $5\%/\sqrt{12}$ – corresponding to an approximate annualized standard deviation of 5% – by adjusting the dollar scale of the EQ and SPD carry trades accordingly.

Our final strategy is labeled OPT, which involves sequential mean-variance optimization. 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 $w_t^{OPT} = \kappa_t H_t^{-1}\mu_t$, where H_t is the conditional covariance matrix, and κ_t is a scaling factor that sets the sum of the absolute values of the weights equal to one as in the EQ strategy. If the models of the conditional moments are correct, the conditional Sharpe ratio will equal $\sqrt{\mu_t' H_t^{-1}\mu_t}$.[10]

Table I reports the first four moments of the various carry trade strategies and their (annualized) 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 Section B of the online appendix. [11]

[10] 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.

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

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 significantly negatively skewed, with the OPT strategy having the most negative skewness of -0.89 (0.34). Table I 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 I 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.[12]

Table II 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. For the non-US base-currencies, the average annualized strategy returns range from 2.33% (1.02) for the SEK to 3.92% (1.50) for the NZD, and are all statistically significance at the .06 marginal level of significance or smaller. However, these mean returns are all less than the 3.96% (0.88) for the USD-based strategy.[13] Despite the lower mean returns, the non-USD strategies are generally higher variance, and as a results the Sharpe ratios of the alternative base-currency carry trades are all smaller than the USD-based Sharpe ratio of 0.78 (0.19). Except for the EUR, the skewness point estimates for the alternative base-currency carry trades are all negative, and the statistical significance of skewness is high for the JPY, NOK, SEK, NZD, and AUD. In addition, the excess kurtosis of each strategy is positive and statistically significant. Only the GBP-based carry trade shows any sign of first-order autocorrelation. Consistent with their (generally) higher return volatilities, the maximum gains and losses on these strategies generally exceed those of 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 have fewer

[12]The strategy returns 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.

[13]Given their standard errors it is unlikely that we would be able to reject equivalence of the means.

positive monthly returns than does the USD-base strategy.[14]

B. Carry-Trade Exposures to Risk Factors

We now examine 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 the returns to zero-investment portfolios, F_t, that represent 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.

B.1. Equity Market Risks

Table III presents the results of regressions of our carry-trade returns on the three Fama-French (1993) equity market risk factors: the excess market return, $R_{m,t}$, as proxied by the return of the value-weighted portfolio of stocks on the NYSE, AMEX, and NASDAQ markets over the one month 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, $R_{HML,t}$.[15] While eight of the 15 loadings on the factors have t-statistics greater than 1.96, the regressions R^2s are small. Moreover, these equity market factors leave most of the average returns of the carry trades unexplained. The average alphas range from 1.83% ($t = 3.72$) for the OPT strategy, to 5.55% ($t = 4.84$) for the SPD-RR strategy. These equity market risk factors clearly do not explain the average carry trade returns.

B.2. Pure FX Risks

Table IV 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

[14]For the NZD and AUD, for which the sample is smaller, the percentage of positive monthly returns is slightly smaller than for the USD.

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

portfolio six containing the highest interest rate currencies. Their two risk factors are the average 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.[16] Given its construction as the difference in returns on high and low interest rate portfolios, it is not surprising 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. While this pure FX risk model better explains the average returns to our strategies than does the set of equity factor, the regression alphas remain statistically significant, and range from a low of 1.29% for the OPT portfolio to 3.60% for the SPD-RR portfolio.[17]

B.3. **Bond Market Risks**

Movements in exchange rates are relative rates of currency depreciation, and in theory reflect all sources of aggregate risks in the stochastic discount factors of the two currencies. Thus it is logical that the risk factors that explain bond market returns in the two countries should also have explanatory power for the carry trade. Table V 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, suggesting that unexpected positive returns on the two-year note (*i.e.*, decreases in the 2-year note yield) are bad for the carry trades. The R^2s of the regressions remain between .02 and .05, as in the equity market regressions. The constants in the regressions indicate that the carry trade alphas remain statistically significant after these risk adjustments, ranging from 2.15% to 6.71% (annualized).

[16]The factor return data are from Adrien Verdelhan's web site, and the sample period is 1983:11-2013:08 for 358 observations.

[17]Note however that the robust t-statistic on the intercept for the EQ portfolio falls to 1.73.

B.4. **Volatility Risk**

To capture the possible exposure of the carry trade to equity market volatility, we introduce the return on an equity variance swap as a risk factor. [18] This return is calculated as

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

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 $t+1$. The VIX data are obtained from the CBOE web site. The availability of VIX data limits our sample to 1990:02-2013:08 (283 monthly observations). 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.

Tables VI and VII present regressions which incorporate, respectively, the equity and bond factors in addition to the variance swap returns. Because the sample period here is different than in Tables III and V, we reproduce the regressions of these two tables over this new sample period in the left panels, and then add the volatility risk factors to these regression in the right panels.

In both tables, the coefficients on $R_{VS,t+1}$ are negative, indicating that carry trades perform badly when equity volatility increases. However, the coefficients are small and not statistically significant. Moreover, this exposure is not enough to explain the profitability of the trades: the intercepts (alphas) in these regressions remain almost the same and continue to be statistically significant.

IV. Dollar Neutral and Pure Dollar Carry Trades

We saw in Section II that the historical efficacy of the EQ carry trade depends on the base currency in which it is implemented. In particular, the results in Table II showed that the EQ-USD strategy had a higher return and Sharpe ratio than for any other base currency. The performance differentials in Table II reflect the construction of the EQ strategy which, like the carry trade strategies examined in most academic studies, takes equal sized positions in each currency in the sample against the base currency. This results in a strategy that can have extreme variation over time in the weight on the base currency.

[18] Menkhoff, Sarno, Schmeling, and Schrimpf (2012) introduce foreign exchange volatility as a risk factor. To develop a traded risk factor, they project FX volatility onto a set of currency returns sorted on interest rate differentials. Because the resulting portfolio has a correlation of 0.8 with $R_{HML-FX,t}$, we find that their volatility risk factor has similar explanatory power to the pure foreign exchange risk model described in the previous section, and consequently we do not report explicit results here.

For example, the USD-based EQ strategy takes long positions in those currencies for which the interest rate is higher than the USD interest rate, and short for those currencies with a lower interest rate. Thus, at points in time where the USD interest rate is the highest G10 currency interest rate, the EQ strategy will be short \$(1/9) worth of each of these nine currencies (*i.e.*, \$1 worth of an equal weighted basket of the nine currencies), and long one USD. In contrast, at any point in time where the USD interest rate was the lowest interest rate among the G10 currencies, the strategy would be long an equal-weighted basket of the nine non-US currencies, and short \$1.

We now extend our earlier analysis by decomposing the EQ portfolio into dollar-neutral component and dollar carry components. We show that much of the efficacy of the carry trade is attributable to the dollar component, and we further demonstrate striking differences in the risk characteristics of the two components.

Our *dollar-neutral* carry trade portfolio – which we label EQ0 – takes positions only in the non-US currencies. Its weights are the following:

$$w_{j,t}^{\mathrm{EQ0}} = \left\{ \begin{array}{rl} +\frac{1}{N_t} & \text{if} \quad i_t^j > med\left\{i_t^k\right\} \\ -\frac{1}{N_t} & \text{if} \quad i_t^j < med\left\{i_t^k\right\} \\ 0 & \text{if} \quad i_t^j = med\left\{i_t^k\right\} \end{array} \right\} \tag{12}$$

where $med\left\{i_t^k\right\}$ indicates the median of the non-US interest rates at time t. Assuming nine non-US currencies, at each point in time we take long positions of \$(1/9) in the four highest interest rate currencies, financed by short positions of \$(1/9) in the four in the lowest rate currencies. We take no position is the median interest rate currency. Given, this construction, EQ0 is a long-short portfolio with no direct dollar exposure.

The second columns of Panels A and B of Table VIII report the first four moments of the EQ0 portfolio returns 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 for EQ strategy, the EQ0 volatility is also lower. However, the EQ0 Sharpe ratios are nonetheless about 30% lower than the EQ Sharpe ratios in each sample period. The negative skewness and insignificant autocorrelations of the EQ0 strategy are comparable to those of the EQ strategy. Consistent with the lower volatility, 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 IX 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 0.10. 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 in that the literature currently leans toward the belief that FX carry trades cannot be explained by equity risk factors. Yet, these results suggest that, after eliminating the dollar exposure from the EQ carry trade, the FX carry trade can be explained by commonly used equity risk factors.

A. A Decomposition of the Carry Trade

To better understand the difference between EQ and EQ0 performance, we create a portfolio which we label EQ-minus, defined as the difference between the EQ and the EQ0 portfolio:

$$w_{j,t}^{\text{EQ}-\text{minus}} \equiv w_{j,t}^{\text{EQ}} - w_{j,t}^{\text{EQ0}}$$

where the weights on the EQ and EQ0 portfolios are given in equations (9) and (12). Note that, since both EQ and EQ0 are zero-investment portfolios EQ-minus is as well. A little math gives the exact positions of the EQ-minus portfolio as, if $i_t^{\$} < med\left\{i_t^k\right\}$, then

$$w_{j,t}^{\text{EQ}-\text{minus}} = \left\{ \begin{array}{ccc} 0 & \text{if} & i_t^j > med\left\{i_t^k\right\} \\ \frac{1}{N_t} & \text{if} & i_t^j = med\left\{i_t^k\right\} \\ \frac{2}{N_t} & \text{if} & i_t^{\$} < i_t^j < med\left\{i_t^k\right\} \\ 0 & \text{if} & i_t^j \leq i_t^{\$} \end{array} \right\}$$

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

$$w_{j,t}^{\text{EQ}-\text{minus}} = \left\{ \begin{array}{ccc} 0 & \text{if} & i_t^j > i_t^{\$} \\ -\frac{1}{N_t} & \text{if} & i_t^j = med\left\{i_t^k\right\} \\ -\frac{2}{N_t} & \text{if} & med\left\{i_t^k\right\} < i_t^j \leq i_t^{\$} \\ 0 & \text{if} & i_t^j \leq med\left\{i_t^k\right\} \end{array} \right\}$$

The EQ0 and EQ-minus portfolios decompose the EQ carry trade into two components: a dollar neutral component and a dollar component. EQ-minus 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. Thus, if these rates are close the EQ-minus portfolio will be a portfolio concentrated in just a few currencies.

The third columns of Panels A and B in Table VIII present the first four moments of the EQ-minus strategy. The EQ-minus average returns are statistically significant in both samples, and the Sharpe ratios are close to those of the EQ0 strategy. Skewness of EQ-minus is negative, but statistically insignificant due to the large standard error in both samples. In terms of both Sharpe ratio and skewness, the EQ-minus strategy appears no better than the EQ0 strategy. Note also that the EQ-minus kurtosis is far higher. 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 IX 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 X 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 0.12. 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 0.02.

Finally, Columns 1 to 3 of Table XI 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, the conditional dollar exposure contributes more to the carry trade "puzzle" than does the non-dollar component.

B. The Pure Dollar Factor

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 EQ. However, as noted above, if the USD interest rate is close to the median non-USD interest rate it will take positions in relatively few currencies. This is consistent with the large kurtosis noted in Table VIII. 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 define the strategy EQ-USD as:

$$w_{j,t}^{\mathrm{EQ-USD}} = \begin{Bmatrix} +\frac{1}{N} & \text{if} & med\left\{i_t^k\right\} > i_t^{\$} \\ -\frac{1}{N} & \text{if} & med\left\{i_t^k\right\} \leq i_t^{\$} \end{Bmatrix}$$

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 VIII present the first four moments of the returns to the EQ-USD strategy for the full sample and the sample for which VIX data are 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 lower than the other three strategies, and it is statistically insignificant in both periods. Also consistent with the greater diversification of EQ-USD, its excess kurtosis is lower, though still statistically significant.

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 IX, X and XI report regressions of the returns of EQ-USD on the Fama-French (1993) three factors, the bond factors, and the FX risk factors respectively. 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 XII for the shorter sample period, the foreign exchange risk factors and the volatility factor have significant loadings, but the regression intercept (alpha) 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 which is not explained by its (small) exposures to standard risk factors. Finally, the insignificant negative skewness of the EQ-USD portfolio returns indicate that negative skewness is not an explanation for the abnormal excess return of this strategy.

V. Downside Risk and the Carry Trade

Through the lens of the decomposition of the last section, we next examine downside risk as an explanation for the carry trade premium. We follow two recent studies: Lettau, Maggiori, and Weber (2014) and Jurek (2014).

A. The Lettau, Maggiori, and Weber (2014) Analysis

Lettau, Maggiori, and Weber (2014) 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.[19] However, Lettau, Maggiori, and Weber (2014) further observe that the exposure of the carry trade to the return on the market is larger conditional on a negative market return. Based on this, they explore the ability of the downside market risk model of Ang, Chen, and Xing (2006) to explain carry returns.

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.[20] 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.

[19]Dobrynskaya (2014) uses a slightly different specification than Lettau, Maggiori, and Weber (2014) and reaches similar conclusions.

[20]We also considered two alternative definitions of $R^-_{m,t}$ based on alternative "cutoffs" of $R_{m,t} < \overline{R_m}$, where $\overline{R_m}$ is the sample mean, and $R_{m,t} < 0$. The results are similar to the reported results and are available in the online appendix.

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

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

Notice that a key requirement of this model is that β^- be significantly different from β. Lettau, Maggiori, and Weber (2014) do not explicitly test this restriction and only report homoskedastic OLS standard errors of their estimates. To test this explanation of the carry trade premium, we first run a bivariate regression of a carry trade return on a constant; an indicator dummy variable, I^- which equals 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

$$R_t = \alpha_1 + \alpha_2 I^- + \beta_1 R_{m,t} + \beta_2 R^-_{m,t} + \varepsilon_t \tag{13}$$

In equation (13), 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 down-state; 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 Newey and West (1987) heteroskedasticity and autocorrelation consistent standard errors with 3 lags.[21]

Table XIII 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

[21]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 $(\beta^- - \beta_1)$.

indicating that this currency strategy is less exposed to the market's downside risk than to the upside of market returns.[22]

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 $\lambda^- = 1.41\%$, or 16.92% per annum. When they include only currencies, they estimate $\lambda^- = 2.18\%$, 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 XIII 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. 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 XIV 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

[22]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.

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 XIV 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 β_2 coefficients of portfolios P4 and P5 are smaller than those of portfolios P1 to P3. More importantly, the β_2 coefficients are all insignificantly different from zero.

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 the hypothesis that $\beta_2 = 0$ 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 Figure 3 of Lettau, Maggiori, and Weber (2014) shows that the relative downside betas, the difference between betas estimated directly on the downside market return and those estimated on the market return, of six similarly constructed currency portfolios from a comparably large number of countries are roughly monotonically increasing. Three things are important to note. First, differences in estimation technique do not account for the different results. Lettau, Maggiori, and Weber (2014) estimate β^{-} in separate univariate regressions, while we simultaneously estimate β^{-}, β_1 and β_2. Nevertheless, the estimated values of β^{-} are invariant to this change. The second thing to note is that we report Newey-West (1994) t-statistics in Part B of Table XV in which case the t-statistic of β_2 is 1.14 while the corresponding OLS t-statistic is 1.83. A third difference involves the number of currencies and the sample periods. 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 0.44. 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 0.84. 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 XV 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 XV 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 XV 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 not reliably different from standard betas, and the resulting differences in the two betas are not sufficiently large to account for the average returns to our carry trade portfolios.

B. The Jurek (2014) Analysis

Jurek (2014) examines the exposure of the carry trade to downside risk by regressing the returns to a set of zero-investment carry trade portfolios on a *downside risk index* (DRI), which is the return from a zero-investment portfolio which sells S&P 500 puts.[23,24] This approach has the advantage that, for a standard time series regressions with the DRI (and other zero-investment factor portfolio returns) as dependent variables, the intercept can be interpreted a measure of abnormal returns with respect to the set of factor returns. This is in contrast to the regression in equation (13), where $R^-_{m,t}$ is not a traded portfolio return.

In our analysis, we use DRI returns from January 1990 to August 2013.[25] Table A.1 in

[23] 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. 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.

[24] 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 focus here on the DRI.

[25] We are grateful to Jakub Jurek for providing the DRI returns used in Jurek (2014), which are constructs the DRI by splicing data from the Berkeley Options Database (1990:01-1996:12) with data from OptionMetrics (1996:01-2012:06). We use OptionMetrics data to extend the DRI returns forward to August 2013.

the online appendix presents summary statistics for the DRI returns over this sample period. 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, its excess kurtosis of 13.57, and the fact that the excess return to the DRI is positive in more that 82% of the months of our sample period.

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 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 economically smaller and statistically insignificant as evidence that this measure of downside risk explains the average returns of the carry trades quite well.

Table XVI presents our analysis of the DRI exposures of the carry-trade portfolios. For the EQ, SPD, EQ-RR, SPD-RR and OPT portfolios, are results are largely consistent with Jurek's findings. The slope coefficients on the DRI return are statistically significant.[26]. In addition, while the intercepts are reduced dramatically, they are still mostly statistically significant.

The reason for this difference is revealed in the last three portfolios. For the EQ0 (dollar neutral) portfolio the slope coefficient is highly statistically significant ($t = 5.14$), and the intercept t-statistic is only 0.13. Strikingly, for the EQ-minus and the EQ-USD portfolios the point estimates for the loading on the DRI are actually *negative* (though statistically insignificant). Consistent with this, the intercept for the EQ-USD portfolio regression remains large and statistically significant.

The reason for the differences in the findings on the first five portfolios are differences in portfolio construction: Jurek defines spread as the absolute distance between country i's interest rate and the median interest rate of the G10 countries while we define spread as the absolute distance between country i's interest rate and the interest rate of US dollar. As a result, the spread-weighted carry trades in Jurek (2014) is likely to have less exposure to US dollar than our SPD.

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.

In Panel B, we include the DRI with the three Fama-French (1993) risk factors as independent variables in the regression. Here, we find that none of the slope coefficients on

[26]The t-statistics on our slope coefficients are not as large as those reported in Jurek (2014). We report t-statistics based on Newey-West standard errors with 3 lags. We have confirmed that OLS t-statistics are larger, and approximately equal to those reported by Jurek.

DRI is significantly different from zero, and the intercepts all retain their magnitude and statistical significance, with the exception of EQ0.

VI. Analysis of the Hedged Carry Trade

We now analyze the returns of hedged carry trade strategies: specifically, we supplement the EQ, SPD, and EQ-USD portfolios examined earlier with positions in currency options so as to protect these strategies against large losses, as described in Section II.B. As discussed in Section I, we obtained high quality USD-denominated foreign currency options data over the period from September 2000 to August 2013. 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 costs 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 XVII reports the results for the hedged carry trades. For comparison, the statistics for the corresponding unhedged EQ, SPD and EQ-USD carry trades over the same sample period 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 (and 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 than in the longer 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, SPD and EQ-USD strategies are 38, 34 and 61 basis points less (respectively) than their unhedged counterparts and for the 25Δ strategies, the hedged strategy returns are 87, 129 and 145 basis points less than their respective unhedged counterparts. Also, 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, we see that hedging only provides limited protection against substantive losses for the EQ and SPD strategies: the maximum monthly loss for the EQ strategy is 4.12%, compared to maximum losses for the 10Δ and 25Δ hedged strategies of 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 10Δ and 25Δ hedged SPD strategies are 6.30% and 4.75%, respectively. Hedging the EQ-USD strategy does help to avoid a substantive loss: the maximum losses are 5.30% and 3.68% for the 10Δ and 25Δ hedged strategies, compared to 7.15% for the unhedged EQ-USD strategy.

A. 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 XVIII, where we examine the hedged carry trade exposures to the three Fama-French (1993) equity 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 0.20. 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 0.26. 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 exposures to the market return and HML remain statistically significant in the hedged SPD strategy regressions.

Both the hedged and unhedged EQ-USD strategy have no significant exposure to the any of the Fama-French (1993) factors in the shorter sample, and the intercept terms are both relatively large, but are statistically significant. Panel B of Table XVIII 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 XIX 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 the regression intercepts, none of which 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 again associated with a decrease in the return to the trade. Panel B of Table XIX 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 XX 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 just 0.10. The DRI has no ability to explain the return to the hedged EQ-USD strategy, and the t-statistics for the constant terms remain only marginally significant.

VII. Drawdown Analysis

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.[27]

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 XXI 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 normalizes them by the corresponding ratios under the *i.i.d.* assumption. If the daily returns were independently and identically distributed, the normalized ratios would equal 1.

Table XXI 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, which is consistent with small positive autocorrelations at the daily frequency. Ratios of standardized monthly skewness relative to daily skewness vary considerably across

[27]While traders in foreign exchange markets can easily adjust their carry trade strategies at the daily frequency, if not intraday, 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.

the portfolios. For the EQ and SPD portfolios, the normalized ratios are 7.1 and 2.4, indicating that the monthly skewness values are well above what the values would be if the daily returns were *i.i.d.*. On the other hand, the same ratios for the risk rebalanced 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 rebalanced portfolios conforms better to the *i.i.d.* assumption. Similarly, normalized ratios between the monthly and daily kurtosis values 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 the *drawdown*, which we define as the percentage loss from the previous high-water mark to the following lowest point. The second is the *pure drawdown*, which we defined as the percentage loss from consecutive daily negative returns. Finally we define the *maximum loss* 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 of the maximum loss over 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.[28] The second model captures non-normality 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.

[28] 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.

A. Drawdowns

Table XXII 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 because rebounds occur in high volatility periods.

B. Maximum Losses

Table XXIII 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.[29]

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.[30] 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 XXIII 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.

C. Pure Drawdowns

Table XXIV 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

[29] 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 XXIII.

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

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 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.[31]

For the risk-rebalanced 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

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

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.

VIII. 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, but rebalancing monthly. 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, but 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 from the *ex ante* distribution that rational investors perceived certainly cannot be ruled out.

References

Ackermann, Fabian, Walt Pohl, and Karl Schmedders, 2012, On the risk and return of the carry trade, Swiss Finance Institute Research Paper Series No. 12-36.

Ang, Andrew, Joseph Chen, and Yuhang Xing, 2006, Downside risk, *Review of Financial Studies* 19, 1191-1239.

Backus, David K., Federico Gavazzoni, Chris Telmer and Stanley E. Zin, 2010, Monetary policy and the uncovered interest rate parity puzzle, manuscript, Stern School of Business, New York University.

Bakshi, Gurdip, Peter Carr, and Liuren Wu, 2008, Stochastic risk premiums, stochastic skewness in currency options, and stochastic discount factors in international economies, *Journal of Financial Economics*, 87, 132-156.

Bakshi, Gurdip and George Panayotov, 2013, Predictability of currency carry trades and asset pricing implications, *Journal of Financial Economics* 110, 139-163.

Bansal, Ravi, and Ivan Shaliastovich, 2013, A long-run risks explanation of predictability puzzles in bond and currency markets. *Review of Financial Studies* 26,1-33.

Beber, Alessandro, Francis Breedon, and Andrea Buraschi, 2010, Differences in beliefs and currency risk premia, *Journal of Financial Economics* 98, 415-438.

Bekaert, Geert and George Panayotov, 2015, Good carry, bad carry. Manuscript, Columbia Business School.

Bhansali, Vineer, 2007, Volatility and the carry trade, *The Journal of Fixed Income* 17, 72-84.

Bilson, John F.O., 1981, The 'speculative efficiency' hypothesis, *Journal of Business* 54, 435-451.

Breedon, Francis, 2001, Market liquidity under stress: Observations from the FX market, Bank for International Settlements Papers No. 2, Proceedings of a workshop on Market Liquidity, April.

Brunnermeier, Markus K., Stefan Nagel, and Lasse H. Pedersen, 2009, Carry trade and currency crashes, *NBER Macroeconomics Annual* 23, 313-347.

Burnside, Craig, 2012, Carry trades and risk, in Jessica James, Ian W. Marsh, and Lucio Sarno, eds. *Handbook of Exchange Rates.* Hoboken, NJ: John Wiley and Sons.

Burnside Craig, Martin S. Eichenbaum, Isaac Kleshchelski, S. Rebelo, 2011, Do peso problems explain the returns to the carry trade? *Review of Financial Studies* 24, 853-891.

Caballero, Ricardo J. and Joseph B. Doyle, 2012, Carry Trade and Systemic Risk: Why are FX Options so Cheap? manuscript, MIT.

Carr, Peter and Liuren Wu, 2007, Stochastic Skew for Currency Options, *Journal of Financial Economics*, 86(1), p. 213-247.

Chernov, Mikhail, Jeremy Graveline, and Irina Zviadadze, 2013, Sources of risk in currency returns, manuscript, UCLA.

Christiansen, Charlotte, Angelo Ranaldo, and Paul Soderlind, 2011, The time-varying systematic risk of carry trade strategies, *Journal of Financial and Quantitative Analysis* 46, 1107-1125.

Clarida, Richard, Josh Davis, and Niels Pedersen, 2009, Currency carry trade regimes: Beyond the Fama regression, *Journal of International Money and Finance* 28, 1375-1389.

Carry on speculating: How traders have been triumphing over economic theory, (2007), *The Economist,* February 22.

Dobrynskaya, Victoria, 2014, Downside market risk of carry trades, *Review of Finance* 24, 1-29.

Engel, Charles, 1996, The forward discount anomaly and the risk premium: a survey of recent evidence, *Journal of Empirical Finance* 3, 123-192.

Evans, Martin D.D., 1996, Peso problems: Their theoretical and empirical implications. In G.S. Maddala and C.R. Rao, eds., *Handbook of Statistics, Volume 14*. Elsevier Science: Amsterdam, 613-646.

Fama, Eugene, 1984, Forward and spot exchange rates, *Journal of Monetary Economics* 14, 319-348.

Fama, Eugene and Kenneth French, 1993, Common risk factors in the returns on stocks and bonds, *Journal of Financial Economics* 33, 3-56.

Farhi, Emmanuel and Xavier Gabaix, 2011, Rare disasters and exchange rates, manuscript, Harvard University.

Farhi, Emmanuel, Samuel P. Fraiberger, Xavier Gabaix, Romain Ranciere, and Adrien Verdelhan, 2013, Crash risk in currency markets, manuscript, Harvard University.

Froot, Kenneth and Richard Thaler, 1990, Anomalies: foreign exchange, *Journal of Economic Perspectives* 4, 179-192.

Hansen, Lars Peter, 1982, Large sample properties of generalized method of moments estimators, *Econometrica* 50, 1029-1054.

Hansen, Lars Peter, and Robert J. Hodrick, 1983, Risk averse speculation in the forward foreign exchange market: An econometric analysis of linear models, Chapter 4 in Jacob A. Frenkel, ed., *Exchange Rates and International Macroeconomics*, NBER and the University of Chicago Press, 113-142.

Hassan, Tarek A. and Rui Mano, 2014, Forward and spot rates in a multicurrency world, NBER Working Paper No. 20294.

Hodrick, Robert J., 1987, *The Empirical Evidence on the Efficiency of Forward and Futures Foreign Exchange Markets*, Chur, Switzerland: Harwood Academic Publishers.

Jordà, Òscar, and Alan M. Taylor, 2012, The carry trade and fundamentals: Nothing to fear but FEER itself, *Journal of International Economics* 88, 74-90.

Jurek, Jakub W., 2014, Crash-neutral currency carry trades, forthcoming *Journal of Financial Economics.*

Jurek, Jakub W., and Eric Stafford, 2014, The cost of capital for alternative investments, forthcoming *Journal of Finance.*

J.P. Morgan, 1996, *RiskMetrics Technical Document, Part II: Statistics of Financial Market Returns*, 4th edition, New York.

Koijen, Ralph S.J., Tobias J. Moskowitz, Lasse Heje Pedersen, and Evert B. Vrugt, 2013, Carry, manuscript, London Business School.

Krasker, William S., 1980, The 'peso problem' in testing the efficiency of forward foreign exchange markets, *Journal of Monetary Economics* 6, 269-276.

Lettau, Martin, Matteo Maggiori, and Michael Weber, 2014, Conditional currency risk premia, manuscript, forthcoming *Journal of Financial Economics.*

Lewis, Karen K., 1989, Can learning affect exchange-rate behavior?: The case of the dollar in the early 1980s, *Journal of Monetary Economics* 23, 79-100.

Longstaff, Francis A., Jun Pan, Lasse H. Pedersen, and Kenneth J. Singleton, 2011, How sovereign is sovereign credit risk? *American Economic Journal: Macroeconomics* 3, 75-103.

Lustig, Hanno, and Adrien Verdelhan, 2007, The cross section of foreign currency risk premia and consumption growth risk, *American Economic Review* 97, 89-117.

Lustig, Hanno, Nikolai Roussanov, and Adrien Verdelhan, 2011, Common risk factors in currency markets, *Review of Financial Studies* 24, 3731-3777.

Lustig, Hanno, Nikolai Roussanov, and Adrien Verdelhan, 2014, Countercyclical currency risk premia, *Journal of Financial Economics* 111, 527-553.

Mancini, Loriano, Angelo Ranaldo, Jan Wrampelmeyer, 2013, Liquidity in the foreign exchange market: Measurement, commonality, and risk premiums, *Journal of Finance* 68, 1805-1841.

Meese, Richard A., and Kenneth Rogoff, 1983, Empirical exchange rate models of the seventies: Do they fit out of sample? *Journal of International Economics* 14, 3-24.

Melvin, Michael, and Duncan Shand, 2014, When carry goes bad: The when, how, and why of currency carry unwinds, manuscript, BlackRock, San Francisco.

Menkhoff, Lukas, Lucio Sarno, Maik Schmeling, and Andreas Schrimpf, 2012, Carry trades and global fx volatility, *Journal of Finance* 67, 681-718.

Newey, Whitney K. and Kenneth D. West, 1987, A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix, *Econometrica* 55, 703-708.

Rafferty, Barry, 2012, Currency returns, skewness, and crash risk, manuscript, Duke University

Ranaldo, Angelo and Paul Soderlind, 2010, Safe haven currencies, *Review of Finance* 10, 385-407.

Sarno, Lucio, Paul Schneider and Christian Wagner, 2012, Properties of foreign exchange risk premiums, *Journal of Financial Economics* 105, 279-310.

Sornette, Didier, 2003, *Why Stock Markets Crash: Critical Events in Complex Financial Systems*. Princeton University Press: Princeton, NJ.

Table I: 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 online 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 II: Summary Statistics of the Carry Trade by Base Currency

This table presents summary statistics on the monthly zero-investment portfolio returns to the equal weight EQ 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 online 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 III: Carry Trade Exposures to Equity Risk Factors

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 IV: Carry Trade Exposures to FX Risks

This table presents regressions of the carry trade returns of four 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 V: 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 VI: Carry Trade Exposure 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 III. 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 VII: Carry Trade Exposure 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 V.
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 VIII: Summary Statistics for the Dollar-Neutral and Pure-Dollar Carry 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, and the mean and standard deviation are annualized. The Sharpe ratio is the ratio of the annualized mean and standard deviation, and its standard error is calculated using the delta method (see online 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 IX: Dollar Neutral and Pure Dollar Carry Trade Exposures to 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 X: Dollar Neutral and Pure Dollar Carry Trade Exposures to 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]
$\beta_{\text{10y}-\text{2y}}$	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 XI: Dollar Neutral and Pure Dollar 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 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 XII: Pure-Dollar Carry – Risk Factor Analysis

This table presents regressions of the EQ-USD returns on the Fama and French (1993) equity factors, the two pure foreign exchange risk factors constructed by Lustig, Roussanov, and Verdelhan (2011), and the 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 alpha is in annualized percentage terms. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

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

Table XIII: Carry Trade Exposures to Downside Market Risk

This table presents regressions of the carry trade returns of six different strategies on the market- and downside-market returns defined by Lettau, Maggiori, and Weber (2014). The excess market return $R_{m,t}$ is the CRSP value-weighted market return minus the one-month treasury-bill return; 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 XIV: LRV Portfolios – Exposure to Downside Market Risk

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 excess market return $R_{m,t}$ is the CRSP value-weighted market return minus the one-month treasury-bill return; 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 XV: LMW Portfolios – Exposure to Downside Market Risk

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 excess market return $R_{m,t}$ is the CRSP value-weighted market return minus the one-month treasury-bill return; 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 XVI: Carry Trade Exposure to the 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 (2014). 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 (2014). 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 XVII: 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 online Appendix B.) The hedging strategy is described in Section B.

	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	0.53	0.42	0.34	0.69	0.64	0.50	0.44
(std. err.)	(0.31)	(0.31)	(0.26)	(0.29)	(0.26)	(0.29)	(0.27)	(0.25)	(0.24)
Skewness	-0.32	-0.23	0.20	0.02	0.27	0.28	0.70	0.54	0.93
(std. err.)	(0.20)	(0.28)	(0.26)	(0.19)	(0.27)	(0.25)	(0.26)	(0.23)	(0.23)
Excess Kurtosis	0.71	1.88	0.84	0.36	0.65	1.40	1.54	0.65	1.22
(std. err.)	(0.43)	(0.60)	(0.42)	(0.33)	(0.40)	(0.57)	(0.60)	(0.53)	(0.87)
Autocorrelation	0.01	0.02	-0.11	-0.07	-0.13	-0.02	-0.07	-0.13	-0.16
(std. err.)	(0.12)	(0.11)	(0.08)	(0.10)	(0.10)	(0.10)	(0.09)	(0.09)	(0.10)
Max (%)	4.04	8.01	8.83	3.75	3.48	7.67	7.01	8.56	8.44
Min (%)	-4.12	-7.44	-7.15	-2.93	-3.52	-6.30	-4.75	-5.30	-3.68
No. Positive	93	99	85	94	86	97	91	84	76
No. Negative	62	56	70	61	69	58	64	71	79

Table XVIII: Hedged Carry Trade Exposure 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.

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

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 XIX: Hedged Carry Trade Exposure 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.

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

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 XX: Hedged Carry Trade Exposure to the 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 (2014). 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 XXI: 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 normalizes these ratios by the expected ratios if daily returns were *i.i.d.* Therefore, if daily returns were indeed *i.i.d.*, the normalized ratios would be approximately 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 XXII: 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 XXIII: 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 XXIV: 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