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The Carry Trade: Risks and Drawdowns

Kent Daniel
Robert J. Hodrick
Zhongjin Lu

[1]*Columbia Business School, Columbia University, New York, NY 10027 and National Bureau of Economic Research (NBER), Cambridge, MA 02138; kd2371@columbia.edu.*
[2]*Columbia Business School, Columbia University, New York, NY 10027 and National Bureau of Economic Research (NBER), Cambridge, MA 02138; rh169@columbia.edu*
[3]*Terry College of Business, University of Georgia, Athens, GA 30602; zlu15@uga.edu.*

ABSTRACT

We find important differences in dollar-based and dollar-neutral G10 carry trades. Dollar-neutral trades have positive average returns, are highly negatively skewed, are correlated with risk factors, and exhibit considerable downside risk. In contrast, a diversified dollar-carry portfolio has a higher average excess return, a higher Sharpe ratio, minimal skewness, is unconditionally uncorrelated with standard risk-factors, and exhibits no downside risk. Distributions of drawdowns and maximum losses from daily data indicate a role for time-varying autocorrelation in determining negative skewness at longer horizons.

Keywords: currency carry trade, currency risk factors, market efficiency

JEL Codes: F31, G12, G15

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1 Introduction

This paper empirically examines returns to carry trades in the major international currency markets including their exposures to various risk factors. A carry trade is an investment in a high interest rate currency that is funded by borrowing in a low interest rate currency. The 'carry' is the *ex-ante* observable positive interest differential. Returns to the carry trades are uncertain because the exchange rate between the two currencies may change. An individual 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]

Carry trades are known to have high Sharpe ratios, as emphasized by Burnside *et al.* (2011a). Consistent with this, our baseline carry trade has an annualized Sharpe ratio of 0.78 over the 1976:02-2013:08 sample period. Alternative versions, which we discuss below, have Sharpe ratios as high as 1.02.

While such return premiums are obviously inconsistent with the theory of uncovered interest rate parity, the academic literature offers numerous explanations for the existence of these return premiums. Brunnermeier *et al.* (2008) document that returns to standard carry trades are negatively skewed and exhibit infrequent large losses. While their evidence is suggestive that such downside risk could be priced, they do no formal asset pricing tests. Negative skewness per se is not enough to explain the profitability of carry trades as Bekaert and Panayotov (2015) develop "good" carry trades that retain high average returns and do not have significantly negative skewness. Lettau *et al.* (2014) and Dobrynskaya (2014) find that carry trade portfolio returns are differentially exposed to the return on the equity market when the market is significantly down. They estimate a high price of downside risk and conclude that such downside risk explains the

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[1]Koijen *et al.* (2015) 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.

profitability of the carry trade. Jurek (2014) similarly finds that currency carry trades are strongly exposed to the returns of the Jurek and Stafford (2015) downside risk index (DRI) portfolio, and he concludes that the abnormal returns of currency carry trades are indistinguishable from zero after controlling for their exposure to DRI and other equity risk factors. Lustig *et al.* (2014) find that the average forward discount of currencies relative to the U.S. dollar is a particularly strong predictor of excess currency returns. They conclude that common movements of the dollar relative to all currencies are a primary driver of dollar-based carry trade returns.

We examine these and other potential explanations for carry trade premiums by decomposing the standard carry trade into *dollar-carry* and *dollar-neutral-carry* components. The carry trade, as commonly implemented in academic studies, can have a large positive or negative exposure to the U.S. dollar, depending on the level of USD interest rates relative to the median non-USD interest rate. Our diversified, dynamic dollar strategy captures this time-varying dollar exposure.

We show that the majority of the excess return of our basic carry trade is attributable to the time-varying dollar component. This view supports the analysis of Lustig *et al.* (2014) who develop a dollar-carry strategy based on the average forward discount with a larger set of currencies than ours. We find that the average excess return of the dollar-neutral component of our basic carry trade is different from zero, but the returns are highly negatively skewed, are correlated with standard risk factors, and exhibit considerable downside risk. In contrast, a dynamic dollar strategy diversified across the G10 currencies has a higher average excess return, a higher Sharpe ratio, minimal skewness, is uncorrelated with standard risk-factors, and exhibits no downside risk. While Lustig *et al.* (2014) conclude that their multi-country affine model is consistent with the observed returns on their dollar-carry strategy, we argue that the priced risks in such a model would manifest themselves in statistically significant coefficients in our asset pricing regressions, which we do not observe. We consequently do not interpret our results through the lens of their model.

Additionally, we examine how spread-weighting and risk-rebalancing affect the profitability and risk of the basic carry trade. Our spread weighted portfolio conditionally invests more in the currencies with the highest interest differentials relative to the dollar. We also employ a simple estimated 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 also show that returns are dependent on the base currency with the dollar base providing the largest average return.

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 trade returns result from sequences of losses rather than large single-day drops.

2 Background Ideas and Essential Theory

By covered 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 (short) in currencies trading at forward discounts (premiums). Such forward market trades are profitable as long as the currency trading at the forward discount

[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.

depreciates less than the forward discount.

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 unbiased forward rates. First, the difference between forward rates and expected future spot rates could result from an equilibrium risk premium. Second, the foreign exchange market could be inefficient. Third, rational expectations might not characterize expectations if investors must learn about their environment, and fourth, so-called *peso problems* might be present 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 *et al.* (2014) develop a theory of countercyclical currency risk premiums. Carr and Wu (2009) 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 priced risk factors. For example, Lustig *et al.* (2011) argue that common movements in the carry trade across portfolios of currencies indicate rational risk premiums. Rafferty (2012) relates carry

[3] Hassan and Mano (2015) find that 70% of carry trade profitability is due to static interest rate differentials, while Bekaert and Panayotov (2015) develop static trades that are 50% as profitable as their more dynamic ones. Because a substantive fraction of carry trade profitability is effectively unconditional, while rational explanations of the forward premium anomaly typically involve dynamic, time-varying risk premiums, Hassan and Mano (2015) argue that reconciling carry trade profitability and the forward premium anomaly may require separate explanations.

trade returns to a skewness risk factor in currency markets. Dobrynskaya (2014) and Lettau *et al.* (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 S&P 500 index puts, which has severe downside risk, explains the carry trade. Christiansen *et al.* (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 Söderlind (2010) argue that the funding currencies have 'safe haven' attributes, which implies that they tend to appreciate during times of crisis. Menkhoff *et al.* (2012) argue that carry trades are exposed to global FX volatility risk. Beber *et al.* (2010) note that the yen-dollar carry trade performs poorly when differences of opinion are high. Mancini *et al.* (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 as risk factors. Sarno *et al.* (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 *et al.* (2008) use option prices to infer the dynamics of risk premiums for the dollar, pound and yen pricing kernels.

Burnside *et al.* (2011a) provide an alternative explanation of carry-trade profitability by focusing on peso problems. They examine returns to both standard, unhedged carry trades and carry trades that are hedged against downside risks using option strategies. In contrast to the above studies that find carry trades have exposure to substantive financial risks, Burnside *et al.* (2011a) find that their unhedged carry trades have high profitability but no exposure to a variety of standard sources of risk. But, their hedged carry trades, which also have significant average returns, are exposed to these risks. By postulating an unobserved peso state that occurs with a small probability, Burnside *et al.* (2011a) determine that the peso state involves a very high value for the stochastic discount factor. Jurek (2014) also examines the unhedged and hedged carry trades using out-of-the-money options and an alternative hedging procedure that employs all bilateral option pairs rather than just dollar denominated ones. He concludes that peso states explain at most one-third of the average returns to the carry trade. Farhi and Gabaix (2016) and Farhi *et al.* (2015) also argue that the carry trade is exposed to rare crash states in which high interest rate currencies depreciate. Burnside (2012) reviews the literature examining the risks of carry trades.

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

2.1 Implementing the Carry Trade

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

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 dollar 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

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

Equation (1) scales the size of returns to 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

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

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

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

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

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

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

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

2.2 Pricing Kernels

One of the fundamentals of no-arbitrage pricing is that there is a dollar pricing kernel or stochastic discount factor, M_{t+1}, that prices all dollar returns R_{t+1} (*i.e.*, time $t+1$ payoffs that result from a one dollar investment 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 expected return to the carry trade will be positive if its covariation with the stochastic discount factor is negative.[5]

2.3 The Hedged Carry Trade

Burnside *et al.* (2011b), Caballero and Doyle (2012), Farhi *et al.* (2015), and Jurek (2014) examine hedging the downside risks of the carry trade by purchasing insurance in the foreign currency option markets. To examine this analysis, let C_t and P_t be the dollar prices of one-period foreign currency call and put options with strike price K on one unit of foreign currency. Buying one unit of foreign currency in the forward market costs F_t dollars in one period, which is an unconditional future (time $t+1$) cost. One can also unconditionally buy the foreign currency forward by buying a call option with strike price K and selling a put option with the same strike price, in which case the future cost is $K + C_t(1+i_t^\$) - P_t(1+i_t^\$)$. To prevent arbitrage, these unconditional future costs must be equal, which implies

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

This is the put-call parity relationship for foreign currency options.

Now, suppose a dollar-based speculator wants to be long w_t units of foreign currency in the forward market. The payoff is negative if the realized future spot exchange rate—expressed in dollars per unit of 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

[5] Examples of such models include Nielsen and Saá-Requejo (1993) and Frachot (1996), who develop the first no arbitrage pricing models; Backus *et al.* (2012), who offer an explanation in terms of monetary policy conducted through Taylor Rules; Farhi and Gabaix (2016), who develop a crash risk model; Bansal and Shaliastovich (2013) who develop a long run risks explanation; and Lustig *et al.* (2014) who calibrate a no-arbitrage model of countercyclical currency risks. Sarno *et al.* (2012) estimate an affine model of the bond markets in two currencies and the rate of depreciation in the corresponding currency market.

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

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

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

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

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

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

We examine hedged carry trades implemented with either 10Δ or 25Δ options, where Δ measures the sensitivity of the option price to movements in the underlying exchange rate.[6] Specifically, for the 10Δ strategy, we combine each long (short) position in a foreign currency with the purchase an out-of-the money put (call) with $\Delta = -0.10$ (0.10). Because the hedged carry trades are also zero net investment strategies, their returns must also satisfy equation (5).

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

3 Data

In constructing our carry trade returns, we use data on the world's major currencies, the so-called 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).[7] 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 monthly observations on the carry trade. Data for the AUD and the NZD start in October 1986. Interest rate data are eurocurrency interest rates from Datastream.

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

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,

[7] Investable carry trade indices based on G10 currencies include the iPath Optimized Currency Carry ETN and the Powershares DB G10 Currency Harvest Fund. The Bank for International Settlements (2014) triennial survey reports that the G10 currencies accounted for 88% of global foreign exchange market average daily turnover in April 2013. Academic research that focuses on the profitability of carry trade strategies in the G10 currencies includes Burnside *et al.* (2011a), Christiansen *et al.* (2011), Farhi *et al.* (2015), and Jurek (2014).

Longstaff *et al.* (2011) demonstrate that sovereign risk premiums, as measured by credit default swaps (CDS), do not just measure idiosyncratic sovereign default risk because the CDS returns covary positively 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 J.P. 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 have 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.

4 Returns and Risks of the Carry Trade

Table 1 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 data are available.

4.1 Basic Carry Trade Statistics

Our first strategy, designated *EQ*, has equal absolute value weights. The weight on currency j is therefore:

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

where N_t is the number of currencies in our database at time t. Thus, if the currency j interest rate 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. This version of the carry trade is the most studied in academic articles.[9] The return to the EQ strategy from time t to time $t+1$ is then

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

[9] A partial list of studies that use an equally weighted strategy includes Bakshi and Panayotov (2013), Bekaert and Panayotov (2015), Brunnermeier *et al.* (2008), Burnside

Table 1: Summary statistics of USD carry trade returns

Description: This table presents summary statistics on returns to five carry trade strategies: 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 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 first-order autocorrelation, 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).

Interpretation: Carry trade returns have statistically significant Sharpe ratios larger than many other investments and exhibit negative skewness.

	Carry Trade Weighting Method				
	EQ	EQ-RR	SPD	SPD-RR	OPT
Mean Ret (% p.a.)	3.96	5.44	6.60	6.18	2.10
	(0.91)	(1.13)	(1.31)	(1.09)	(0.47)
Standard Deviation	5.06	5.90	7.62	6.08	2.62
	(0.28)	(0.22)	(0.41)	(0.24)	(0.17)
Sharpe Ratio	0.78	0.92	0.87	1.02	0.80
	(0.19)	(0.20)	(0.19)	(0.19)	(0.20)
Skewness	-0.49	-0.37	-0.31	-0.44	-0.89
	(0.21)	(0.11)	(0.19)	(0.14)	(0.34)
Excess Kurtosis	2.01	0.40	1.78	0.90	3.91
	(0.53)	(0.21)	(0.35)	(0.29)	(1.22)
Autocorrelation	0.08	0.16	0.02	0.09	0.06
	(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

the weighted sum of the 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, which we implement using the equivalent forward market transactions as discussed in Section 2.1.

The second strategy, labeled SPD, is 'spread-weighted.' Like the EQ strategy, it is long (short) currencies that have a positive (negative) interest differential relative to the dollar, but the size of the investment in a particular currency is determined by the relative 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 sum of absolute values of the weights in the foreign currencies is again one, but the SPD strategy invests proportionately more in currencies that have larger interest differentials.[10]

Because the return volatilities of the EQ and SPD strategies rise and fall with changes in exchange rate volatilities, such strategies would not generally be employed by traders in FX markets who are typically constrained by a *value-at-risk* requirement, defined as the maximum loss that could 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%. Traders consequently must scale their investments based on some estimate of portfolio 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 for which we use 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

et al. (2011b), Clarida *et al.* (2009), Lettau *et al.* (2014), Lustig *et al.* (2011) and Lustig *et al.* (2014).

[10] Jurek (2014) spread weights by taking positions on the basis of the absolute distance of country j's interest rate from the average of the interest rates in countries with ranks five and six.

model for h_t^{ij} is

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

where because of the daily horizon, we treat the product of the returns as equivalent to the product of the innovations in the returns. We set $\delta = 0.06$, as suggested in J. P. Morgan (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 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 portfolios accordingly.

Our final strategy in this section involves sequential mean-variance optimization and is labeled OPT. 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, 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 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 $\sqrt{\mu_t' H_t^{-1}\mu_t}$.[11]

Table 1 reports the first four moments of the various carry trade strategies and their (annualized) Sharpe ratios and first-order autocorrelations. Standard errors are based on the Generalized Method of Moments of Hansen (1982), as explained in Section B of the online appendix. Throughout the paper, when we discuss estimated parameters, GMM standard errors, calculated using three Newey and West (1987) lags, are in parentheses and the associated robust t-statistics are in square brackets.

For the full sample, the carry trades for a USD-based investor have statistically significant mean 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. Jurek (2014) also finds that spread-weighting improves the performance of the carry trades. The strategies have impressive Sharpe ratios, which range from 0.78 (0.19) for the EQ strategy to

[11] Ackermann *et al.* (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.

1.02 (0.19) for the SPD-RR strategy. As Brunnermeier *et al.* (2008) note, each of these strategies is significantly negatively skewed, with the OPT strategy having the most negative skewness of -0.89 (0.34). Table 1 reports positive excess kurtosis that is statistically significant for all strategies. The first-order autocorrelations of the strategies are low, as would be expected in currency markets, and only for the EQ-RR strategy can we reject that the first-order autocorrelation is zero. Of course, it is well known that this test has very low power against interesting alternatives. The minimum monthly returns for the strategies are all quite large, ranging from -4.01% for the OPT strategy to -7.26% for the SPD. The maximum monthly returns range from 3.21% for the OPT to 8.07% for the SPD. Finally, Table 1 indicates that the carry trade strategies are profitable on between 288 months for the EQ strategy and 303 months for the OPT strategy out of the total of 451 months.[12]

4.2 Base Currency and Measurement Currency

The preceding discussion and most academic research about the carry trade takes the perspective of a U.S.-based investor for whom the USD is, in our terminology, both the *base currency* and the *measurement currency*. Here, we use *measurement currency* to denote the currency in which the investor measures his or her profits. The *base currency* denotes the currency which is the basis for the positions that the carry trade takes.

For example, for the EQ strategy that is most often studied in the academic literature, the USD is most often the base currency. The EQ strategy goes goes long (short) all currencies with an interest rate higher (lower) than the USD interest rate. Financing of the long high-interest-rate currency positions is done by borrowing in USD, and the capital that is raised by shorting the low-interest-rate currencies is assumed to be invested in USD. Were such a strategy implemented in an alternative base currency, the returns would be different for two reasons. First, the “cutoff-rate” that determines whether a currency is bought or sold would be the base-currency interest rate rather than the USD interest rate. Second, the financing of the long positions and the investing from the short positions would be done in the alternative base currency, rather than in USD. As as extreme example,

[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.

suppose the USD interest rate is the highest, and the JPY interest rate is the lowest in the G-10. In this case, the USD-based EQ strategy would be long 1 unit of USD, and short 1/9th of every other currency. The JPY-based EQ strategy, in contrast, would be long only 1/9th unit of USD, and would be short 1 unit of JPY.

The measurement currency for the EQ carry trade that is the basis for most academic papers is also generally the USD. Note that the measurement currency need not be the same as the base currency.[13] For example, a European investor could implement the EQ carry trade with a USD base currency, but measure the returns in EUR. To do so, this investor would go long (short) all currencies with an interest rate higher (lower) than the USD interest rate, borrow in USD to finance the long (high-interest-rate) currency positions, and invest the short proceeds (raised by shorting the low-interest-rate currencies) in USD. However, this investor would measure her profits in her EUR home currency.

One might imagine that the measurement currency would have a large effect on the performance of the carry trade; to stick to our example from the preceding paragraph with a USD base currency and an EUR measurement currency, one might think that when the all other currencies appreciate relative to the EUR, that EUR-measured carry trade return would be substantively higher than the USD-measured return. Interestingly, this effect is small, and it is vanishingly small in continuous time for diffusion processes. The reason is that carry-trade returns are excess returns, and to convert the payoffs measured in USD into EUR, you convert both the long-side and the short-side payoffs. The result of a EUR depreciation over an interval, for example, means that the EUR-measured long-side payoff will be higher, but the EUR-measure short-side payoff will be lower by roughly the same amount.

There is, however, a difference in average returns to these carry trades from changing the measurement currency that arises as a result of any covariance between the carry-trade return and the appreciation of the measurement currency. We provide a mathematical derivation of this in online appendix C, and confirm empirically that this covariance almost fully captures the differences that arise from using an alternative measurement currency. We also compare the results presented in Table 2, which are denominated in USD, to results denominated in the base currency, and

[13] We thank the editor, Ivo Welch, for pointing out this distinction.

verify that the performance ordering that we see in this table (both average returns and Sharpe-ratios) is independent of the currency in which the excess-returns are denominated.

While the measurement currency doesn't affect our results, the choice of base currency turns out to have a large effect. Table 2 presents the summary statistics for EQ carry trades with alternative base currencies but where, to allow for comparisons between the columns, the excess returns are all measured in USD. 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 USD-based EQ strategy. For the non-USD-based currencies, the mean annualized strategy returns range from 2.42% (1.26) for the CHF to 4.70% (1.53) for the NZD. All mean returns are statistically significant at the .06 marginal level of significance or smaller. The USD-base-currency strategy has the second highest mean return, but the highest Sharpe ratio among these strategies.[14] Despite their lower mean returns, the non-USD-based strategies generally have higher volatilities, and as a results their Sharpe ratios are all smaller than the USD-based Sharpe ratio of 0.78 (0.19). Except for the EUR, the point estimates of skewness for the alternative base-currency carry trades are all negative, and the statistical significance of skewness is high for the JPY, NOK, SEK, CHF, 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. Only the return volatility of the CAD-based strategy is lower than the USD-based one, and we thus find that the maximum gains and losses on these strategies generally exceed those of the USD-based strategy with maximum monthly losses for the JPY, SEK, CHF, NZD, and AUD carry trades exceeding 10%. The alternative base-currency carry trades also have fewer positive monthly returns than does the USD-base strategy.[15] These results show that carry trade profitability is not just a USD phenomenon, but that the USD is potentially more important than other currencies in determining the profitability. We explore this in more depth below.

[14] It is unlikely that we would be able to reject equivalence of the means, given the standard errors.

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

Table 2: Summary Statistics of the EQ Carry Trade by Base Currency

Description: Each column of this table presents summary statistics on monthly excess returns to the equal weight EQ carry trade strategy, for a given base currency. Each excess return is dollar demoninated. The sample period is 1976:02-2013:08 except for the AUD and the NZD, which start in October 1986. The reported mean, standard deviation, skewness, excess kurtosis, and first-order autocorrelation, and their associated standard errors (in parentheses) are simultaneous GMM estimates. The mean and standard deviation of the monthly excess returns are annualized, and in percent. 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).

Interpretation: The mean returns are statistically and economically large for every base currency. The USD-base-currency strategy has the highest Sharpe ratio.

	Carry Trade Base Currency									
	CAD	EUR	JPY	NOK	SEK	CHF	GBP	NZD	AUD	USD
Mean Return	3.08	2.45	2.54	2.90	2.64	2.42	3.40	4.70	3.85	3.96
	(0.74)	(0.92)	(1.79)	(0.82)	(0.97)	(1.26)	(0.97)	(1.53)	(1.40)	(0.91)
Std. Dev.	4.24	5.30	9.77	5.02	5.61	7.26	5.59	8.36	7.48	5.06
	(0.21)	(0.26)	(0.70)	(0.29)	(0.65)	(0.43)	(0.39)	(0.82)	(0.59)	(0.28)
Sharpe Ratio	0.73	0.46	0.26	0.58	0.47	0.33	0.61	0.56	0.52	0.78
	(0.18)	(0.17)	(0.19)	(0.18)	(0.21)	(0.18)	(0.18)	(0.19)	(0.20)	(0.19)
Skewness	-0.07	-0.02	-1.13	-0.42	-2.83	-0.69	0.10	-0.40	-0.63	-0.49
	(0.19)	(0.18)	(0.42)	(0.31)	(0.84)	(0.31)	(0.50)	(0.29)	(0.25)	(0.21)
Excess Kurtosis	1.49	1.25	4.98	2.81	20.46	2.79	4.80	4.48	2.96	2.01
	(0.36)	(0.39)	(1.96)	(0.86)	(5.95)	(1.17)	(1.85)	(1.17)	(1.43)	(0.53)
Autocorrelation	0.03	0.01	0.08	0.00	0.06	-0.02	0.09	-0.11	-0.08	0.08
	(0.07)	(0.06)	(0.08)	(0.06)	(0.05)	(0.06)	(0.05)	(0.10)	(0.11)	(0.07)
Max	4.71	6.05	8.75	6.55	5.42	8.49	9.78	10.02	7.86	4.78
Min.	-4.20	-5.20	-17.29	-6.86	-13.89	-11.06	-8.12	-12.21	-11.04	-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

4.3 Carry-Trade Exposures to Risk Factors

We now examine whether the average returns to the dollar-based 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. To measure risk exposures, we regress a carry trade return, R_t, on sources of risks, F_t, as in

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

In most of our analysis we use market-traded risk factors that are returns to zero-investment portfolios in which case α measures the average return of the carry trade not explained by its unconditional exposure to the risks included in the regression multiplied by the average returns to those risks.

4.3.1 Equity Market Risks

Panel A of Table 3 presents results for equity market risks represented by the three Fama and French (1993) 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, $R_{HML,t}$.[16] While eight of the 15 loadings on the risk factors have t-statistics greater than 1.96, the R^2's are all small. Moreover, these equity market risks leave most of the average returns of the carry trades unexplained as the α's range from 1.83% for the OPT strategy to 5.55% for the SPD-RR strategy with all t-statistics larger than 3.72. These equity market risks clearly do not explain average carry trade returns, consistent with the analysis in Burnside *et al.* (2011b), among others.

4.3.2 Pure FX Risks

Panel B of Table 3 presents results for the two foreign exchange market risks proposed by Lustig *et al.* (2011) who sort 35 currencies into six portfolios based on their interest rates relative to the dollar interest rate, with

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

Table 3: **Carry Trade Exposures to Equity, FX and Bond Risk Factors**

Description: The Table presents regressions of returns to five carry trade strategies on the three Fama and French (1993) equity market risk factors in Panel A, the two pure foreign exchange risk factors constructed by Lustig *et al.* (2011) in Panel B, and the U.S. equity market and two USD bond market risk factors in Panel C. The reported α's are annualized percentages. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Interpretation: The only insignificant α estimate in the Table is for the EQ portfolio with the FX Factors of Lustig *et al.* (2011) as explanatory factors. However, the α's remain significant once the carry trade is either spread-weighted or risk-rebalanced.

	Carry Trade Strategy				
	EQ	SPD	EQ-RR	SPD-RR	OPT
Panel A: Equity Factors, 1976:02-2013:08					
α	3.39	5.34	4.95	5.55	1.83
	[3.76]	[4.00]	[4.27]	[4.84]	[3.72]
β_{MKT}	0.05	0.10	0.05	0.06	0.02
	[2.46]	[2.88]	[2.25]	[2.33]	[1.88]
β_{SMB}	-0.03	0.00	-0.03	-0.01	0.01
	[-0.90]	[0.06]	[-0.89]	[-0.18]	[0.96]
β_{HML}	0.07	0.13	0.05	0.07	0.03
	[2.21]	[2.93]	[1.62]	[2.27]	[1.98]
R^2	.04	.05	.02	.02	.02
Panel B: FX Factors, 1983:11-2013:08					
α	1.47	2.86	2.86	3.60	1.29
	[1.73]	[2.34]	[2.81]	[3.44]	[2.87]
β_{RX}	0.14	0.31	0.01	0.11	0.01
	[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
	[8.24]	[7.04]	[8.85]	[6.57]	[6.22]
R^2	.31	.34	.29	.28	.13
Panel C: Bond Factors, 1976:01-2013:08					
α	4.19	6.71	5.74	6.43	2.15
	[4.51]	[4.97]	[5.03]	[5.74]	[4.65]
β_{MKT}	0.04	0.08	0.04	0.04	0.02
	[1.81]	[2.36]	[1.92]	[2.01]	[1.74]
β_{10y}	-0.39	-0.51	-0.44	-0.41	-0.12
	[-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
	[2.46]	[2.21]	[3.26]	[2.93]	[2.30]
R^2	.05	.05	.05	.04	.02

portfolio one (six) containing the lowest (highest) interest rate currencies. Their two risk factors are $R_{RX,t}$, the mean return on all six portfolios, and $R_{HML-FX,t}$, which is the return difference between portfolios 6 and 1. Notably, $R_{RX,t}$ has a correlation of .99 with the first principal component of the six portfolio returns, and $R_{HML-FX,t}$ has a correlation of .94 with the second principal component.[17] Given its construction, it is not surprising that $R_{HML-FX,t}$ has significant explanatory power for our carry trade returns, with t-statistics between 6.22 for the OPT portfolio and 8.85 for the EQ-RR portfolio. The R^2's are also higher than with the equity risk factors, ranging between .13 and .34. While this pure FX risk model better explains the average returns to our strategies than do the equity risks, the α's remain statistically significant and range from a low of 1.29% for the OPT portfolio to 3.60% for the SPD-RR portfolio.[18] While Lustig *et al.* (2011) essentially demonstrate that the returns on their carry trade portfolios have a reduced dimensionality, the conditioning information provided by spread-weighting and risk-rebalancing allows those conditional trades to demonstrate abnormal profits relative to that reduced factor space.

4.3.3 Bond Market Risks

Movements in exchange rates are relative rates of currency depreciation, and in theory should reflect all sources of aggregate risks in the stochastic discount factors associated with the two currencies. Because bond markets explicitly price risks in the stochastic discount factor, it is logical that bond market risk factors should also have explanatory power for the carry trade.[19] Panel C of Table 3 presents the results of regressions of the carry trade returns on the excess equity market return and two USD bond market risk factors: 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 return data are from CRSP.

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

[18] Note however that the t-statistic of the α for the EQ portfolio falls to 1.73.

[19] Sarno *et al.* (2012) find that reduced form affine models designed to price bond yields, which have small bond pricing errors, are unable to capture the dynamics of the rates of currency depreciation.

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. Nevertheless, the R^2's remain between .02 and .05, as in the equity market regressions. The statistically significant α's, ranging from 2.15% for OPT to 6.71% for SPD, indicate that bond market risks do not explain the carry trade returns.

4.3.4 Volatility Risk

To capture possible exposure of the carry trade to equity market volatility, we introduce the return on an equity variance swap as a risk factor.[20] This return is calculated as

$$R_{VS,t+1} = \sum_{d=1}^{Ndays} \left(\ln \frac{P_{t+1,d}}{P_{t+1,d-1}} \right)^2 \left(\frac{252}{Ndays} \right) - \mathrm{VIX}_t^2,$$

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 continue to examine the α's to assess whether exposure of the carry trade to volatility risk explains the average returns.

Table 4 presents regressions which incorporate the equity and bond factors in addition to the variance swap returns. Because the sample period here is different from the one in Table 3, 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.

[20]Menkhoff *et al.* (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 .80 with $R_{HML-FX,t}$, we find that their volatility risk factor has similar explanatory power to the pure foreign exchange risk model described previously, and consequently, we do not report those results here.

Table 4: **Carry Trade Exposure to Equity and Volatility Risks**

Description: This table reports regressions of five carry trade returns on risk factors as in Panels A and C of Table 3, but it also includes the return on a variance swap as a risk factor. The sample period is 1990:02-2013:08 (283 observations). The reported α's are annualized percentages. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Interpretation: The estimated α's fall slightly and become statistically insignificant for the EQ and EQ-RR strategy after controlling for exposure to both the bond-market factors and the variance swap returns. All other estimated α's remain statistically significant.

	EQ	EQ-RR	SPD	SPD-RR	OPT	EQ	EQ-RR	SPD	SPD-RR	OPT
	Panel A: Equity Risk Factors									
α	3.11	4.15	4.51	4.54	1.38	2.87	3.76	4.22	4.20	1.32
	[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
	[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
	[-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
	[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
						[-0.94]	[-0.90]	[-1.24]	[-1.40]	[-0.41]
R^2	.07	.10	.04	.04	.04	.07	.11	.04	.05	.04
	Panel B: Bond Risk Factors									
α	2.83	3.77	4.75	4.71	1.60	2.32	2.79	4.38	4.13	1.45
	[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
	[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
	[1.05]	[1.57]	[-0.26]	[0.28]	[-0.15]	[1.26]	[1.85]	[-0.05]	[0.58]	[0.04]
β_{10y-2y}	-0.35	-0.73	0.08	-0.10	0.01	-0.44	-0.91	0.01	-0.20	-0.02
	[-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
						[-1.39]	[-1.69]	[-1.25]	[-1.76]	[-0.70]
R^2	.04	.08	.02	.02	.02	.05	.09	.02	.03	.02

In both Panels A and B of Table 4, the coefficients on $R_{VS,t+1}$ are negative, indicating that carry trades perform badly when equity volatility increases as stressed by Bhansali (2007) and Clarida *et al.* (2009). However, these slope coefficients are small and not statistically significant. Moreover, exposure to volatility risk is not enough to explain the profitability of the trades as the α's are reduced only slightly and continue to remain statistically significant.

5 Dollar Neutral and Pure Dollar Carry Trades

Lustig *et al.* (2014) and Jurek (2014) find important differences between dollar-based carry trades and dollar-neutral carry trades. The analysis in Section 4 confirms that the historical efficacy of the EQ carry trade depends on the base currency in which it is implemented. In particular, Table 2 shows that the USD-based EQ strategy had a higher Sharpe ratio than for any other base currency. We now extend our earlier analysis by decomposing the EQ portfolio into dollar-neutral and dollar-carry components. We confirm that much of the efficacy of the carry trade is attributable to the dollar-carry component, and we further demonstrate striking differences in the risk characteristics of the two components.

Our *dollar-neutral* carry trade portfolio – which we label EQ-0\$ – takes positions only in the non-USD currencies. The EQ-0\$ weights are:

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

where $med\left\{i_t^k\right\}$ indicates the median of the non-USD interest rates at time t, and N_t is the number of non-USD currencies in the sample at time t. Then, assuming nine non-USD currencies, we take long positions of \$(1/9) in the four highest interest rate currencies, financed by short positions of \$(1/9) in the four lowest rate currencies. We take no position in the median interest rate currency. Given this construction, EQ-0\$ is a long-short portfolio with no direct dollar exposure.

Tables 5 and 6 present summary statistics and analysis of the risk-exposures of the EQ and EQ-0\$ portfolios, and two additional portfolios that capture the dollar component of the carry trade, which we describe in Sections 5.1 and 5.2.

Table 5: Summary Statistics for the Dollar-Neutral and Pure-Dollar Carry Trades

Description: This table presents summary statistics on returns to four carry trade strategies. The first three are the equal-weighted (EQ), dollar-neutral (EQ-0$) and dollar (EQ-$) strategies. EQ-$ is the difference between EQ and EQ-0$. EQ-D$ is the dynamic dollar strategy. 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 sample 1990:02-2013:08 when variance swap data are available.

Interpretation: The dollar-neutral and dollar components of the EQ strategy, EQ-0$ and EQ-$, both have statistically significant mean returns and Sharpe ratios, though the point estimates for the dollar component are slightly larger. The dynamic dollar strategy (EQ-D$) is more volatile, but its Sharpe ratio is higher and skewness is lower than that of the EQ-$ strategy.

	Panel A: 1976/02-2013/08				Panel B: 1990/2-2013/8			
	EQ	EQ-0$	EQ-$	EQ-D$	EQ	EQ-0$	EQ-$	EQ-D$
Mean Ret (% p.a.)	3.96	1.61	2.35	5.54	3.83	1.72	2.11	5.21
	(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
	(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
	(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
	(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
	(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
	(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 6: Dollar Neutral and Pure Dollar Carry Trade Risk Exposures

Description: Panels A, B and C present the results of regressions of carry trade returns on the risk factors considered in Table 3. The reported α's are annualized percentages. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Interpretation: The dollar and dollar-neutral components of the EQ carry trade behave very differently: the dollar-neutral component's return is explained both by the equity factors and the bond factors; the dollar component's return is not. In particular, the $alpha$'s of the dynamic-dollar strategy remain strongly statistically significant with all sets of explanatory factors.

	Carry Trade Strategy			
	EQ	EQ-0$	EQ-$	EQ-D$
Panel A: Equity Factors, 1976:02-2013:08				
α	3.39	1.03	2.36	5.41
	[3.76]	[1.54]	[3.60]	[3.70]
β_{MKT}	0.05	0.08	-0.02	0.01
	[2.46]	[5.29]	[-1.24]	[0.21]
β_{SMB}	-0.03	0.02	-0.05	-0.05
	[-0.90]	[1.00]	[-1.84]	[-1.04]
β_{HML}	0.07	0.05	0.02	0.06
	[2.21]	[2.83]	[0.84]	[1.08]
R^2	.04	.10	.04	.01
Panel B: FX Factors, 1983:11-2013:08				
α	1.47	-0.03	1.49	5.18
	[1.73]	[-0.06]	[1.86]	[3.40]
β_{RX}	0.14	-0.02	0.15	0.52
	[2.27]	[-0.50]	[2.80]	[4.31]
β_{HML-FX}	0.28	0.24	0.04	0.00
	[8.24]	[11.03]	[1.58]	[-0.01]
R^2	.31	.41	.09	.20
Panel C: Bond Factors, 1976:01-2013:08				
α	4.19	1.50	2.69	5.82
	[4.51]	[2.77]	[3.88]	[4.01]
β_{MKT}	0.04	0.06	-0.03	-0.01
	[1.81]	[5.48]	[-1.60]	[-0.35]
β_{10y}	-0.39	-0.25	-0.14	-0.22
	[-2.97]	[-4.42]	[-1.16]	[-0.92]
β_{10y-2y}	0.46	0.29	0.17	0.32
	[2.46]	[3.52]	[1.02]	[0.93]
R^2	.05	.12	.02	.01

Table 7: Dynamic Dollar Strategy – Risk Factor Analysis

Description: This table presents regressions of the EQ-D$ returns on the full set of risk factors, including the variance swap. The sample period is 1990:02-2013:08 (283 observations). The reported α is an annualized percentage. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Interpretation: The only factors to which the EQ-D$ strategy has statistically significant exposures are the RX and variance swap returns. The α remains statistically significant after controlling for these exposures.

	α	β_{MKT}	β_{SMB}	β_{HML}	β_{10y}	β_{10y-2y}	β_{RX}	β_{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	.19
	[2.79]	[0.62]	[-0.36]	[1.15]	[1.47]	[-1.53]	[3.14]	[2.03]	[2.67]	

The second columns of Panels A and B of Table 5 report the first four moments of the EQ-0$ 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 sample when VIX data are available. For ease of comparison, we report the same set of statistics for the EQ strategy in Column 1. The EQ-0$ portfolio has statistically significant mean annual returns in both samples, 1.61% (0.58) for the full sample and 1.72% (0.72) for the later sample. While these mean returns are lower than for EQ strategy, the EQ-0$ volatility is also lower. However, the EQ-0$ Sharpe ratios are nonetheless about 30% lower than the EQ Sharpe ratios in each sample period. The negative skewness and insignificant autocorrelations of the EQ-0$ 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 EQ-0$ strategy is exposed to risks.

The second column of Panels A and B in Table 6 shows that the alphas of the EQ-0$ strategy are zero after controlling for either the three Fama and French (1993) equity market risk factors, or the Lustig *et al.* (2014) FX factors. Panel A shows that EQ-0$ 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 α has a t-statistic of 1.54, and the R^2 is .10. In comparison, the regression of EQ returns on the same equity risk factors has an α of 3.39 with a t-statistic of 3.76 and an R^2 of only .04. The

Fama and French (1993) three factor model clearly does a better job of explaining the average return of the EQ-0$ strategy than that of the EQ strategy.

These results are consistent with Jurek (2014) who investigates a shorter sample and finds marginally significant α's in his spread-weighted carry trade regressions when adding the Carhart (1997) momentum factor to the three Fama and French (1993) model. He finds significant exposures to the market return and HML, but smaller, insignificant α's in his spread-weighted, dollar-neutral, carry trade regressions on the same factors. These results suggest that, after eliminating the dollar exposure from the EQ strategy, the average profitability of the developed currency carry trade can be explained by commonly used equity risk factors.

5.1 A Decomposition of the Carry Trade

To better understand the performance difference between EQ and EQ-0$, we create the EQ-$ portfolio, defined as the difference between the EQ and the EQ-0$ portfolios:

$$w_{j,t}^{\text{EQ-\$}} \equiv w_{j,t}^{\text{EQ}} - w_{j,t}^{\text{EQ-0\$}}$$

where the weights on the EQ and EQ-0$ portfolios are given in equations (9) and (12). Note that because both EQ and EQ-0$ are zero-investment portfolios, EQ-$ is as well. The exact positions of the EQ-$ portfolio depend on whether $i_t^{\$}$ is below or above the median interest rate. If $i_t^{\$} < median\left\{i_t^k\right\}$, then

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

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

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

The EQ-0\$ and EQ-\$ portfolios decompose the EQ carry trade into two components: a dollar-neutral component and a dollar component. EQ-\$ 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 interest rates are close, the EQ-\$ portfolio will be concentrated in just a few currencies.

The third columns of Panels A and B in Table 5 present the first four moments of the EQ-\$ strategy. The EQ-\$ mean returns are statistically significant in both samples, and the Sharpe ratios are close to those of the EQ-0\$ strategy. Skewness of EQ-\$ is negative but statistically insignificant due to the large standard error in both samples. In terms of both Sharpe ratio and skewness, the EQ-\$ strategy appears no better than the EQ-0\$ strategy. Note also that the kurtosis of EQ-\$ is far higher. Nevertheless, the EQ-\$ strategy has a correlation of -.11 with the EQ-0\$ strategy, and the following results illustrate that the EQ-\$ strategy also differs significantly from the EQ-0\$ strategy in its risk exposures.

Column 3 of Panel A in Table 6 presents regressions of EQ-\$ returns on the three Fama and French (1993) risk factors. Unlike EQ-0\$, only the SMB factor shows any explanatory power for the EQ-\$ returns. The α is 2.36% with a t-statistic of 3.60. The R^2 is .04. The equity market risks clearly do not explain the average returns to the EQ-\$ strategy.

Columns 1 to 3 of Panel B in Table 6 present regressions of the returns of EQ and its two components, EQ-0\$ and EQ-\$, on the two FX risk factors. The two factor FX model completely explains the average returns of the EQ-0\$ strategy while explaining only 25% of the average returns of EQ-\$. The α for EQ-\$ is also significant with a value of 1.49% and a t-statistic of 1.86 in the FX two factor model.

Finally, Columns 1 to 3 of Panel C in Table 6 present regressions of the returns to the EQ strategy and its two components, EQ-0\$ 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 EQ-0\$ and a relatively high R^2 of .12. By comparison, none of the risk factors has any significant explanatory power for the returns on the EQ-\$ strategy, and the resulting R^2 is only .02.

In summary, these results suggest that for the G10 currency dollar-based carry trade, the conditional dollar exposure contributes more to the carry trade “puzzle” than does the non-dollar component. This conclusion is consistent with the analysis of Lustig *et al.* (2014) who conclude that by conditioning investments on the level of the average forward discount U.S. investors earn large currency excess returns that are not correlated with traditional carry trade returns.

5.2 The Dynamic Dollar Strategy

The EQ-$ 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 EQ-0$ 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, EQ-$ takes positions in relatively few currencies. Absence of diversification is consistent with the large kurtosis noted in Table 5. 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-$ to all foreign currencies. We define our diversified, *dynamic dollar* strategy, EQ-D$, as:

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

The EQ-D$ strategy focuses on the conditional exposure of the U.S. dollar. It goes long (short) nine foreign currencies against the dollar when the dollar interest rate is lower (higher) than the global median interest rate. The EQ-D$ strategy is essentially the G10 counterpart of the "dollar carry" strategy developed by Lustig *et al.* (2014) who take an equal weight long (short) position in 20 developed currencies versus a short (long) position in the dollar if the dollar interest rate is lower (higher) that the average foreign interest rate.

The fourth columns of Panels A and B of Table 5 present the first four moments of the returns to the EQ-D$ strategy for the full sample and the VIX sample. We find that EQ-D$ has statistically significant mean annual returns of 5.54% (1.37) for the full sample and 5.21% (1.60) for the VIX sample, substantially higher than the means of EQ-$. Although its volatility is also higher than the EQ-$ strategy, its Sharpe ratio of 0.68 (0.18) in the full sample and 0.66 (0.21) in the VIX sample are larger although not significantly different from those of the EQ-$ strategy. Skewness of the EQ-D$ strategy is lower than the other three strategies and is statistically insignificant in both periods. Also, consistent with the greater diversification of EQ-D$, its excess kurtosis is lower, though still statistically significant.

Thus, the EQ-D$ strategy does not suffer from the extreme negative skewness often mentioned as the hallmark of carry trades. In addition, the fourth column of Table 6 reports regressions of the returns of EQ-D$ on the three Fama and French (1993) equity market factors, the bond market factors, and the FX risk factors. The only significant loading is on $R_{RX,t}$, which goes long all foreign currencies. The α's range from 5.18% [$t = 3.40$] in the FX risks regression to 5.82% [$t = 4.01$] for the bond market risks regression. When we use all of the risk factors simultaneously in Table 7 for the shorter sample period, the foreign exchange risk factors and the volatility factor have significant loadings, but the α of 4.52% remains large and statistically significant. These findings are consistent with those of Lustig *et al.* (2014) who report that their dollar-carry strategy is unconditionally uncorrelated with the U.S. market return and their R_{HML-FX}.

In summary, 60% of the premium earned by the EQ carry strategy can be attributed to the EQ-$ component, but more importantly, the EQ-D$ portfolio built on this conditional dollar exposure earns a large premium that is not explained by its small exposures to standard risk factors. Finally, the insignificant negative skewness of the EQ-D$ portfolio returns indicates that negative skewness does not explain the abnormal excess return of this strategy.

6 Downside Risk and the Carry Trade

We turn now to the question of whether downside risk, defined as the covariance of a return with the market return when the market return is significantly negative, can explain the high average carry trade returns. Lettau *et al.* (2014) and Jurek (2014) use different approaches to measure downside risk, and both studies conclude that downside-risk explains the average returns to the carry trade.[21]

We examine downside risk as an explanation for the carry trade premium through the lens of the return decomposition of the last section. Consistent with the findings of Lettau *et al.* (2014) and Jurek (2014), we

[21] Dobrynskaya (2014) uses a slightly different econometric specification than Lettau *et al.* (2014) but reaches similar conclusions. We therefore focus our discussion only on the latter.

find that EQ-0$ exhibits considerable downside risk. However, consistent with our findings with regard to other potential risk factors, we find that EQ-$ and EQ-D$ exhibit no significant downside risk, and their high average returns remain high after these risk adjustments. Thus, it is the dollar-neutral component of the carry trade that is exposed to downside risk, even though the dollar-carry component is responsible for most of the high average return earned by the carry trade.

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

Lettau *et al.* (2014) note that although portfolios of high interest rate currencies have higher exposures (β's) to the market return than portfolios of low interest rate currencies, the differences in unconditional market β's, combined with the average return to the market, prove to be insufficiently large to explain the magnitude of average carry trade returns. However, Lettau *et al.* (2014) further observe that the conditional exposures of carry trade returns to the return on the market when it is down are larger than their respective unconditional exposures. Based on this observation, they explore the ability of the downside risk model of Ang *et al.* (2006) to explain the high average carry trade returns.

In their empirical analysis, Lettau *et al.* (2014) define the downside market return, which we denote $R^{-}_{m,t}$, as the market return when it is one sample standard deviation below its sample mean and zero otherwise.[22] They run OLS regressions of portfolio returns, R_t, on a constant and either $R_{m,t}$ or $R^{-}_{m,t}$ to define the risk exposures, β and β^{-}. From these risk exposures, they argue that the expected return on a portfolio can be written as

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

where the sample mean return on the market is used for $E(R_{m,t})$ and the price of downside risk, λ^{-}, must be estimated in a cross-sectional regression of average returns, adjusted for their unconditional exposure to the market, on the beta differentials.[23]

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[22]We also considered two other definitions of $R^{-}_{m,t}$ based on alternative definitions of the downstate, either $R_{m,t} < \overline{R_m}$, where $\overline{R_m}$ is the sample mean, or $R_{m,t} < 0$. These results (in Table A.2 of the online appendix) are similar to the results reported here.

[23]In this section, we follow the approach of Lettau *et al.* (2014) even though we agree with Burnside and Graveline (2016), who are critical of this approach. Burnside and Graveline (2016) note that this restricted two-beta representation of downside risk cannot

Lettau *et al.* (2014) work with 53 currency returns sorted into six portfolios. They find that high interest rate differential portfolios have slightly higher β's than low interest rate differential portfolios, but these differential market risks, when combined with the mean return on the market are insufficient to explain the cross-sectional differences in the average returns on the portfolios. Nevertheless, the point estimates of $\beta^{-}-\beta$ are sufficiently monotonic that a cross-sectional regression of market-adjusted average returns, from a variety of assets including currency returns, on beta differentials produces a large price of downside risk, λ^{-}. Based on this Lettau *et al.* (2014) conclude that the average returns on the currency portfolios are explained by the downside risk model.

To examine this possible explanation of our carry trade returns, we first run two univariate regressions where the dependent variable is a carry trade return:

$$R_t = \alpha + \beta R_{m,t} + e_t$$
$$R_t^{-} = \alpha^{-} + \beta^{-} R_{m,t}^{-} + e_t^{-}$$

The first regression uses all of the data; the second uses data only when the market return is in the downstate. The downside risk theory requires that β^{-} be different from β. Hence, as a first step, we explicitly test the difference between β^{-} and β with a $\chi^2(1)$ constructed from GMM using Newey and West (1987) standard errors with three lags. Table 8 presents the results for our eight carry trade portfolios.

In the basic regressions in Panel A we find estimates of unconditional β's that are quite small, ranging from -0.03 for the EQ-\$ portfolio to 0.07 for the SPD portfolio. Only the β's of the EQ-0\$ and the SPD portfolios are significantly different from 0 at the .05 marginal level of significance. The EQ-\$ and EQ-D\$ strategies, on the other hand, have slightly negative β's, which are statistically insignificantly different from 0. Because the risk factor in these first regressions is an excess return, the α's can be interpreted as average abnormal returns, and all of the α's except the EQ-0\$ are strongly significantly different from zero, as the smallest Newey-West t-statistic is 3.78.

Panel B of Table 8 examines the downside regression. The estimates of β^{-} are also small, ranging from -0.14 for EQ-D\$ to 0.15 for SPD. These

be derived from a stochastic discount factor (SDF) model that has the properties that one would want to impose, including that the SDF is monotonically decreasing as $R_{m,t}$ crosses the boundary from the down state into the up state.

Table 8: Carry Trade Exposures to Downside Market Risk

Description: This table presents analysis of the downside market risk explanation of the carry trade premium offered by Lettau *et al.* (2014). Panel A presents estimated coefficients and GMM-based standard errors for the monthly regression

$$R_t = \alpha + \beta \cdot R_{m,t} + \epsilon_t,$$

where $R_{m,t}$ is the CRSP value-weighted market return minus the one-month Treasury bill return. Panel B presents results from the same regression, but where the sample includes only months for which the excess market return $R_{m,t}$ was at least one sample standard deviation below its sample mean. Panel B also reports the $\chi^2(1)$ statistic that tests the difference in the two slope coefficients (i.e., β and β^-), and the p-value associated with that χ^2 statistic. Panel C calculates $\beta^- - \beta$ and uses estimates of downside risk premiums, λ^-'s, from Lettau *et al.* (2014) to calculate expected returns on the carry trades from the downside risk model. The sample period is 1976:02-2013:08 (451 observations). The α estimates in Panels A and B and the premium estimates in Panel C are annualized, and GMM-based autocorrelation and heteroskedasticity consistent t-statistics are given in square brackets.

Interpretation: Strikingly, the estimates of the downside beta (β^-) and the unconditional beta (β) are almost equal, and the p-value associated with the χ^2 statistic shows that they are not statistically different. Panel C shows that the estimated magnitudes of the downside risk premia are small (using either value of λ^-) compared with the estimated premium presented in Panel A.

Panel A:	EQ	SPD	EQ-RR	SPD-RR	OPT	EQ-0$	EQ-$	EQ-D$
α	3.72	6.08	5.18	5.92	1.98	1.18	2.54	5.63
	[4.01]	[4.55]	[4.50]	[5.30]	[4.12]	[2.06]	[3.78]	[4.03]
β	0.03	0.07	0.04	0.04	0.02	0.06	-0.03	-0.01
	[1.55]	[2.13]	[1.59]	[1.71]	[1.51]	[4.78]	[-1.68]	[-0.36]

Panel B:	EQ	SPD	EQ-RR	SPD-RR	OPT	EQ-0$	EQ-$	EQ-D$
α^-	2.82	13.21	4.19	14.05	1.49	6.79	-3.97	-4.50
	[0.48]	[1.78]	[0.45]	[2.10]	[0.44]	[1.84]	[-0.83]	[-0.45]
β^-	0.03	0.15	0.05	0.14	0.02	0.13	-0.10	-0.14
	[0.53]	[1.92]	[0.42]	[1.74]	[0.41]	[3.07]	[-1.83]	[-1.22]
$\chi^2(1)$	0.00	1.06	0.01	1.96	0.00	3.59	1.97	1.42
p-value	1.00	0.30	0.92	0.16	0.98	0.06	0.16	0.23

Panel C:	EQ	SPD	EQ-RR	SPD-RR	OPT	EQ-0$	EQ-$	EQ-D$
β^--β	0.00	0.08	0.01	0.10	0.00	0.07	-0.07	-0.13
	Downside Risk Premium$(\beta^- - \beta) \times \lambda^-$							
$\lambda^- = 16.9$	0.00	1.31	0.16	1.63	0.01	1.22	-1.22	-2.21
$\lambda^- = 26.2$	0.00	2.02	0.25	2.53	0.02	1.89	-1.89	-3.28

estimates are either equal to or only slightly larger, in absolute value, than the corresponding β estimates. The standard errors of the estimates of β^- are sufficiently large that the largest t-statistic, other than for the EQ-0$ portfolio, is only 1.92, which coincides with a marginal level of significance of .03. The p-values of the tests of the equality of β^- and β are all larger than .16, except for the EQ-0$ portfolio where we can reject the null hypothesis at the .06 marginal level of significance. Notice also that the negative estimate of β^- for the EQ-D$ strategy indicates that this strategy is inversely exposed to the market's downside risk.[24] Rather than concluding that this downside risk model cannot explain our carry trade returns, we confront our portfolio returns and the estimates of their risk exposures with the prices of downside risk estimated by Lettau *et al.* (2014).

Because $R^-_{m,t}$ is not a return, one cannot interpret the constants in these regressions as abnormal returns, which is why Lettau *et al.* (2014) perform a cross-sectional analysis of market-adjusted average returns on risk exposures to estimate the additional price of downside market risk. To determine how much our estimated exposures to downside risk could possibly explain the average returns to our carry trades, we combine our point estimates of $\beta^- - \beta$ with the point estimates of the price of downside risk from Lettau *et al.* (2014), rather than performing our own cross-sectional analysis on a small number of assets. Lettau *et al.* (2014) include assets other than currencies in their cross-sectional analysis and find large positive prices of downside market risk, depending on the cross-section of assets included. When they include currencies and equities with returns measured in percentage points per month, they estimate $\lambda^- = 1.41\%$, or 16.9% per annum. When they include only currencies, they estimate λ^- = 2.18%, or 26.2% per annum. The last two rows of Panel C in Table 8 multiply our estimates of $\beta^- - \beta$ by either 16.9% or 26.2%. Doing so provides the explained part of our average carry trade returns that is due to downside risk exposure. Compared to the α's in Panel A, the extra return

[24]Because the EQ-D$ strategy takes positions in all foreign currencies relative to the USD 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 dollar interest rate. For example, if the USD interest rate is below the median interest rate but above the JPY interest rate, the EQ-D$ strategy will go long the JPY, which could massively appreciate in a market crash as carry trades unwind leading to a large gain for the EQ-D$ strategy whereas the carry trade strategy would have shorted the JPY and would have experienced a large loss when the market crashed.

explained by downside risk exposure is minimal for the EQ, EQ-RR, and OPT strategies. The downside risk premium explains between 0% and 10% of the CAPM α's of these three strategies. For the SPD and SPD-RR strategies, the downside risk premium explains between 21.5% and 42.7% of the CAPM α's. Notice also that the negative estimate of β^- for the EQ-D$ strategy implies that the downside market risk theory cannot explain the excess return of the EQ-D$ 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 redo the above downside risk analysis using the five interest rate sorted portfolios of Lettau *et al.* (2014). Portfolio P1 (P5) contains the lowest (highest) interest rate currencies. The results presented in Table 9 have the same format as Table 8.

Panel A of Table 9 demonstrates that the β's of these portfolios are also small, but they are monotonically increasing from 0.01 for P1 to 0.10 for P5. The CAPM α's are also monotonically increasing from -1.77% [-1.17] for P1 to 3.27% [1.73] for P5. While these α's are not particularly statistically significant, the P5—P1 portfolio has an α of 5.04% with a t-statistic of 3.76. Panel B of Table 9 shows that the point estimates of β^- also monotonically increase from 0.01 for P1 to 0.22 for P5, but these five estimates are insignificantly different from zero as the largest t-statistic is 1.23. The p-values of the tests of the equality of β^- to β for the five portfolios are all larger than .43, and the test for the P5—P1 portfolio has a .29 marginal level of significance. Although we do not find significant beta differentials in Panel B, we again combine the point estimates of $\beta^- - \beta$ with the estimated prices of downside risk from Lettau *et al.* (2014), as above. Panel C of Table 9 shows that the predicted downside risk premiums are 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 -1.77% and the CAPM α's of the P2 and P3 portfolios are -0.69% and 0.96%, respectively. Nevertheless, we note that 36% or 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 estimates of the annualized downside risk premium of 16.9% or 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

Table 9: LMW Portfolios – Exposure to Downside Market Risk

Description: This table presents an analysis of the downside market risk explanation of carry trade returns offered by Lettau *et al.* (2014) using their developed country portfolio returns. The five portfolios contain currency returns from low interest rate countries in P1 to high interest rate countries in P5. The calculations in Panels A, B and C follow the description given in Table 8.

Interpretation: This table again shows that the estimated downside risk betas are close to the unconditional betas. Particularly for the low interest-rate-currency portfolio (P1) and for the difference portfolio, the magnitudes of the estimated downside risk premiums are small relative to the size of the premiums.

Panel A:	P1	P2	P3	P4	P5	P5-P1
α	-1.77	-0.69	0.96	2.15	3.27	5.04
	[-1.17]	[-0.40]	[0.58]	[1.35]	[1.73]	[3.76]
β	0.01	0.05	0.05	0.06	0.11	0.10
	[0.29]	[1.29]	[1.31]	[1.72]	[2.20]	[3.08]

Panel B:	P1	P2	P3	P4	P5	P5-P1
α^-	1.16	-3.71	1.88	11.93	14.08	12.92
	[0.08]	[-0.26]	[0.12]	[1.02]	[0.73]	[1.27]
β^-	0.01	0.02	0.05	0.15	0.22	0.21
	[0.08]	[0.15]	[0.29]	[1.23]	[1.00]	[1.89]
$\chi^2(1)$	0.00	0.03	0.00	0.62	0.32	1.11
p-value	0.99	0.85	0.99	0.43	0.57	0.29

Panel C:	P1	P2	P3	P4	P5	P5-P1
$\beta^- - \beta$	0.00	-0.02	-0.00	0.09	0.11	0.11
	Downside Risk Premium$\left(\beta^- - \beta\right) \times \lambda^-$					
$\lambda^- = 16.9$	0.03	-0.41	-0.03	1.45	1.82	1.79
$\lambda^- = 26.2$	0.05	-0.63	-0.05	2.25	2.83	2.78

for the average returns to carry trade portfolios, even allowing for very large downside-risk prices.

6.2 The Jurek (2014) Downside Risk Analysis

Jurek (2014) examines the exposure of carry trades to downside risk by regressing carry trade returns on a *downside risk index* (DRI), defined to be the monthly return from a zero-investment, levered portfolio that sells S&P 500 puts with an average maturity of six weeks. The DRI is developed and explored in Jurek and Stafford (2015), 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 (2015) show that an appropriately levered investment in selling puts 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.[25] Because the DRI is an excess return, this approach to downside risk has the advantage that the estimated regression intercept can be interpreted as a measure of abnormal returns with respect to the traded risk factor.

Our analysis uses DRI returns from January 1990 to August 2013.[26] Table A.1 in 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 monthly regressions of spread-weighted and spread-weighted/dollar-neutral carry trades over the 1990:1-2012:06 period, and he reports slope coefficients [OLS t-statistics] on the DRI of 0.3514 [6.41] and 0.3250 [5.85], respectively, and α's of 0.0019 [0.14] and -0.0032 [-0.22], respectively. Jurek (2014) interprets the strong significance of the slopes and the fact that the α's are economically small and

[25] Caballero and Doyle (2012) 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.

[26] We are grateful to Jakub Jurek for providing the DRI returns used in Jurek (2014). His data are constructed 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 to August 2013.

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

Panel A of Table 10 presents the results of regressing the monthly returns to our carry trade portfolios on the DRI returns. For the EQ, SPD, EQ-RR, SPD-RR and OPT portfolios our results are consistent with Jurek's findings, in that the slope coefficients on the DRI return are statistically significant.[27] However, in contrast with Jurek's findings, the α's remain mostly statistically significant. The key reason for this difference is revealed in the last three portfolios: for the EQ-0$ (dollar-neutral) portfolio the slope coefficient is highly statistically significant ($t = 5.14$), and the t-statistic of the α is only 0.13, consistent with Jurek's finding that the returns of the carry trade portfolio are explained by its exposure to the DRI. In contrast to Jurek's results, though, for the EQ-$ and the EQ-D$ portfolios, the point estimates of the slope coefficients on DRI are actually *negative* (though statistically insignificant), and the α for the EQ-D$ portfolio remains large and statistically significant.

Differences in the findings on the first five portfolios arise from differences in portfolio construction. Jurek (2014) defines the spread as the absolute distance between country i's interest rate and the average of the interest rates on the fifth and sixth of the G10 countries while we define the spread as the absolute distance between country i's interest rate and the USD interest rate. As a result, our spread-weighted carry trade has more exposure to the USD than the comparable portfolio in Jurek (2014).

This evidence is again consistent with the hypothesis that, while the dollar-neutral component of our carry trades is exposed to downside risk, the dollar component has no significant exposure, and its premium remains strong after controlling for its exposure to downside risk in the form of the Jurek and Stafford (2015) DRI.

In Panel B, we include the DRI with the three Fama and French (1993) risk factors as regressors. Here, we find that none of the slope coefficients on DRI is significantly different from zero, and the α's all retain their magnitude and statistical significance, with the exception of the dollar-neutral EQ-0$ strategy. These findings reinforce the conclusion that the high returns of the dynamic dollar strategy cannot be explained by exposure

[27] Our robust t-statistics are not as large as those reported in Jurek (2014), who reports OLS results. In unreported results, we find that OLS t-statistics are larger, and approximately equal to Jurek's. We think OLS t-statistics are inappropriate given the conditional heteroskedasticity in the data.

Table 10: Carry Trade Exposure to the Downside Risk Index

Description: This table presents regressions of carry trade returns on the downside risk index (DRI) derived by Jurek and Stafford (2015) in Panel A. Panel B augments the Panel A regression with the three Fama-French risk factors. The sample period is 1990:01-2013:07 (283 observations). The reported α's are annualized percentages. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Interpretation: The downside risk index does a good job explaining the returns of the dollar-neutral-carry portfolio, but it still fails to explain the premium associated with the dollar carry portfolios.

Panel A:	EQ	SPD	EQ-RR	SPD-RR	OPT	EQ-0$	EQ-$	EQ-D$
α	2.59	3.22	4.18	4.07	1.26	0.10	2.49	5.37
	[2.05]	[1.74]	[2.99]	[2.67]	[2.17]	[0.13]	[2.39]	[2.83]
β_{DRI}	0.14	0.28	0.10	0.13	0.05	0.18	-0.04	-0.01
	[2.45]	[2.90]	[1.89]	[2.36]	[2.26]	[5.14]	[-0.76]	[-0.11]
R^2	.03	.06	.02	.03	.02	.14	.00	.00

Panel B:	EQ	SPD	EQ-RR	SPD-RR	OPT	EQ-0$	EQ-$	EQ-D$
α	2.90	3.70	4.33	4.09	1.22	0.45	2.45	6.07
	[2.31]	[1.98]	[3.04]	[2.60]	[2.08]	[0.51]	[2.33]	[3.05]
β_{DRI}	0.05	0.09	0.05	0.08	0.03	0.09	-0.04	-0.19
	[0.64]	[0.79]	[0.73]	[1.08]	[0.85]	[1.49]	[-0.53]	[-1.33]
β_{MKT}	0.07	0.13	0.04	0.04	0.02	0.05	0.01	0.11
	[1.63]	[2.07]	[1.04]	[1.01]	[0.99]	[2.54]	[0.41]	[1.86]
β_{SMB}	-0.04	-0.01	-0.04	-0.01	0.01	0.01	-0.05	-0.04
	[-0.90]	[-0.13]	[-0.99]	[-0.33]	[1.05]	[0.74]	[-1.48]	[-0.71]
β_{HML}	0.06	0.13	0.04	0.06	0.03	0.03	0.03	0.07
	[1.68]	[2.65]	[1.16]	[1.89]	[2.41]	[1.85]	[0.96]	[1.18]
R^2	.06	.10	.03	.04	.04	.17	.03	.02

to the DRI.

7 Analysis of the Hedged Carry Trade

We now analyze the returns of hedged carry trade strategies: specifically, we supplement the EQ, SPD, and EQ-D$ portfolios examined earlier with positions in currency options so as to protect these strategies against large losses, as described in Section 2.3. The sample period is from September 2000 to August 2013. Jurek (2014) utilizes 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 directly hedging bilateral non-USD exposure with the appropriate bilateral option for which the volatility of the non-USD 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 in going from our unhedged strategies to the hedged strategies overstate the reductions in profitability that traders would actually have experienced.

Table 11 reports the results for the hedged carry trades. For comparison, the statistics for the corresponding unhedged EQ, SPD and EQ-D$ carry trades over the same sample are reported in the first three columns of the table. The first thing to notice is that, in this shorter sample, the profitability of the unhedged carry trades is not as large as in the full sample. The annualized mean returns (standard errors) are only 2.22% (1.43) for the EQ strategy, 5.55% (2.50) for the SPD strategy, and 4.58% (2.27) for the EQ-D$ 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-D$ 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 average unhedged returns. For the 10Δ (25Δ) strategies, the average profitabilities of the hedged EQ, SPD and EQ-D$ strategies are 38 (87), 34 (129), and 61 (145) basis points less than their respective unhedged counterparts. Also, the statistical significance

Table 11: Hedged Carry Trade Performance

Description: This table presents summary statistics for the currency-hedged carry trades for the EQ, SPD, and EQ-D$ strategies. The sample period is 2000:10-2013:08. The sample includes G10 currencies other than Swedish krona, for which we do not 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 2.3. Autocorrelation and heteroskedasticity consistent standard errors from GMM are in parentheses.

Interpretation: The mean returns associated with the three carry-trade portfolios become slightly smaller once the returns are hedged. The Sharpe ratios are very similar.

	EQ	SPD	EQ-D$	EQ		SPD		EQ-D$	
	Unhedged			10Δ	25Δ	10Δ	25Δ	10Δ	25Δ
Mean Ret (% p.a.)	2.22	5.55	4.58	1.84	1.35	5.21	4.26	3.97	3.13
	(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
	(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
	(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
	(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
	(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
	(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

of the average returns of the hedged EQ strategies is 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-D$ strategy causes a slight deterioration in the statistical significance of the mean return as the p-values of the hedged EQ-D$ 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, notice that hedging provides only 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-D$ 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-D$ strategy.

7.1 Risk Exposures of the Hedged Carry Trades

We now examine whether risk exposures of the different versions of the unhedged and hedged carry trades for the shorter sample period can explain their average returns. Panel A of Table 12 examines exposures to the three Fama and French (1993) factors in Panel A, and we add the return on the variance swap in Panel B. For the shorter sample, the α for the unhedged EQ strategy is 1.80% with a t-statistic of 1.55 and a corresponding p-value of .12. There is strong statistically significant exposure to the market return, and the R^2 is .20.[28] 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

[28]The exposure to the market in the shorter sample, $\hat{\beta}_{\text{MKT}} = 0.13$ [5.26], is substantively larger than the estimate for the full sample, 0.05 [2.46]. An anonymous referee suggests that the stronger relation between carry trade returns and market returns in this post-2000 sub-sample is consistent with increased synchronization across different markets, particularly since the financial crisis. We leave an investigation of this very interesting phenomenon to future research.

of .26. Nevertheless, the α of the SPD strategy remains important and statistically significant at 4.23% [2.13]. Hedging these carry trades does not have a large effect on the magnitude or statistical significance of the results as the α's in the EQ-10Δ and EQ-25Δ strategies are both smaller with smaller t-statistics while the α's in the SPD-10Δ and SPD-25Δ strategies are only slightly smaller and remain statistically significant. The exposures to the market return and HML also remain statistically significant for the hedged SPD strategy.

Both the hedged and unhedged EQ-D$ strategies have no statistically significant exposure to the Fama and French (1993) factors in the shorter sample, and although the α's remain relatively large, they are statistically insignificant at the .10 marginal level of significance. Panel B of Table 12 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-D$ strategy where it is statistically significant for both the unhedged and hedged returns. The positive coefficients on the variance swap return indicate that the EQ-D$ strategy does well when the equity market becomes more volatile. The addition of the variance swap with its negative price of risk raises the α's in these regressions and increases the t-statistics such that they are now statistically different from zero at the .035 marginal level of significance.

Panel A of Table 13 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 all three strategies. For the EQ carry trade, the significance of the bond market factors in the full sample is now gone, while the return on the equity market is strong, as was just reported. For the SPD strategy, the bond market factors are now statistically significant as before, but the signs of the coefficients are opposite to those estimated from the full sample.

Hedging these two carry trades causes very little change in the slope coefficients or the t-statistics but reduces the magnitude of the α's, none of which has a t-statistic larger than 1.57. For the EQ-D$ strategy, the bond market risk factors are statistically significant and nearly equal and opposite in sign indicating that a positive two-year bond return is associated with a positive return to the strategy. Notice, though, that the estimated slope coefficients on the bond market returns are opposite in sign from those for the full sample. Panel B of Table 13 adds the return to the variance swap as a risk factor to the bond risks. In conjunction with the bond market factors,

Table 12: Hedged Carry Trade Exposure to Equity Risks

Description: This table presents regressions of the hedged carry trade returns of the EQ, SPD, and EQ-D$ strategies on the three Fama and French (1993) risk factors in Panel A. The second regression specification includes the return on a variance swap in Panel B. The sample period is 2000:10-2013:08 (155 observations) and includes G10 currencies other than the Swedish krona, for which we do not have option data. Results for unhedged returns over the same sample are also reported. The α's are annualized percentages. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Interpretation: Over this shorter time period for which we have option data, the α's for the carry strategies are smaller. Hedging the tail risk using 10 Delta and 25 Delta options reduces the α's just slightly. The α's of the SPD strategy remain statistically significant, even over the shorter sample, after hedging tail risk, and controlling for the variance-swap return.

Panel A:	Unhedged			10Δ	25Δ	10Δ	25Δ	10Δ	25Δ
	EQ	SPD	EQ-D$	EQ		SPD		EQ-D$	
α	1.80	4.23	3.88	1.45	1.01	3.95	3.18	3.29	2.54
	[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
	[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
	[-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
	[1.17]	[3.14]	[1.18]	[1.11]	[1.17]	[3.19]	[3.27]	[1.27]	[1.32]
R^2	.20	.26	.03	.18	.13	.26	.22	.03	.03
Panel B:	Unhedged			10Δ	25Δ	10Δ	25Δ	10Δ	25Δ
	EQ	SPD	EQ-D$	EQ		SPD		EQ-D$	
α	1.58	4.07	4.76	1.43	1.15	3.92	3.30	4.17	3.39
	[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
	[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
	[-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
	[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
	[-1.30]	[-0.45]	[2.10]	[-0.11]	[0.74]	[-0.09]	[0.37]	[2.18]	[2.29]
R^2	.21	.26	.07	.18	.14	.26	.22	.08	.08

Table 13: Hedged Carry Trade Exposure to Bond Risks

Description: This table presents regressions of the hedged carry trade returns of EQ, SPD, and EQ-D$ strategies on the excess return on the U.S. equity market and two EQ-D$ 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 not in Panel A. The second regressions in Panel B include the return on a variance swap. The sample period is 2000:10-2013:08 (155 observations) and includes G10 currencies other than the Swedish krona, for which we do not have option data. Results for unhedged returns over the same sample are also reported. The α's are annualized percentages. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Interpretation: Over this shorter 2000:10-2013:08 time period for which we have option data, the α's for the carry strategies are smaller and are all statistically insignificant at conventional levels. Hedging the tail risk using 10 Delta and 25 Delta options reduces the α's just slightly. Controlling for the variance-swap return doesn't affect this conclusion.

Panel A:	Unhedged			10Δ	25Δ	10Δ	25Δ	10Δ	25Δ
	EQ	SPD	EQ-D$	EQ		SPD		EQ-D$	
α	1.51	3.00	2.13	1.09	0.60	2.80	2.11	1.67	1.15
	[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
	[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
	[0.56]	[2.12]	[2.36]	[0.90]	[1.47]	[2.23]	[2.66]	[2.39]	[2.49]
$\beta_{\mathrm{10y-2y}}$	-0.10	-0.96	-1.61	-0.21	-0.38	-0.94	-1.04	-1.52	-1.43
	[-0.30]	[-1.76]	[-2.11]	[-0.66]	[-1.24]	[-1.87]	[-2.29]	[-2.12]	[-2.20]
R^2	.21	.27	.08	.19	.14	.27	.24	.08	.08
Panel B:	**Unhedged**			**10Δ**	**25Δ**	**10Δ**	**25Δ**	**10Δ**	**25Δ**
	EQ	SPD	EQ-D$	EQ		SPD		EQ-D$	
α	1.15	2.46	3.14	1.01	0.71	2.48	1.98	2.68	2.14
	[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
	[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
	[0.83]	[2.39]	[2.29]	[0.95]	[1.39]	[2.39]	[2.75]	[2.36]	[2.51]
$\beta_{\mathrm{10y-2y}}$	-0.21	-1.11	-1.32	-0.23	-0.34	-1.03	-1.08	-1.23	-1.15
	[-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
	[-1.45]	[-0.97]	[1.53]	[-0.27]	[0.40]	[-0.61]	[-0.26]	[1.59]	[1.70]
R^2	.22	.27	.10	.19	.14	.27	.24	.10	.10

the return to the variance swap only has explanatory power for the hedged EQ-D$ strategies, and the α's have reduced statistical significance. Given the substantive differences between the coefficient estimates in the shorter sample versus the full sample, we are unwilling to conclude that bond market risk factors have unconditional ability to explain the unhedged and the hedged returns to the EQ-D$ strategy.

Table 14 demonstrates that the downside risk indicator (DRI) of Jurek and Stafford (2015) has strong significance for the EQ and SPD strategies, both in their unhedged and hedged forms, for the shorter sample. The slope coefficients are statistically significant, and the α's are also insignificantly different from zero indicating that the DRI alone has the power to explain these carry trades. Consistent with our findings (with a longer sample) in Section 6.2, the DRI has no ability to explain the unhedged EQ-D$ strategy as the slope coefficient is essentially zero leaving an α of 4.58%, albeit with a t-statistic that has a p-value of just .10. The DRI has no ability to explain the return to the hedged EQ-D$ strategy either, and the α's remain large with t-statistics that are marginally significant at the .10 level. Consistent with our findings for the unhedged strategies, the dynamic dollar strategy does not appear to be unconditionally significantly exposed to any of the proposed risk factors, despite its high average returns.

8 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 early 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.[29]

[29] While traders in foreign exchange markets can easily adjust their carry trade strategies at the daily frequency, or even intraday, with minimal transaction costs, we choose to

Table 14: Hedged Carry Trade Exposure to the Downside Risk Index

Description: This table presents regressions of the hedged carry trade returns of EQ, SPD, and EQ-D$ strategies on the downside risk index (DRI) reported by Jurek and Stafford (2015). The sample period is 2000:10-2013:08 (155 observations) and includes G10 currencies other than Swedish krona, for which we do not have option data. Results for unhedged returns over the same sample are also reported. The α's are annualized percentages. Autocorrelation and heteroskedasticity consistent t-statistics from GMM are in square brackets.

Interpretation: Over this shorter time period for which we have option data, the EQ and SPD strategies have a statistically significant exposure to the DRI returns. This is not affected by hedging with currency options. However, DRI has no ability to explain the EQ-D$ strategy returns, before or after hedging.

	Unhedged			10Δ	25Δ	10Δ	25Δ	10Δ	25Δ
	EQ	SPD	EQ-D$	EQ		SPD		EQ-D$	
α	0.12	1.73	4.58	0.31	0.51	2.15	2.18	4.21	3.72
	[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
	[4.97]	[3.40]	[0.20]	[3.54]	[1.94]	[3.17]	[2.41]	[0.04]	[-0.25]
R^2	.16	.16	.00	.11	.05	.14	.09	.00	.00

To calculate daily returns for a monthly carry trade strategy, we consider a trader that has one dollar of capital 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 assume traders borrow and lend at the prorated one month euro-currency interest rates, and we infer foreign interest rates from the USD interest rate and covered interest rate parity. At time $t-1$, the trader also enters one of the five carry trade strategies, EQ, EQ-RR, SPD, SPD-RR, or EQ-D$, which are rebalanced at the end of month t. Let $P_{t,\tau}$ represent the cumulative 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. The excess daily return can then be calculated as follows:

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.

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

Panel A of Table 15 shows summary statistics of these daily returns from the five strategies. The daily returns are annualized for ease of comparison to the corresponding annualized monthly returns in Panel B. If the daily returns 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 be the $\sqrt{21} = 4.58$ times the standardized monthly skewness, and standardized daily kurtosis would be 21 times the standardized monthly kurtosis. For ease of comparison, Panel C presents the ratios of monthly central moments to daily central moments, where the ratios are normalized by their values under the *i.i.d.* assumption, in which case each of the normalized ratios would equal 1.

A comparison of Panels A and B shows that the annualized daily mean returns for the five strategies are within seven basis points of their annualized monthly counterparts. The annualized daily standard deviations are all just slightly below the annualized monthly standard deviations, which is consistent with the return processes having small positive autocorrelations at the daily frequency. Given that the means and standard deviations match quite well, the annualized Sharpe ratios of the daily and monthly series are also essentially the same.

In contrast with the first two moments, the higher moments of the five strategies show considerable differences across their daily and monthly values. The most extreme result is for the EQ-D$ portfolio where the difference in skewness between the daily value of 0.01 and the monthly value of -0.11 leads to a large standardized ratio of -51.2. The ratios of standardized monthly skewness to daily skewness for the EQ and SPD portfolios are 7.1 and 2.4, respectively, indicating that the skewness of the monthly returns is far more negative than what it would be if the daily returns were *i.i.d.*. On the other hand, the same ratios for the EQ-RR portfolio of 1.7 and the SPD-RR portfolio of 1.3 are markedly closer to 1. This is not surprising because risk rebalancing targets a constant predicted variance, which reduces the serial dependence in the conditional variance of the return. As a result, the data generating processes of the risk

Table 15: Summary Statistics of Daily Carry Trade Returns

Description: This table reports summary statistics on the daily returns for five carry trade strategies in Panel A and monthly returns in Panel B. 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). The maximum and minimum daily and monthly returns are not annualized. Panel C examines 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.* Hence, if daily returns were indeed *i.i.d.*, the normalized ratios would be approximately 1.

Interpretation: Comparing the estimates of skewness and excess kurtosis in Panel A with those presented in Panel B, after normalizing, as we do in Panel C, shows that the high levels of skewness and kurtosis for the monthly returns are inconsistent with the daily returns being i.i.d.

	Panel A: Daily Carry Trade Returns					Panel B: Monthly Carry Trade Returns				
	EQ	EQ-RR	SPD	SPD-RR	EQ-D$	EQ	EQ-RR	SPD	SPD-RR	EQ-D$
Mean Ret (% p.a.)	3.92	5.38	6.53	6.13	5.47	3.96	5.44	6.60	6.18	5.54
	(0.82)	(0.91)	(1.18)	(0.93)	(1.25)	(0.91)	(1.13)	(1.31)	(1.09)	(1.37)
Standard Dev.	5.06	5.54	7.25	5.65	7.68	5.06	5.90	7.62	6.08	8.18
	(0.10)	(0.11)	(0.15)	(0.15)	(0.11)	(0.28)	(0.22)	(0.41)	(0.24)	(0.38)
Sharpe Ratio	0.77	0.97	0.90	1.08	0.71	0.78	0.92	0.87	1.02	0.68
	(0.17)	(0.17)	(0.17)	(0.18)	(0.16)	(0.19)	(0.20)	(0.19)	(0.19)	(0.18)
Skewness	-0.32	-1.01	-0.59	-1.62	0.01	-0.49	-0.37	-0.31	-0.44	-0.11
	(0.17)	(0.43)	(0.33)	(0.71)	(0.15)	(0.21)	(0.11)	(0.19)	(0.14)	(0.17)
Excess Kurt.	7.46	11.90	10.25	24.43	4.66	2.01	0.40	1.78	0.90	0.86
	(1.16)	(6.61)	(4.05)	(12.02)	(1.22)	(0.53)	(0.21)	(0.35)	(0.29)	(0.31)
Autocorr.	0.03	0.02	0.02	0.02	0.01	0.08	0.16	0.02	0.09	0.00
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.07)	(0.05)	(0.07)	(0.05)	(0.06)
Max (%)	3.12	2.13	4.52	2.58	5.08	4.78	5.71	8.07	5.96	9.03
Min (%)	-2.78	-5.64	-6.57	-6.61	-3.71	-6.01	-4.90	-7.26	-5.88	-8.27
No. Positive	5230	5230	5223	5223	4988	288	288	297	297	273
No. Negative	4342	4342	4349	4349	4584	163	163	154	154	178

Panel C: Normalized Ratios of Higher Central Moments

	EQ	EQ-RR	SPD	SPD-RR	EQ-D$
Mean Ret (% p.a.)	1.0	1.0	1.0	1.0	1.0
Standard Deviation	1.0	0.9	1.0	0.9	0.9
Sharpe Ratio	1.0	1.1	1.0	1.1	1.1
Skewness	7.1	1.7	2.4	1.3	-51.2
Kurtosis	5.7	0.7	3.7	0.8	3.9

rebalanced portfolios conform better to the *i.i.d.* assumption. The values of daily skewness for the EQ-RR and SPD-RR strategies do reveal substantive negative values of -1.01 and -1.62, respectively. Similarly, normalized ratios between the monthly and daily values of kurtosis are far above the value implied by the *i.i.d.* assumption for the EQ, SPD, and EQ-D$ portfolios, whereas the same ratios for the EQ-RR and SPD-RR portfolios are again much closer to 1. Lastly, the minimum (actual, not annualized) daily returns are of similar size to the minimum (actual, not annualized) monthly returns for all five 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 now use two measures to characterize the downside risks of the carry trades. Consistent with the literature, we define a *drawdown* as the percentage loss from the previous high-water mark to the following lowest point. The *pure drawdown* measure of Sornette (2003) is the percentage loss from consecutive daily negative returns. We rank the drawdowns from most extreme to least extreme, and we compare these empirical distributions to those generated by simulating daily excess returns of the five strategies from counterfactual models under the assumption that the returns are independent across time using independent bootstrapping with replacement. This approach allows for non-normality in the data but retains the independence of daily innovations.[30] We simulate 10,000 trials of the same number of daily observations as the actual data, and we calculate the probability (reported as a p-value) of observing the empirical patterns in the simulations.

8.1 Drawdowns

Panel A of Table 16 reports the magnitudes (labeled “Mag.”) of the 10 worst drawdowns, their p-values (labeled “p-b”) under the bootstrap simulations, and the number of days (labeled “days”) over which that particular drawdown occurred. In thinking about the p-values, it is important to remember that we are doing multiple comparisons, and while we will discuss

[30]Chernov *et al.* (2016) use historical currency return processes and option data to estimate stochastic volatility jump-diffusion models. We have not attempted to simulate from these more realistic but decidedly more complex models to generate distributions of drawdowns and maximum losses.

the individual *p*-values, we want to be conservative in assessing whether the strategies deviate significantly from the *i.i.d.* bootstrap distributions. Because we are examining 10 drawdowns, we will use the Bonferroni bound, dividing the marginal significance level for our joint hypothesis test, of say .05, by 10. Hence, observing a *p*-value of .005 for any one of the drawdowns allows us to conclude that the simulation model is rejected at the .05 level. The smallest *p*-values for the five strategies are .005 for the EQ, .002 for the SPD, .009 for the EQ-RR, .021 for the SPD-RR, and .004 for the EQ-D$. Thus, we can be reasonably confident that the *i.i.d.* bootstrap distributions do not characterize the data generating processes.

The worst drawdown from the EQ strategy is 12.0%. This corresponds to a *p*-value of .13, indicating that the probability of observing one drawdown worse than 12.0% is not inconsistent with the *i.i.d.* bootstrap. This large drawdown was not a crash, though, as it took 93 days to go from the peak to trough. The second through fourth worst EQ drawdowns are 10.8%, 9.6%, and 7.8%, and their *p*-values indicate that the probabilities of observing the same or larger number of drawdowns worse than those magnitudes is less than 2% under the bootstrap. Therefore, while a single worst drawdown of 12.0% is not unlikely under the assumptions 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. Each of the 10 worst drawdowns of the EQ strategy occurred over at least 21 days with 3 taking more than 100 days.

For the SPD strategy, the worst drawdown is 21.5%, which corresponds to a *p*-value of .023 for the bootstrap distribution. This worst drawdown occurred over a 162 day period. The SPD strategy experienced 10 drawdowns with magnitudes greater than 8.2%, which is a very unlikely event in the simulations as the *p*-value of the tenth drawdown is .002. The number of days it took to experience each of the 10 worst drawdowns also exceeds 50. Risk-rebalancing has a minimal effect on the drawdowns of the EQ strategy as it slightly increases the magnitude of seven of the 10 largest, while risk rebalancing the SPD strategy cuts the largest drawdown in half. The distributions of drawdowns for the EQ-RR and SPD-RR strategies often reach *p*-values below .05, but risk rebalancing does raise the Bonferroni bounds from 5% and 2% for the EQ and SPD strategies, respectively, to 9% and 21% for the risk rebalanced versions. Risk rebalancing also tends to lengthen the period over which the maximum drawdowns are experienced because rebounds tend to occur in high volatility periods.

Table 16: Drawdowns and Pure Drawdowns

Description: This table examines the distributions of the drawdowns of five carry trade strategies under bootstrap simulations. Data include the magnitude (labeled Mag.) of the drawdown, the p-value (labeled "p-b") from the simulated distribution, and the number of "days" over which that drawdown occurred. The strategies are the basic equal-weighted (EQ) and spread-weighted (SPD) strategies, their risk-rebalanced versions (labeled -RR), and the dynamic dollar strategy (EQ-D$). The sample period is 1976:02-2013:08 except for the AUD and the NZD, which start in October 1986.

Interpretation: the low p-values that come from the bootstrap simulation show that the large drawdowns that we observe are inconsistent with daily returns being drawn from an i.i.d. distribution.

	EQ			SPD			EQ-RR			SPD-RR			EQ-D$		
	Panel A: Worst 10 Drawdowns														
N	Mag.	p-b	days	Mag.	p-b	days	Mag.	p-b	days	Mag.	p-b	days	Mag.	p-b	days
1	12.0%	13.0%	93	21.5%	2.3%	162	14.1%	6.4%	352	10.2%	40.3%	68	17.4%	25.0%	114
2	10.8%	1.8%	106	13.2%	9.8%	59	10.5%	4.9%	339	9.7%	14.3%	339	12.6%	35.3%	633
3	9.6%	0.5%	97	9.5%	46.0%	133	9.0%	3.6%	68	8.4%	13.4%	79	12.1%	15.7%	106
4	7.8%	1.4%	111	9.4%	21.8%	95	8.6%	0.9%	304	7.6%	13.4%	67	11.0%	13.2%	51
5	5.8%	24.0%	36	9.4%	8.9%	50	7.8%	1.1%	67	7.2%	8.8%	61	10.9%	3.7%	499
6	5.2%	36.0%	21	9.0%	5.1%	61	6.6%	5.3%	52	7.1%	3.2%	113	10.5%	2.1%	69
7	5.2%	19.6%	48	8.9%	1.9%	37	6.5%	2.6%	97	6.7%	2.6%	95	9.6%	2.9%	97
8	4.9%	22.3%	31	8.4%	2.0%	304	5.6%	13.5%	59	6.4%	2.1%	17	9.3%	1.1%	36
9	4.8%	12.0%	77	8.2%	0.9%	66	5.5%	6.9%	36	5.8%	3.8%	5	9.3%	0.4%	129
10	4.7%	8.1%	135	8.2%	0.2%	64	5.5%	2.9%	5	5.6%	2.5%	1	8.8%	0.4%	122
	Panel B: Worst 10 Pure Drawdowns														
N	Mag.	p-b	days	Mag.	p-b	days	Mag.	p-b	days	Mag.	p-b	days	Mag.	p-b	days
1	5.2%	1.4%	6	7.3%	19.1%	6	5.6%	57.9%	1	6.6%	61.3%	1	5.7%	23.2%	4
2	4.4%	0.5%	11	6.9%	6.4%	6	5.5%	28.3%	5	5.8%	44.0%	5	5.0%	21.7%	6
3	3.8%	0.5%	4	6.5%	5.9%	1	4.6%	14.4%	7	5.6%	29.0%	1	4.6%	18.3%	10
4	3.8%	0.1%	5	6.2%	2.4%	5	4.1%	13.1%	7	4.5%	27.3%	5	4.1%	44.8%	4
5	3.5%	0.1%	4	5.8%	0.7%	7	3.7%	14.3%	7	4.2%	22.1%	7	4.1%	27.1%	2
6	3.5%	0.0%	2	4.8%	0.8%	8	3.7%	6.6%	5	3.7%	14.7%	5	4.0%	17.9%	5
7	3.3%	0.0%	3	4.7%	0.3%	5	3.3%	9.3%	1	3.6%	8.2%	6	4.0%	11.0%	3
8	3.2%	0.0%	7	4.6%	0.1%	3	3.3%	4.6%	6	3.5%	4.5%	9	3.9%	9.8%	6
9	3.2%	0.0%	6	4.4%	0.1%	7	3.1%	4.9%	4	3.4%	2.3%	7	3.9%	5.6%	4
10	3.1%	0.0%	7	4.4%	0.0%	3	3.0%	4.3%	4	3.2%	1.8%	6	3.9%	3.2%	10

The maximum drawdown of the EQ-D$ strategy is 17.4%, which occurred over 114 days. With a p-value of .25, this is not a particularly anomalous event in the simulations. Nevertheless, the 10-th worst drawdown was 8.8%, which occurred over 122 days, and observing 10 or more drawdowns of this magnitude in the simulations has a p-value of .004. Consequently, we can reject the *i.i.d.* bootstrap distribution for this strategy at the .04 marginal level of significance.

8.2 Pure Drawdowns

Panel B of Table 16 reports the magnitudes (labeled Mag.) of the 10 worst pure drawdowns, their p-values (labeled "p-b") under the bootstrap simulations, and the number of days (labeled "days") over which that particular drawdown occurred.

Examination of the p-values indicates that both the EQ and SPD strategies experience pure drawdowns that never occur in the simulations. Thus, we can confidently reject the *i.i.d.* bootstrap even with consideration of the Bonferroni bound. This is not true for the other three strategies where there is insufficient evidence to formally reject the simulation models. 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. Nevertheless, the decrease in the p-values for smaller but still sizeable drawdowns suggests that we need a richer model to capture the serial dependence in the data to fully match the frequencies of less extreme but still severe downside events.

For the EQ strategy, the worst pure drawdown is 5.2% with a p-value of .014, and it was experienced over 6 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 3.1% which never occurs in the simulations. These pure drawdowns occurred between 3 and 11 business days.

Similar observations can be made for the SPD strategy. Observing a 10th-largest pure drawdown of 4.4% never occurs in the simulations. 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 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, 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 observe five pure drawdowns of this magnitude or larger in 22.1% of the bootstrap simulations. For the EQ-D$ strategy, the most severe pure drawdown was 5.7%, which occurred over 4 days. With a p-value of .23 this would not be considered a particularly anomalous event. However, the 10-th worst pure drawdown is 3.9%, which took 10 trading days. The likelihood of 10 pure drawdowns of this magnitude or worse is only 3.2%, based on our simulations.

To sum up, studying these five carry trade strategies at the daily frequency 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 an independent bootstrap distribution fails to match the empirical frequencies of downside events in most cases. 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.

9 Conclusions

This paper provides some perspectives on the risks of currency carry trades that differ from the conventional wisdom in the literature. First, it is generally argued that exposure to the three Fama and 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

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

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 *et al.* (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 dynamic dollar strategy earns a significant abnormal return in the presence of equity market risks, bond market risks, FX risks, and a volatility risk factor. The dynamic dollar strategy also has insignificant skewness, indicating that crash risk cannot explain its abnormal return. Our fourth finding that is inconsistent with the literature is that the exposures of our carry trades to downside market risk are not statistically significantly different from their unconditional exposures. Thus, the downside risk explanation of Dobrynskaya (2014) and Lettau *et al.* (2014) does not explain the average returns to our strategies. We find that the downside risk explanation of Jurek (2014) explains the non-dollar carry trade, but it also fails to explain our dynamic dollar strategy.

We also show that both spread-weighting and risk-rebalancing the currency positions improve the Sharpe ratios of the carry trades. It is surprising that the returns to these strategies continue to earn significant abnormal returns in the presence of the HML_{FX} risk factor proposed by Lustig *et al.* (2011), which is basically a carry trade risk factor.

The choice of benchmark currency also matters. We show that equally weighted carry trades can have a Sharpe ratio as low as 0.26 when the JPY is chosen as the benchmark currency and as high as 0.78 when the USD is chosen as the benchmark currency. Changing the base currency of the carry trade dynamically changes the currency exposures which explains the difference between these carry trade strategies.

Our conclusions about the profitability of the dynamic dollar strategy differ from those of Lustig *et al.* (2014) who also investigate a 'dollar carry' strategy, but with a larger set of currencies. Empirically, their dollar carry returns, like ours, have only a small correlation with the US equity market return. Lustig *et al.* (2014) develop a reduced-form, multi-country affine model, which matches many of the moments of the data, including an unconditional correlation between dollar carry returns and world equity market returns of .10, close to the .14 in the data. However, we conjecture that their model would imply significant correlations between dollar carry returns and both U.S. equity market and U.S. bond market returns, because, in the model, these returns and dollar-denominated exchange rates are driven by a common set of shocks. These implications are inconsistent with our empirical findings. Thus, at this point, we think that explaining the return to the dynamic dollar strategy in this paper is an open question.

We also initiate a discussion of the attributes of the distributions of the drawdowns of different strategies using daily data, but rebalancing the portfolios at a monthly interval. 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. In most cases, the largest drawdowns of our carry trade strategies lie outside of the 95% confidence intervals generated by simulating from an $i.i.d.$ bootstrap. We conclude that adding conditional autocorrelation, especially in down states, is 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 and learning explain 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 also change over time, in which case learning becomes a possible explanation, but this requires 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.

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