ANNUAL REVIEW OF FINANCIAL ECONOMICS (/content/journals/financial) **Volume 3, 2011**

(/content/journals/financial/3/1)

Carry Trade and Momentum in Currency Markets

Craig Burnside (/search?value1=Craig+Burnside&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true)[1,2], Martin Eichenbaum (/search?value1=Martin+Eichenbaum&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true)[2,3,4], and Sergio Rebelo (/search?value1=Sergio+Rebelo&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true)[2,3,5]

View Affiliations

Vol. 3:511-535 (Volume publication date December 2011)

First published as a Review in Advance on September 09, 2011

ABSTRACT

We examine the empirical properties of the payoffs to two popular currency speculation strategies: the carry trade and momentum. We review three possible explanations for the apparent profitability of these strategies. The first is that speculators are being compensated for bearing risk. The second is that these strategies are vulnerable to rare disasters or peso problems. The third is that there is price pressure in currency markets.

Keywords

uncovered interest parity (/search?option1=pub_keyword&value1="uncovered interest parity"), **exchange rates (/search?option1=pub_keyword&value1="exchange rates")**, **currency speculation (/search?option1=pub_keyword&value1="currency speculation")**, **rare disaster (/search?option1=pub_keyword&value1="rare disaster")**, **peso problem (/search?option1=pub_keyword&value1="peso problem")**, **price pressure (/search?option1=pub_keyword&value1="price pressure")**

1. INTRODUCTION

In this review we examine the empirical properties of the payoffs to two currency speculation strategies: the carry trade and momentum. We then assess the plausibility of the theories proposed in the literature to explain the profitability of these strategies.

The carry trade consists of borrowing low–interest rate currencies and lending high–interest rate currencies. The momentum strategy consists of going long (short) on currencies for which long positions have yielded positive (negative) returns in the recent past.

The carry trade, one of the oldest and most popular currency speculation strategies, is motivated by the failure of uncovered interest parity (UIP) documented by **Bilson (1981)** and **Fama (1984)**. (See **Hodrick 1987** and **Engel 1996** for surveys of the literature on UIP.) This strategy has received a great deal of attention in the academic literature as researchers struggle to explain its apparent profitability. Papers that study this strategy include **Lustig & Verdelhan (2007)**, **Brunnermeier et al. (2009)**, **Jordà & Taylor (2009)**, **Farhi et al. (2009)**, **Lustig et al. (2009)**, **Rafferty (2010)**, **Burnside et al. (2011)**, and **Menkhoff et al. (2011a)**.

In related work, several authors have studied the properties of currency momentum strategies. These authors include **Okunev & White (2003)**, **Asness et al. (2009)**, **Lustig et al. (2009)**, **Moskowitz et al. (2010)**, **Rafferty (2010)**, and **Menkhoff et al. (2011a**,**b**).

We begin by addressing the question: Is the profitability of the carry trade and momentum strategies just compensation for risk, at least as conventionally measured? After reviewing the empirical evidence, we conclude that the answer is no. This conclusion rests on the fact that the covariance between the payoffs to these two strategies and conventional risk factors is not statistically significant.[1]

The difficulty in explaining the profitability of the carry trade with conventional risk factors has led researchers such as **Lustig et al. (2009)** and **Menkhoff et al. (2011a)** to construct empirical risk factors specifically designed to price the average payoffs to portfolios of carry trade strategies. One natural question is whether these risk factors explain the profitability of the momentum strategy. We find that they do not.

An alternative explanation for the profitability of our two strategies is that it reflects the presence of rare disasters or peso problem explanations. We argue, on empirical grounds, that the 2008 financial crisis cannot be used as an example of the kind of rare disaster that rationalizes the profitability of currency trading. The reason is simple: Momentum made money during the financial crisis.

We then consider the literature that uses currency options data to characterize the nature of the peso event that rationalizes the profitability of carry and momentum. On the basis of this analysis, we argue that the peso event features moderate losses but a high value of the stochastic discount factor (SDF).

Finally, we explore an alternative explanation for the profitability of the carry trade and momentum strategies. This alternative relies on the existence of price pressure in foreign exchange markets. By price pressure we mean that the price at which investors can buy or sell currencies depends on the quantity they wish to transact. Price pressure introduces a wedge between marginal and average payoffs to a trading strategy. As a result, observed average payoffs can be positive even though the marginal trade is not profitable. So, traders do not increase their exposure to the strategy to the point where observed average risk-adjusted payoffs are zero.

The review is organized as follows. In Section 2 we describe the empirical properties of the payoffs to the two currency strategies that we consider. In Section 3 we discuss risk-based explanations for the profitability of these strategies. Section 4 discusses the impact on inference that results from rare disasters or peso problems. Section 5 provides a brief discussion of the implications of price pressure. A final section concludes.

2. CURRENCY STRATEGIES

In this section we describe the carry trade and currency momentum strategies.

The carry trade strategy

This strategy consists of borrowing low–interest rate currencies and lending high–interest rate currencies. Assume that the domestic currency is the U.S. dollar (USD) and denote the USD risk-free rate by i_t. Let the interest rate on risk-free foreign denominated securities be i_t^*. Abstracting from transactions costs, the payoff to taking a long position on foreign currency is

$$z_{t+1}^L = (1+i_t^*)\frac{S_{t+1}}{S_t} - (1+i_t). \tag{1}$$

Here S_t denotes the spot exchange rate expressed as USD per foreign currency unit (FCU).

The payoff to the carry trade strategy is

$$z_{t+1}^C = \text{sign}(i_t^* - i_t) z_{t+1}^L. \tag{2}$$

An alternative way to implement the carry trade is to use forward contracts. We denote by F_t the time-t forward exchange rate for contracts that mature at time t+1, expressed as USD per FCU. A currency is said to be at a forward premium relative to the USD if F_t exceeds S_t. The carry trade can be implemented by selling forward currencies that are at a forward premium and buying forward currencies that are at a forward discount. The time t payoff to this strategy can be written as

$$z_{t+1}^F = \text{sign}(F_t - S_t)(F_t - S_{t+1}). \tag{3}$$

It is easy to show that, when covered interest parity (CIP) holds, these two ways of implementing the carry trade are equivalent in the sense that z_{t+1}^C and z_{t+1}^F are proportional.[2] So, whenever one strategy makes positive profits so does the other.

The portfolio carry trade strategy that we consider combines all the individual carry trades in an equally weighted portfolio. The total value of the bet is normalized to one USD. We refer to this strategy as the carry trade portfolio. It is the same as the equally weighted strategy studied by **Burnside et al. (2011)**.

The momentum strategy

This strategy involves selling (buying) an FCU forward if it was profitable to sell (buy) an FCU forward at time $t - \tau$. Following **Lustig et al. (2009)**, **Moskowitz et al. (2010)**, **Rafferty (2010)**, and **Menkhoff et al. (2011a)**, we define momentum in terms of the previous month's return; that is, we choose $\tau = 1$. The excess return to the momentum str ategy is

$$z_{t+1}^{M} = \text{sign}\left(z_t^L\right) z_{t+1}^{L}. \tag{4}$$

We consider momentum trades conducted one currency at a time against the USD. We also consider a portfolio momentum strategy that combines all the individual momentum trades in an equally weighted portfolio with the total value of the bet being normalized to one USD. We refer to this strategy as the momentum portfolio.[3]

2.1. The Payoffs to Carry and Momentum

Table 1 provides summary statistics for the payoffs to our two currency strategies implemented for 20 major currencies, over the sample period 1976–2010. (See **Burnside et al. 2011** for a description of our data sources.) In every case, the size of the bet is normalized to one USD.

Table 1

Annualized excess returns of investment strategies (Feb. 1976–Dec. 2010)

Toggle display: Table 1

Open Table 1 fullscreen (/content/table/10.1146/annurev-financial-102710-144913.tbl1?fmt=ahah&fullscreen=true&lang=en)

I
e
C
a
r
y
t
a
c
e
M
c
r
e
r
t
u
r
F

C
a
r
y
t
a
c
e
c

M
c
r
e
r
t
u
r
c

5
C
5
C
s
r
a
t
e
g
y
d

U
S
s
c
c
k
s
e

[a] The mean excess returns of the currency portfolios are not equal to the average mean excess returns of the respective individual currency trades because the sample period varies by currency.

[b] Heteroskedasticity-consistent GMM standard errors are in parentheses.

[c]The carry trade (momentum) portfolio is formed as the average of up to 20 individual currency carry (momentum) trades against the U.S. dollar (USD).

[d]The 50-50 strategy is an equally weighted average of the carry and momentum portfolios.

[e]The U.S. stock market return is the value-weighted excess return on all U.S. stocks.

The carry trade strategy

Consider, first, the equally weighted carry trade strategy. This strategy has an average payoff of 4.6%, with a standard deviation of 5.1%, and a Sharpe ratio of 0.89. In comparison, the average excess return to the U.S. stock market over the same period is 6.5%, with a standard deviation of 15.7% and a Sharpe ratio of 0.41.

Consider, next, the average payoff to the individual carry trades. Averaged across the 20 currencies, this payoff is 4.6%, with an average standard deviation of 11.3%.[4] The corresponding Sharpe ratio is 0.42. The Sharpe ratio of the equally weighted carry trade is more than twice as large. Consistent with **Burnside et al. (2007, 2008)**, this difference is entirely attributable to the gains of diversifying across currencies, which cuts volatility by more than 50%.

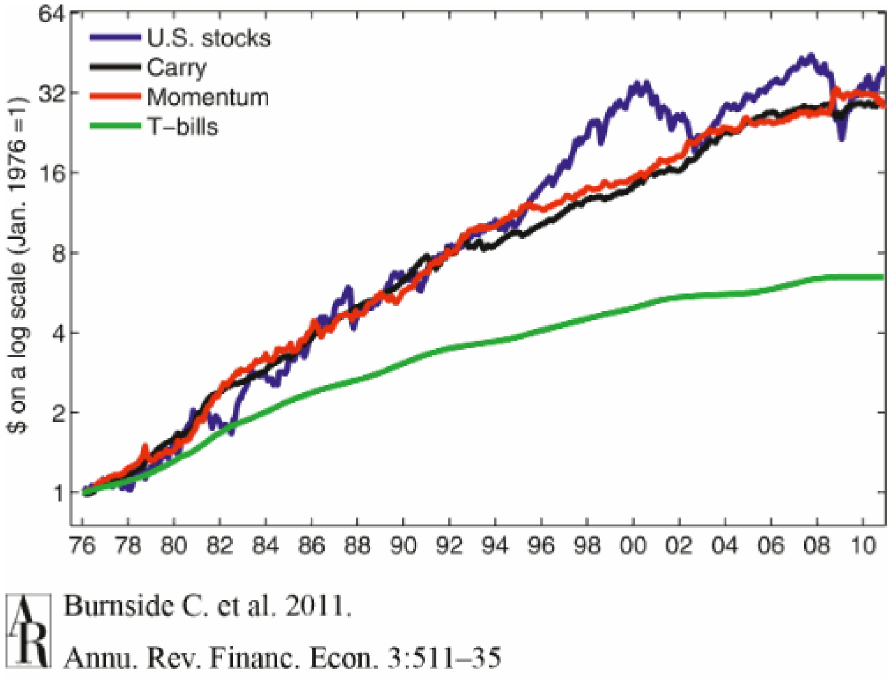
The momentum strategy

The equally weighted momentum strategy is also highly profitable, yielding an average payoff of 4.5%. These payoffs have a standard deviation of 7.3% and a Sharpe ratio of 0.62. Again, there are substantial returns to diversifying across individual momentum strategies. The average payoff of individual momentum strategies across the 20 currencies is equal to 4.9%. The corresponding average standard deviation is 11.3% and the Sharpe ratio is 0.43. An equally weighted combination of the two currency strategies, which we call the 50-50 strategy, has an average payoff of 4.5%, a standard deviation of 4.6%, and a Sharpe ratio of 0.98. The high Sharpe ratio of the combined strategy reflects the low correlation between the payoffs to the two strategies.

Figure 1 displays the cumulative returns to investing in the carry and momentum portfolios, in the U.S. stock market, and in Treasury bills. Because the currency strategies involve zero net investment, we compute the cumulative payoffs as follows. We initially deposit one USD in a bank account that yields the same rate of return as the Treasury bill rate. In the beginning of every period we bet the balance of the bank account on the strategy. At the end of the period, payoffs to the strategy are deposited into the bank account. **Figure 1** shows that the cumulative returns to the carry and momentum portfolios are almost as high as the cumulative return to investing in stocks. By the end of the sample the carry trade, momentum, and stock portfolios are worth $30.09, $27.98, and $40.22, respectively. However, the cumulative returns to the stock market are much more volatile than those of the currency portfolios. Also, note that most of the returns to holding stocks occur prior to the year 2000. An investor holding the market portfolio from the end of August 2000 until December 2010 earned a cumulative return of only 14.9%. Investors in risk-free assets, carry, and momentum earned cumulative returns of 26.7%, 93.9%, and 76.1%, respectively, over the same period.

Figure 1

Cumulative monthly returns of investment strategies (Feb. 1976–Dec. 2010). The figure plots the cumulative returns of a trader who begins with $1 in January 1976 and invests his accumulated earnings exclusively in one of four strategies. For T-bills and U.S. stocks we use the risk-free rate and v alue-weighted market return reported in Kenneth French's database. The carry trade and momentum portfolios are formed by taking equally weighted forward positions in up to 20 currencies versus the USD. For the carry trade portfolio, the foreign currency is sold (bought) forward if it is currently at a forward premium (discount). For the momentum portfolio, the foreign currency is sold (bought) forward, if, selling (buying) it forward in the previous period was profitable.



Click to view

(/docserver/fulltext/financial/3/1/fe30c1.f1.gif) Download as PowerPoint (/docserver/fulltext/financial/3/1/fe30c1.f1.ppt?mimeType=application/vnd.ms-powerpoint)

The payoffs to currency strategies are often characterized as being highly skewed (see, e.g., **Brunnermeier et al. 2009**). Our point estimates indicate that carry trade payoffs are skewed, but this skewness is not statistically significant. Interestingly, carry trade payoffs are less skewed than the payoffs to the U.S. stock market. The payoffs to the momentum portfolio are actually positively skewed, though not significantly so.

As far as fat tails are concerned, currency returns display excess kurtosis, with noticeable central peakedness, especially in the case of the carry trade portfolio. It is not obvious, however, that investors would be deterred by this kurtosis, given the relatively small variance of carry trade payoffs, when compared to that of the aggregate stock market. Indeed, **Burnside et al. (2006)** use a simple portfolio allocation model to show that a hypothetical investor with constant relative risk aversion preferences, and a risk aversion coefficient of five, would allocate three times as much of his portfolio to diversified carry trades as he would to U.S. stocks.

2.2. Mechanical Explanations for Why These Strategies Work

In this section, we relate the observed profitability of the carry trade and momentum strategies to the empirical failure of UIP. The payoffs to the strategies can each be written as

$$z_{t+1} = u_t z^L_{t+1}. \tag{5}$$

The two strategies differ only in the definition of u_t.

Consider, first, the case in which agents are risk neutral about nominal payoffs. In this case the conditional expected return to taking a long position in foreign currency should be zero; that is,

$$E_t(z_{t+1}^L) = E_t\left[(1+i_t^*)\frac{S_{t+1}}{S_t} - (1+i_t)\right] = 0. \quad (6)$$

This is the UIP condition. When this condition holds, neither strategy generates positive average payoffs because $E_t(z_{t+1}) = u_t E_t(z_{t+1}^L) = 0$, and, therefore, $E(z_{t+1}^L) = 0$.

CIP and UIP, together, imply that the forward exchange rate is an unbiased forecaster of the future spot exchange rate; that is, $F_t = E_t(S_{t+1})$. It has been known since **Bilson (1981)** and **Fama (1984)** that forward-rate unbiasedness fails empirically. So, we should not be surprised that both currency strategies yield nonzero average profits. However, the two strategies differ subtly in how they exploit the fact that the forward rate is not an unbiased predictor of the future spot rate.

To see why the carry trade has positive expected payoffs recall the classic result of **Meese & Rogoff (1983)** that the spot exchange rate is well approximated by a martingale:

$$E_t S_{t+1} \cong S_t. \quad (7)$$

Equations 7 and 3 imply that the expected value of the payoff to the carry trade is

$$E_t(z_{t+1}^F) \cong |F_t - S_t| > 0.$$

So, the carry trade makes positive average profits as long as there is a difference between the forward and spot rates, or, equivalently, an interest rate differential between the domestic currency and the foreign currency.

To gain further insight into the average profitability of the carry trade, note that in our sample

$$\Pr\left[\text{sign}(z_{t+1}^L) = \text{sign}(S_t - F_t)\right] = 0.571.$$

So, the probability that the carry trade is profitable is 0.571. This profitability reflects the ability of the sign of the forward discount to predict the sign of the payoff to a long position in foreign currency. The momentum strategy exploits the fact that, at least in sample, there is information in the sign of z_t^L about the sign of z_{t+1}^L:

$$\Pr\left[\text{sign}(z_{t+1}^L) = \text{sign}(z_t^L)\right] = 0.569.$$

In the next section we turn to the question of whether risk-adjusting the UIP condition can explain the payoffs of the two currency strategies.

3. RISK AND CURRENCY STRATEGIES

In this section we argue that the average payoff to our two currency strategies cannot be justified as compensation for exposure to conventional risk factors. We begin by outlining the theory that underlies our estimation strategy. We then describe how we measure the risk exposures of the two currency strategies. Finally, we discuss our empirical findings.

3.1. Theory

When agents are risk averse the payoffs to the currency strategies must satisfy

$$E_t(z_{t+1}M_{t+1}) = 0. \tag{8}$$

Here, M_{t+1} denotes the SDF that prices payoffs denominated in dollars, and E_t is the mathematical expectations operator given information available at time t.[5]

The unconditional version of **Equation 8** is

$$E(Mz) = 0. \tag{9}$$

This equation can be written as

$$E(z)E(M) + \operatorname{cov}(z, M) = 0. \tag{10}$$

In practice, the average unconditional payoffs to the strategies that we consider are positive. The most straightforward explanation of this finding is that $\operatorname{cov}(z, M) < 0$.

One can always rationalize the observed payoffs to these strategies by using a statistical model to compute the risk premium as a residual. Consider, for example, the carry trade, in which case we can write **Equation 8** as

$$F_t - S_t = E_t(S_{t+1} - S_t) + p_t. \tag{11}$$

Here, p_t is the risk premium which is given by

$$p_t = \frac{\operatorname{cov}_t(M_{t+1}, S_{t+1} - S_t)}{E_t M_{t+1}}.$$

Given a statistical model for $E_t(S_{t+1} - S_t)$, we can use **Equation 11** to back out a time series for p_t and call that residual a risk premium:

$$p_t = F_t - S_t - E_t(S_{t+1} - S_t).$$

By construction, this risk premium can rationalize the payoffs to the carry trade. If the spot exchange rate is a martingale, this procedure amounts to labeling the forward premium the risk premium. Although such an exercise can provide insights, we view the key challenge as finding observable risk factors that are correlated with the payoffs of the two strategies.

Our analysis uses **Equation 9** as our point of departure. We consider linear SDFs that take the form

$$M_t = \xi\left[1 - (f_t - \mu)'b\right]. \tag{12}$$

Here ξ is a scalar, f_t is a $k \times 1$ vector of risk factors, $\mu = E(f_t)$, and b is a $k \times 1$ vector of parameters. We set $\xi = 1$, because ξ is not identified by **Equation 9**. Given this assumption and the model for M given in **Equation 12, Equation 9** can be rewritten as

$$E(z) = \operatorname{cov}(z, f)b = \operatorname{cov}(z, f)\Sigma_f^{-1} \cdot \Sigma_f b = \beta \cdot \lambda, \tag{13}$$

where Σ_f is the covariance matrix of f_t. The betas in **Equation 13** are population coefficients in a regression of z_t on f_t and measure the exposure of the payoff to aggregate risk. The $k \times 1$ vector λ measures the risk premia associated with the risk factors.

3.2. Empirical Strategy

We assess risk-based explanations of the returns to our currency strategies in two ways. First, we ask whether there are risk factors for which the payoffs to the strategies have statistically significant betas. These betas are estimated by running time-series regressions of each portfolio's excess return on a vector of candidate risk factors:

$$z_{it} = a_i + f_t'\beta_i + \epsilon_{it}, \quad t = 1, \ldots, T, \text{ for each } i = 1, \ldots, n. \tag{14}$$

Here T is the sample size, and n is the number of portfolios being studied. This step in our analysis is similar in its a pproach, and in its conclusions, to **Villanueva (2007)**.

Second, we determine whether generalized method of moments (GMM) estimates of a candidate SDF can explain t he returns to the carry trade by testing whether **Equation 9**, or, equivalently, **Equation 13**, holds for the estimated model. We estimate the parameters of the SDF, b and μ, using GMM (**Hansen 1982**), the moment restrictions (**Equa tion 9**), and $E(f) = \mu$. **Equation 9** can be rewritten as

$$E\{z[1 - (f - \mu)'b]\} = 0, \tag{15}$$

where z is an $n \times 1$ vector of excess returns. The GMM estimators of μ and b are $\hat{\mu} = \bar{f}$ and

$$\hat{b} = (d_T' W_T d_T)^{-1} d_T' W_T \bar{z}, \tag{16}$$

where d_T is the sample covariance matrix of z with f, and W_T is a weighting matrix. (**Burnside 2007** provides details of the GMM procedure.) Estimates of λ are obtained from $\hat{b}$ as $\hat{\lambda} = \hat{\Sigma}_f \hat{b}$, where $\hat{\Sigma}_f$ is the sample covariance matrix of f. The model's predicted mean returns, $\hat{z} = d_T \hat{b}$, are estimates of the right-hand side of **Equation 13**. The model R^2 m easures the fit between $\hat{z}$ and $\bar{z}$, the sample average of the mean excess returns. The pricing errors are the residual s, $\hat{\alpha} = \bar{z} - \hat{z}$. We test that the pricing errors are zero using the statistic $J = T\hat{\alpha}' V_T^{-1} \hat{\alpha}$, where V_T is a consistent estimate of the asymptotic covariance matrix of $\sqrt{T}\hat{\alpha}$. The asymptotic distribution of J is χ^2 with $n - k$ degrees of freedom.

In the first GMM step the weighting matrix is $W_T = I_n$, and the estimate of λ and the pricing errors are the same as th e ones obtained by running a cross-sectional regression of average portfolio excess returns on the estimated betas:

$$\bar{z}_i = \hat{\beta}_i' \lambda + \alpha_i, \qquad i = 1, \ldots, n. \tag{17}$$

Here $\bar{z}_i = \frac{1}{T}\sum_{t=1}^{T} z_{it}$, $\hat{\beta}_i$ is the ordinary least squares estimate of β_i, and α_i is the pricing error. In subsequent GMM steps the weighting matrix is chosen optimally. Our results are similar at all stages of GMM, so, due to space limitations, we only present results for iterated GMM.

3.3. Empirical Results With Conventional Risk Factors

In this section we use the empirical methods outlined in the previous section to determine whether there is a candidate SDF that can price the returns to the carry trade and momentum. We consider several models using monthly data: the Capital Asset Pricing Model (CAPM) (**Sharpe 1964**, **Lintner 1965**); the **Fama & French (1993)** three factor model; the quadratic CAPM (**Harvey & Siddique 2000**); and a model that uses the CAPM factor, realized stock market volatility, and their interaction as factors. The latter two models are ones in which the market betas of the assets being studied can be thought of as being time varying. We also consider two models using quarterly data. The first model (the C-CAPM) uses the growth rate of real consumption of nondurables and services as a single factor. This model is a linear approximation to a representative agent model in which households have standard preferences over a single consumption good. The second model (the extended C-CAPM) uses three factors: the growth rate of real consumption of nondurables and services, the growth rate of the service flow from the real stock of durables, and the market return. This model is a linear approximation to a representative agent model in which households have recursive preferences over the two types of consumption good (see **Yogo 2006**).

Table 2 summarizes the estimates we obtain by running the time-series regressions described by **Equation 14** for monthly and quarterly models. In every case, but one, we find that the estimated betas are insignificantly different from zero. The one exception is that the beta for the carry trade associated with the market return in the Fama-French three factor model is statistically significant. However, this coefficient is economically small (0.045). Given our estimates of the Fama-French model, the implied annual expected return of the carry trade portfolio should only be 0.3%. The actual return is 4.6%.

Table 2

Factor betas of the currency portfolios (1976–2010)

Toggle display: Table 2

Open Table 2 fullscreen (/content/table/10.1146/annurev-financial-102710-144913.tbl2?fmt=ahah&fullscreen=true&lang=en)

[a]The table reports estimates of the slope coefficients and the R^2 in a regression of the portfolio payoffs on a constant, and the indicated risk factors. Heteroskedasticity-consistent standard errors are in parentheses. Slope coefficients that are statistically significant at the 5% level are indicated by an asterisk (*). Payoffs are monthly nominal excess returns, and the sample period is Mar. 1976–Dec. 2010, unless otherwise indicated.

[b]The CAPM model uses a single factor, the excess return on the value-weighted U.S. stock market (Mkt-Rf).

[c]The Fama-French model uses Mkt-Rf as well as Fama and French's SMB and HML factors.

[d]The quadratic CAPM uses Mkt-Rf and $1/2(\text{Mkt-Rf})^2$ as factors.

[e]The CAPM-volatility model uses Mkt-Rf and stock volatility (the standard deviation of daily excess returns, measured monthly), and their interaction as factors.

[f]The C-CAPM model uses the log growth rate of real consumption of nondurables and services, and is estimated with quarterly real excess returns (1976Q2–2010Q1).

[g]The extended C-CAPM model uses the C-CAPM factor, the log growth rate of the service flow of durables (assumed to be proportional to the real stock of consumer durables), and the market return (Mkt) as factors.

Table 3 presents estimates of the monthly models based on iterated GMM estimation. **Table 4** presents analogous results for the quarterly models. The models are estimated using the equally weighted carry trade and momentum portfolios, as well as Fama and French's 25 portfolios sorted on the basis of book-to-market value and size. First, note that in every case the pricing errors of the currency strategies are large and statistically significant. So, even though the models have some explanatory power for stocks, none of the models explains the payoffs to the carry trade and currency momentum strategies. Second, all of the models are rejected, at the 5% level, by the pricing-error test.

Table 3

GMM estimates of linear factor models[*] (Mar. 1976–Dec. 2010)

Toggle display: Table 3

Open Table 3 fullscreen (/content/table/10.1146/annurev-financial-102710-144913.tbl3?fmt=ahah&fullscreen=true&lang=en)

*Test assets are the Fama-French 25 portfolios, and the equally weighted carry-trade and currency momentum portfolios. Heteroskedasticity-consistent standard errors are in parentheses, except as noted. An asterisk (*) indicates statistical significance at the 5% level.

[a] b is the parameter vector in the stochastic discount factor (SDF), $m = 1 - (f - \mu)'b$.

[b] λ is the vector of risk premia associated with the factors.

[c] R^2 is a measure of fit between the sample average and model-predicted mean returns.

[d] *J* is the test statistic for the overidentifying restrictions. P-values are reported in parentheses.

[e] Annualized percent.

[f] The CAPM model uses a single factor, the excess return on the value-weighted U.S. stock market (Mkt-Rf).

[g] The Fama-French model uses Mkt-Rf as well as Fama and French's SMB and HML factors.

[h] Stock volatility is the standard deviation of daily excess stock returns (Mkt-Rf), measured monthly.

Table 4

GMM estimates of linear factor models[*] (1976Q2–2010Q1)

Toggle display: Table 4

Open Table 4 fullscreen (/content/table/10.1146/annurev-financial-102710-144913.tbl4?fmt=ahah&fullscreen=true&lang=en)

*Test assets are the Fama-French 25 portfolios, and the equally weighted carry-trade and currency momentum portfolios. Heteroskedasticity-consistent standard errors are in parentheses, except as noted. An asterisk (*) indicates statistical significance at the 5% level.

[a] b is the parameter vector in the stochastic discount factor (SDF), $m = 1 - (f - \mu)'b$.

[b] λ is the vector of risk premia associated with the factors.

[c] R^2 is a measure of fit between the sample average and model-predicted mean returns.

[d] J is the test statistic for the overidentifying restrictions. P-values are reported in parentheses.

[e] Annualized percent.

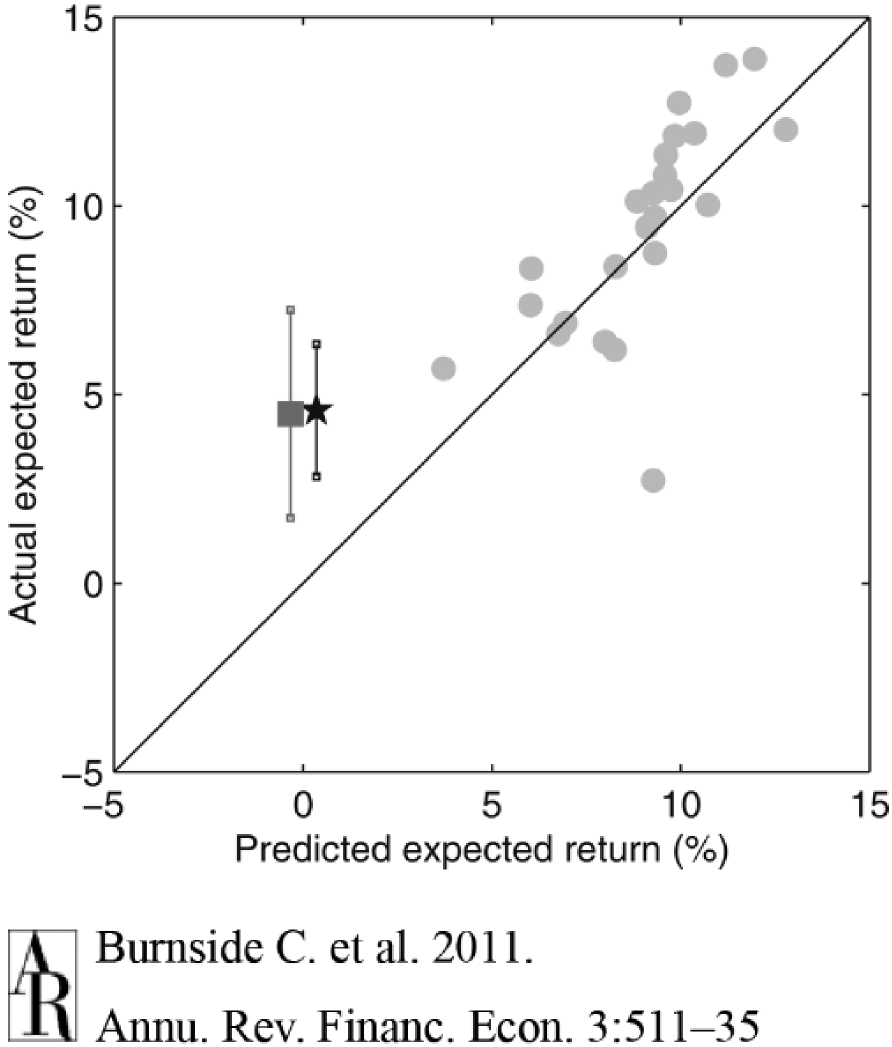
[f] The C-CAPM model uses the log growth rate of real consumption of nondurables and services as a risk factor.

[g] The extended C-CAPM model uses the C-CAPM factor, the log growth rate of the service flow of durables (assumed to be proportional to the real stock of consumer durables), and the market return (Mkt) as factors.

The only model with a reasonably good fit (positive R^2) is the Fama-French model. But, as with the other models, it does a very poor job of explaining the returns to the currency portfolios. **Figure 2** plots $\hat{z}$, the predictions of the Fama-French model for $E(z_t)$, against $\bar{z}$, the sample average of z_t. The circles pertain to the Fama-French portfolios, the star pertains to the carry trade portfolio, and the square pertains to the momentum portfolio. Not surprisingly, the model does a reasonably good job of pricing the excess returns to the Fama-French 25 portfolios. However, the model greatly understates the average payoffs to the currency strategies. The annualized average payoffs to the carry trade and momentum strategies are 4.6 and 4.5%, respectively. The Fama-French model predicts that these average returns should equal 0.2 and −0.2%. The solid lines through the star and square are two-standard error bands for the difference between the data and model average payoff, that is, the pricing error. Clearly, we can reject the hypothesis that the model accounts for the average payoffs to the currency strategies.

Figure 2

Cross-sectional fit of the Fama-French model. For each portfolio, the graph plots the average annualized payoffs of each portfolio, $\bar{z}$ (on the y-axis), against the model-predicted mean return, $\hat{z}$ (on the x-axis). The dots correspond to Fama and French's 25 portfolios sorted on the basis of book-to-market value and firm size. The star represents the carry trade portfolio. The square represents the momentum portfolio. The vertical lines extendi ng above and below the star and square are two-standard error bands for each portfolio's pricing error. When these lines do not cross the 45 degree line, the pricing error is statistically significant at the 5% level.



Click to view (/docserver/fulltext/financial/3/1/fe30523.f2.gif) Download as PowerPoint (/docserver/fulltext/financial/3/1/fe30523.f2.ppt?mimeType=application/vnd.ms-powerpoint)

Overall, our results are consistent with those in **Villanueva (2007)**, **Burnside et al. (2011)**, and **Burnside (2011)**, who show that a wider set of conventional risk factors cannot explain the returns to the carry trade. Our results show that conventional risk factors also cannot explain the returns to the currency momentum portfolio.

3.4. Factors Derived from Currency Returns

We now turn to less traditional risk-factor models in which the factors are derived from the returns to currency strategies. This approach, introduced to the currency literature by **Lustig et al. (2009)**, is similar to the one popularized by **Fama & French (1993)**, who construct risk factors based on the returns to particular stock strategies.

3.4.1. Portfolios of currencies sorted by their forward discount.

Following **Lustig & Verdelhan (2007)**, **Lustig et al. (2009)**, and **Menkhoff et al. (2011a)** we construct five portfolios, labeled S1, S2, S3, S4, and S5, by sorting currencies according to their forward discount against the USD. The sorting is done period by period. Each portfolio is equally weighted and represents the excess return to lending at the ri sk-free rate the currencies included in the portfolio while borrowing an equivalent amount of USD at the risk-free ra te.

Table 5 shows that the average return to portfolios S1–S5 is monotonically increasing. This property is not surprisi ng given Meese & Rogoff's (1983) result that exchange rates are close to a martingale. If the spot exchange rate for e ach currency were exactly a martingale, then the conditional mean of each portfolio's return would equal the avera ge forward discount of the constituent currencies. So, for a large enough sample, the sorting procedure would gen erate portfolios with monotonically increasing average returns.

Table 5

Factor betas of the sorted, carry, and momentum portfolios

Toggle display: Table 5

Open Table 5 fullscreen (/content/table/10.1146/annurev-financial-102710-144913.tbl5?fmt=ahah&fullscreen=true&lang=en)

F c r t c l c

M c r e r t u r

[a]The table reports estimates of the slope coefficients and the R^2 in a regression of the portfolio payoffs on a constant, and the indicated risk factors. Heteroskedasticity-consistent standard errors are in parentheses. Slope coefficients that are statistically significant at the 5% level are indicated by an asterisk (*). Payoffs are monthly nominal excess returns, and the sample period is Mar. 1976–Dec. 2010.

[b]The portfolios are five portfolios of long positions in foreign currency, sorted in increasing order by the forward discount (S1–S5), the carry trade portfolio, and the momentum portfolio.

[c]The DOL factor is the average excess return to portfolios S1–S5.

[d]The HML_{FX} factor is the excess return to being long portfolio S5 and short portfolio S1.

[e]The VOL factor is a measure of realized global currency volatility.

Consistent with the literature, we attempt to explain the cross section of returns to these portfolios of currencies, but we add the equally weighted momentum portfolio to the set of test assets.[6] By focusing on currency portfolios and excluding stock returns from our analysis, we allow for the possibility that markets are segmented, so that currency traders and stock market investors have different SDFs. That said, factors that explain portfolios S1–S5 should also explain the currency momentum portfolio.

3.4.2. Currency-based risk factors.

As with **Lustig et al. (2009)**, we construct two risk factors directly from the sorted portfolios. The first risk factor, which they call the dollar risk factor and denote by DOL, is simply the average excess return of the five sorted portfolios. The second risk factor, which they denote by HML_{FX}, is the return differential between the S5 portfolio (the largest forward discount) and the S1 portfolio (the smallest forward discount). So, HML_{FX} is the payoff to a carry trade strategy in which we go long in the highest forward-discount currencies and go short in the smallest forward-discount currencies.

Following **Menkhoff et al. (2011a)**, we construct a measure of global currency volatility, which we denote by VOL. It is measured monthly, and is the average sample standard deviation of the daily log changes in the values of the currencies in our sample against the USD.

3.4.3. Betas of currency-based factors.

Table 5 summarizes the results of estimating time-series regressions of the monthly excess returns to S1, S2, S3, S4, S5; the carry trade portfolio; and the momentum portfolio on two pairs of risk factors: DOL and HML_{FX}, and DOL and VOL.

The DOL and HML_{FX} factors are highly correlated with the S1–S5 portfolio returns. The betas on the DOL factor are all close to one in value, and statistically significant. The betas of the HML_{FX} factor rise monotonically from −0.48 for S1 to 0.52 for S5. The betas for S2, S3, and S4 are close to zero. Although the R^2 for the five regressions are large, this result is not particularly surprising. Sorting portfolios on the basis of the forward discount produces a monotonic ordering of the expected returns. So, the DOL and HML_{FX} factors create, by construction, a pattern in the betas similar to that in **Table 5**. (See **Burnside 2011** for a detailed discussion.) DOL and HML_{FX} also have positive and significant betas for the equally weighted carry trade portfolio, but the R^2 is much lower in this case. Finally, neither factor has a significant beta for the momentum portfolio.

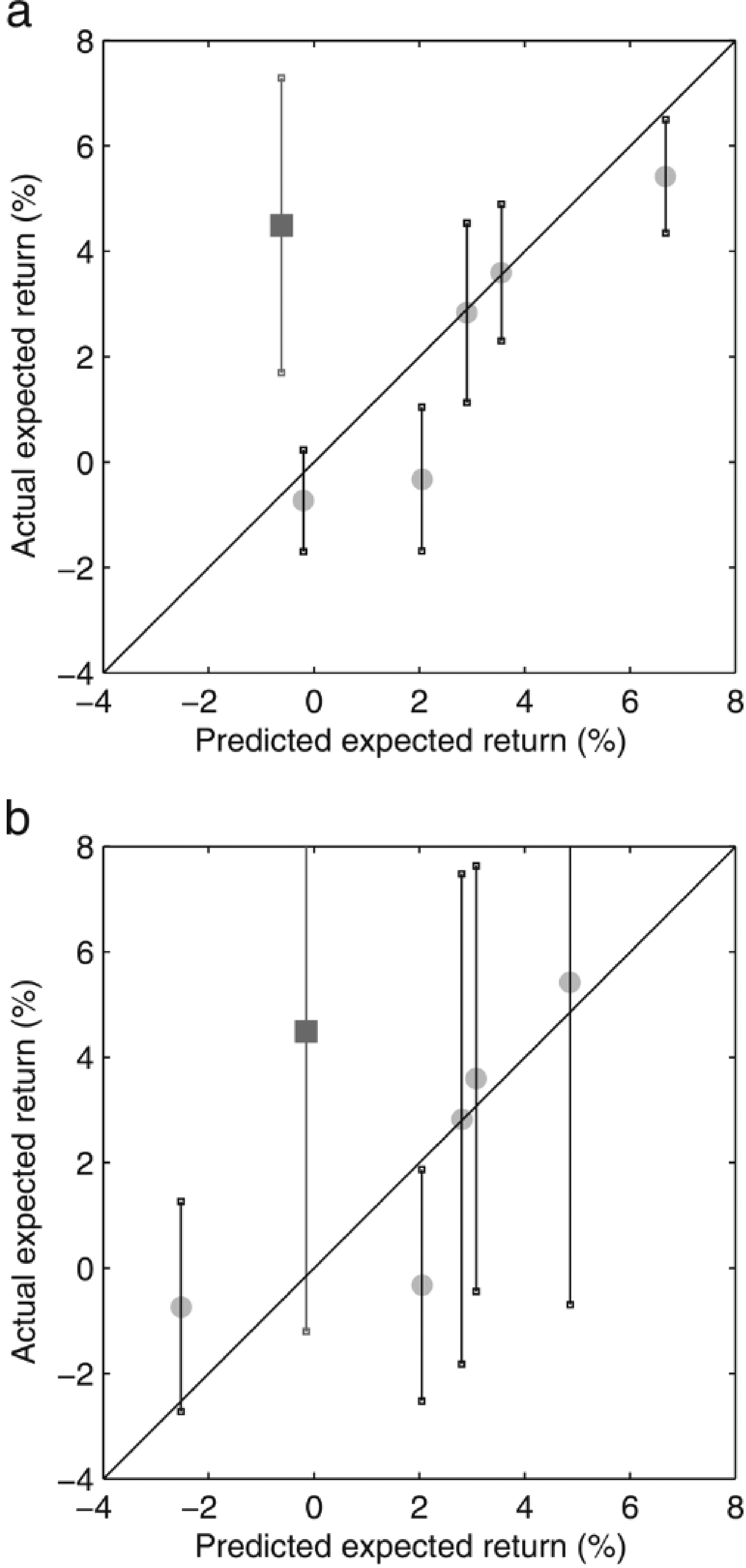
Replacing HML_{FX} with VOL as a factor has very little impact on the betas with respect to DOL. The betas with respect to VOL decrease monotonically as we go from S1 to S5 and are statistically significant for the extreme portfolios (positive for S1 and negative for S5). These findings indicate that when global currency volatility increases, the returns to holding low–interest rate currencies increase and the returns to holding high–interest rate currencies decrease. That is, low–interest rate currencies provide a hedge against increases in volatility. The beta with respect to VOL is also negative and statistically significant for the carry trade portfolio. The beta with respect to VOL is positive but insignificant for the currency momentum portfolio.

3.4.4. Cross-sectional analysis of currency-based risk factors.

Table 6 presents iterated GMM estimates of the SDF for the two currency-based factor models, using portfolios S1–S5 and the momentum portfolio as test assets. **Figure 3** shows the mean returns in the sample plotted against the model-predicted expected returns.

Figure 3

Cross-sectional fit of the currency-based factor models. (*a*) Model uses DOL and HML_{FX} as risk factors. (*b*) Model uses DOL and VOL as risk factors. For each portfolio, the graph plots the average annualized payoffs of each portfolio, $\bar{z}$ (on the y-axis), against the model-predicted mean return, $\hat{z}$ (on the x-axis). The dots correspond to the S1–S5 currency portfolios sorted on the basis of the forward discount. The square represents the momentum portfolio. The vertical lines extending above and below each point are two-standard error bands for each portfolio's pricing error. When these lines do not cross the 45 degree line, the pricing error is statistically significant at the 5% level.



Burnside C. et al. 2011.
Annu. Rev. Financ. Econ. 3:511–35

Click to view

(/docserver/fulltext/financial/3/1/fe30527.f3.gif) Download as PowerPoint (/docserver/fulltext/financial/3/1/fe30527.f3.ppt?mimeType=application/vnd.ms-powerpoint)

Table 6

GMM estimates of currency factor–based models* (Mar. 1976–Dec. 2010)

Toggle display: Table 6

Open Table 6 fullscreen (/content/table/10.1146/annurev-financial-102710-144913.tbl6?fmt=ahah&fullscreen=true&lang=en)

*Test assets are five portfolios of long positions in foreign currency sorted in increasing order by the forward discount (S1–S5), and the momentum portfolio. Heteroskedasticity-consistent standard errors are in parentheses, except as noted. An asterisk (*) indicates statistical significance at the 5% level.

[a] b is the parameter vector in the stochastic discount factor (SDF), $m = 1 - (f - \mu)'b$.

[b] λ is the vector of risk premia associated with the factors.

[c] R^2 is a measure of fit between the sample average and model-predicted mean returns.

[d] J is the test statistic for the overidentifying restrictions. P-values are reported in parentheses.

[e] Annualized percent

[f] Momentum

[g] The DOL factor is the average excess return to portfolios S1–S5.

[h] The HML_{FX} factor is the excess return to being long portfolio S5 and short portfolio S1.

[i] The VOL factor is a measure of realized global currency volatility.

In both cases, the b parameter associated with the DOL factor is statistically insignificant. The risk premium, λ_{DOL}, is positive and significant in one case. But in neither case does exposure to DOL explain much of the variation in expected return across portfolios.

The b and λ parameters associated with the HML_{FX} factor are positive and statistically significant at the 5% level. The b and λ parameters associated with the VOL factor are negative and statistically significant at the 5% level.

Neither the DOL-HML_{FX} model nor the DOL-VOL model does a good job of fitting the overall cross section of average payoffs to the currency strategies. The R^2 is lower than 0.04 for both models. The DOL-HML_{FX} model is rejected on the basis of the pricing-error test. The DOL-VOL model is not rejected. But this apparent success is mostly due to the model's parameters being estimated with less precision than those of the HML_{FX}-based model.

The primary failing of both models is the large pricing error associated with momentum (approximately 5%). To understand this failing recall that the average payoff to the momentum strategy is 4.5%. The DOL-HML_{FX} cannot explain this large payoff because the momentum's beta is close to zero with respect to DOL and is negative with respect to HML_{FX}. The DOL-VOL model does no better because it has a paradoxically positive (but poorly estimated) beta with respect to VOL; that is, momentum is a good hedge against volatility. **Menkhoff et al. (2011a)** find a similar paradox using a set of sorted momentum portfolios.

3.5. Concluding Discussion

The results in this section suggest that observable risk factors explain very little of the average returns to the carry trade and momentum portfolios, resulting in economically large pricing errors. In every case the models can also be rejected based on statistical tests of the pricing errors. Models built from currency-specific factors do have some success in explaining the returns to the carry trade. But, they do not explain the returns to the momentum portfolio.

4. RARE DISASTERS AND PESO PROBLEMS

Authors such as **Jurek (2008)**, **Farhi & Gabaix (2008)**, **Farhi et al. (2009)**, and **Burnside et al. (2011)** have argued that the payoffs to the carry trade can, at least in part, be explained by the presence of rare disasters or peso problems.[7] By rare disasters we mean very low probability events that sharply decrease the payoff and/or sharply increase the value of the SDF. These events may occur in sample. But, due to their low probability, they may be underrepresented relative to their true frequency in population. By a peso problem we mean an extreme form of this problem, where rare disasters do not occur in sample.

Rare disasters

We study the effects of rare disasters on inference using a simple model. Let $\omega \in \Omega$ denote the state of the world, let $z(\omega)$ denote the payoff to a currency strategy in state ω, and let $M(\omega)$ denote the value of the SDF in state ω. We partition Ω, the set of possible states, into two sets. The first set, Ω^N, consists of those values of ω corresponding to non-rare-disaster (normal) events. The second set, Ω^D, consists of those values of ω corresponding to a rare-disaste r event. For simplicity, we assume that Ω^D contains a single event, ω^D. We use the notation $M' = M(\omega^D)$ and $z' = z(\omega^D)$, and assume that $z' < 0$. To simplify, we assume that the conditional and unconditional probability of the rare disaster is p.

Payoffs to a currency strategy must satisfy

$$(1-p)E^N(Mz) + pM'z' = 0, \tag{18}$$

where $E^N(\cdot)$ denotes the expectation over normal states. Because the scale of M is not identified for zero net-investment strategies, we choose the normalization $E^N(M) = 1$.

How can rare disasters explain the profitability of a currency strategy? Assume, for simplicity, that an econometrician can observe M and z and that the sample average of Mz across normal events in the sample equals $E^N(Mz)$. Suppose that in-sample rare disasters occur with frequency $\hat{p} < p$. Because $z' < 0$, the overall sample average of Mz is positive, even though the true unconditional value is zero:

$$(1-\hat{p})E^N(Mz) + \hat{p}M'z' = (p-\hat{p})\left[E^N(Mz) - M'z'\right] > 0.$$

How likely are we to observe an unusually small number of rare disasters in sample? Consider the value of p suggested by **Nakamura et al. (2010)**. These authors define a rare disaster as a large drop in consumption. Using data spanning 24 countries and more than 100 years, they estimate the annual probability of a disaster to be 0.017. The corresponding monthly value of p is 0.0014.

Because most work on currency strategies focuses on the post Bretton-Woods era, we think of a typical sample size as roughly (2011−1973) × 12 = 456 months. For $p = 0.0014$, the expected number of events in a sample of this size is less than one. Indeed, the probability of observing zero rare disasters in a sample of 456 months is roughly 53%.

Can we interpret particular in-sample events as realizations of the rare-disaster event that accounts for the observed profitability of the carry trade and momentum strategies? For example, was the 2008 financial crisis an example of such a rare disaster? The answer is no. To see why, note that **Equation 18** implies that the ratio of risk-adjusted mean payoffs in the normal states must be equal to the ratio of the payoffs in the disaster state:

$$\frac{E^N(Mz_1)}{E^N(Mz_2)} = \frac{z_1'}{z_2'}. \tag{19}$$

Here, z_1' and z_2' denote the payoffs to the carry trade and momentum strategy in the disaster state. We define the disaster period to be August–November 2008 because, during this period, the carry trade suffered a cumulative net loss of approximately 10%, its worst loss over a four-month period in our sample. In contrast, the momentum strategy had a cumulative gain of approximately 24% in this period, its largest over a four-month period in our sample. So the ratio on the right-hand side of **Equation 19** is negative. Because the average risk-adjusted profits of both strategies are positive outside of the crisis period, the left-hand side of **Equation 19** is positive. So, the financial crisis is n ot a plausible example of a rare-disaster event that accounts for the profitability of the carry trade and momentum strategies. Neither are other periods in our sample (early 1991, and late 1992) when carry trades took heavy losses. In these periods the momentum strategy was also highly profitable.

There are two ways to avoid the conclusion that the recent financial crisis is not the type of rare disaster that accounts for the profitability of the carry trade and momentum strategies. The first is to assume that, because of market segmentation, M' is different for the two currency-trading strategies. This hypothesis seems very implausible. The second is to assume that Ω^D contains more than one event, and not all strategies earn negative returns in all of these events. So the financial crisis could be viewed as a rare disaster in which the carry trade has a negative payoff but momentum does not. We cannot rule out this explanation on logical grounds. But it leaves unexplained the in-sample profitability of the momentum strategy.

Peso problems

Recall that a peso problem corresponds to the case where there are no rare disasters in sample, so $\hat{p} = 0$. Absent additional assumptions, the peso-problem explanation of the profitability of our two strategies has no testable implications, given that z' is not observed. To generate testable implications we assume, as above, that there is a single peso event. We can then use data on currency options to develop a test of the peso-problem hypothesis.

Investors can use options to construct hedged versions of currency strategies that are exposed to disaster risk. These hedged strategies put an upper bound on an investor's possible losses. Suppose a currency strategy involves going long (short) on foreign currency. Then this strategy is exposed to large losses if there is a large depreciation (appreciation) of the foreign currency. By buying a put (call) option on foreign currency the investor can bound these losses. The payoff to a hedged strategy, z^H_{t+1}, is given by

$$z^H_{t+1} = \begin{cases} h_{t+1} & \text{if the option is in the money,} \\ z_{t+1} - c_t(1+i_t) & \text{if the option is out of the money.} \end{cases}$$

The variables c_t and i_t denote the cost of the put or call option and i_t denotes the nominal interest rate. The variable h_{t+1} is the lower bound on the investor's net payoff.

Because the hedged strategy is also a zero net-investment strategy, its payoff, z^H, must satisfy

$$(1-p)E^N(Mz^H) + pM'E^N(h) = 0. \tag{20}$$

Using **Equation 20** to solve for pM' and replacing this term in **Equation 18**, we obtain

$$z' = E^N(h)\frac{E^N(Mz)}{E^N(Mz^H)}. \tag{21}$$

Motivated by our previous results we assume that $\text{cov}^N(M,z) = \text{cov}^N(M,z^H) = 0$. Then **Equation 21** simplifies to

$$z' = E^N(h)\frac{E^N(z)}{E^N(z^H)}. \tag{22}$$

Using **Equations 18 and 20** we can derive two expressions for $\rho \equiv pM'/(1-p)$ that are numerically identical given our method of estimating z':

$$\rho = -\frac{E^N(z)}{z'} = -\frac{E^N(z^H)}{E^N(h)}. \tag{23}$$

Here, we estimate ρ because the parameters p and M' are not separately identified by the pricing equations.

We estimate z' and ρ for the carry trade using currency option data from J.P. Morgan for 10 major currencies over the period 1995–2009. As in **Burnside et al. (2011)**, we assume that in the disaster state all of the individual currency carry trades lose money. Consequently, we assume that the investor hedges the equally weighted carry trade strategy by buying at-the-money options. This assumption means that the payoff of the carry trade portfolio in the peso state is the average of the minimum payoffs of the individual carry trades in that state.

The momentum strategy for an individual currency sometimes takes the opposite position of the carry trade strategy. In these instances, if we assume carry is exposed to disaster risk, momentum is naturally hedged against it. This property presents a difficulty for our empirical strategy because it means that the unhedged momentum payoff for an individual currency in the disaster state is occasionally $-z'$, rather than z'.

To bring momentum into our analysis, we consider a 50-50 portfolio that equally combines the carry trade and momentum portfolios. Suppose each of these portfolios is formed with n currencies. When the two underlying strategies agree on the sign of an individual currency trade, the net position in the portfolio for that currency is $\pm 1/n$. In this case, the position is naturally exposed to disaster risk, and this risk can be hedged using options. When the two underlying strategies disagree on the sign of an individual currency trade, the net position for that currency is zero.

Using data on the payoffs to the hedged and unhedged carry trade and 50-50 carry-momentum strategies, and data on the minimum payoffs to the hedged strategies, we estimate the moments that appear on the right-hand sides of **Equations 22 and 23**. Doing so provides us with estimates of z'_1 (the payoff to the equally weighted carry trade in the disaster state) and z'_2 (the payoff to the 50-50 strategy in the disaster state), and two estimates of ρ. Using a Wald test, we can test whether the two estimates of ρ are equal, which they should be, in absence of market segmentation. (**Burnside et al. 2011** discuss a related comparison of the values of M' implied by the carry trade and a hedged stock market strategy.) Alternatively, we can use the pricing equations of the hedged and unhedged versions of the two strategies to estimate the three parameters, z'_1, z'_2, and ρ, using GMM. This system is overidentified, and, therefore, provides us with a simple test of the peso-problem hypothesis.

When we use the first procedure, our estimates are $z'_1 = -0.037$ (0.014) and $z'_2 = -0.091$ (0.006). Standard errors are reported in parenthesis. Our two estimates of ρ are 0.095 (0.059) and 0.159 (0.091). The two estimates of ρ are insignificantly different from each other according to the Wald test (p-value = 0.23). Given the small standard errors associated with z'_1 and z'_2, we can be quite confident that the disaster event is not characterized by large losses to either the carry trade or the 50-50 carry-momentum portfolio.

When we use the second procedure, our estimates of z_1' and z_2' are −0.040 (0.020) and −0.027 (0.015), and our estimate of ρ is 0.089 (0.064). The test of the overidentifying restrictions does not reject the model (p-value = 0.27). A value of ρ of 0.089 means that if we assume that the true probability of a rare event is $p = 0.0014$, then $M' \cong 63$.

Our analysis assumes that the SDF takes on a single value in the rare disaster or peso state. Under alternative assumptions, we can still generate testable implications of the peso-problem hypothesis. For example, **Burnside et al. (2011)** show how to estimate a lower bound for $E^D(z_1)$ allowing for negative covariance between payoffs to the carry trade and the SDF in the peso state.

Overall, we find little evidence against the peso event hypothesis. According to our point estimates, the peso event is not characterized by large losses to the currency strategies. Instead, it is characterized by moderate losses and large values of the SDF.

5. PRICE PRESSURE

In this section we discuss an alternative explanation for the profitability of our currency strategies raised in **Burnside et al. (2006)**. This explanation relies on the existence of price pressure in the foreign exchange market. By price pressure we mean that the price at which investors can buy or sell an asset depends on the quantity they wish to transact. There is a strand of research in finance that stresses the possibility that demand curves for assets are downward sloping. **Shleifer (1986)** and **Mitchell & Pulvino (2004)** present evidence in support of this view for stocks.

Anecdotal evidence gathered from currency traders suggests that a similar phenomenon occurs in foreign exchange markets: Prices move against individual traders when they place large orders. Here we present a simple model that illustrates the implications of price pressure for the profitability of currency-trading strategies.

The case of a single trader

Consider an asset that has a value $v + \epsilon$, where ϵ is a random variable with mean zero. Suppose that there is a single risk-neutral trader who decides to buy x units of the asset. To capture the basic effects of price pressure we suppose that the price of the asset that the trader purchases depends on order size in the following way. The price in the beginning of the day is

$$p_0 = a. \tag{24}$$

As long as $a < v$, it is optimal for the trader to buy a positive quantity of the asset. Trading takes place during the course of a day. At instant t during the day the change in the price depends on the quantity of orders, m_t, submitted at that point in time:

$$\dot{p}_t = bm_t. \tag{25}$$

We assume that b is positive, so that the price is an increasing function of the quantity purchased; that is, there is price pressure.

Suppose the trader wants to buy x units of currency during the day. Consider the following two strategies. Strategy A is to submit an order for x, say, at the end of the day. The price associated with the order is $a + bx$, so that the total cost of the order is $x(a + bx)$.

Strategy B is to break up the order and submit orders of size $m = x/T$ throughout the day. Here, T is the number of tr ading minutes in the day. The price of the asset at time t is given by

$$p_t = a + b\int_0^t m_s ds = a + b\frac{x}{T}t.$$

The total cost of the order is

$$\int_0^T p_t \frac{x}{T} dt = ax + b\frac{1}{2}x^2.$$

It is clear that, from the perspective of the trader, strategy B dominates strategy A. So, we assume that the trader us es strategy B and breaks up the orders. It is useful to rewrite the total cost of the order as $\int_0^x (a + bz)dz$.

The trader's profit, π, is given by

$$\pi = (v + \varepsilon)x - \int_0^x (a + bz)dz.$$

The trader chooses x to maximize the expected value of π.

$$E(\pi) = vx - \int_0^x (a + bz)dz.$$

The first-order condition for this problem implies that the optimal value of x, x^*, is given by

$$x^* = \frac{v - a}{b}.$$

The price paid for the last unit of the asset purchased is

$$p^* = v.$$

We wish to stress two key features of this example. First, the expected profit from the last unit of the asset purchase d by the trader is equal to zero. Second, the total expected profits earned by the trader are positive:

$$E(\pi) = \frac{1}{2}\frac{(v - a)^2}{b}.$$

Consider an econometrician who observes the average trade during the day. He would correctly infer that the strat egy is profitable. Suppose that he ignores the existence of price pressure and assumes that marginal and average p rofits coincide. Then he would incorrectly conclude that the trader is leaving money on the table by not expanding the size of the trade.

The case of *n* traders

Suppose that there is a fixed number, n, of traders. Within the day price pressure is governed by **Equations 24 and 25** where m_t denotes total orders arriving at time t. Consider a Nash equilibrium in which each trader chooses to buy x units of the asset, taking as given that the remaining $n-1$ traders buy $\bar{x}$ units each. The order in which trades occur is randomly determined after traders choose x. Trader j trades from time $T(j-1)/n$ to time Tj/n, where the index j takes values from one to n. Each trader breaks up his orders uniformly within his trading period. Because a representative trader has a probability $1/n$ of being the jth trader, his expected profit is

$$E(\pi) = vx - \sum_{j=0}^{n-1} \frac{1}{n} \int_{j\bar{x}}^{j\bar{x}+x} (a + bz)dz.$$

The optimal value of x satisfies the first-order condition:

$$v = a + bx + \frac{1}{2} b\bar{x}(n-1).$$

In a symmetric equilibrium $x = \bar{x}$, so

$$x = \frac{2(v-a)}{b(1+n)}.$$

The average expected profit across traders is positive and equal to

$$E(\pi) = \frac{2(v-a)^2}{b(1+n)^2} > 0.$$

The expected profit of a trader who has a position j in the trading queue is

$$E(\pi_j) = \frac{2(v-a)^2}{b(1+n)^2} [n + 2(1-j)].$$

So, when n is large, roughly half of the traders make profits and the other half make losses. The profits of the winners are larger than the losses of the losers, which is why average profits across traders are positive.

As in the single trader case, an econometrician who observes the average trade during the day would conclude that the strategy is profitable. He might wonder why traders do not increase their positions until this profitability vanishes. But, although the average trade generates profits, the marginal trade makes losses. So, there is no reason for traders to expand their positions. No money is being left on the table.

6. CONCLUSION

We discuss two conventional explanations for the apparent profitability of the carry trade and momentum strategies. The first is that investors are compensated for the risk they bear. Although this hypothesis is very appealing, we find little evidence to support it. The second conventional explanation is that the profitability of the two currency strategies results from a rare disaster or peso problem. We argue that the recent financial crisis is not a rare disaster from the standpoint of a currency speculator who uses both the carry trade and momentum strategies. We also argue that the peso event is not characterized by large losses to currency speculators. Instead, it features moderate losses and high values of the SDF.

Finally, we discuss the potential role of price pressure in explaining the profitability of the two currency strategies. Although this approach shows some promise, two important questions remain to be answered. First, is the form of price pressure postulated in our example empirically plausible for currency markets? Second, what is the source of this price pressure?

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

LITERATURE CITED

Asness CS, Moskowitz TJ, Pedersen LH. **2009**. *Value and momentum everywhere* Work. Pap., Univ. Chic **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Value+and+momentum+everywhere&publication_year=2009&)**

Backus DK, Foresi S, Telmer CI. **2001**. Affine term structure models and the forward premium anomaly. *J. Finance* 56:(1)279–304 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Affine+term+structure+models+and+the+forward+premium+anomaly&journal=J.+Finance&volume=56&pages=279-304&publication_year=2001&)**

Bekaert G, Hodrick RJ. **1992**. Characterizing predictable components in excess returns on equity and foreign exchange markets. *J. Finance* 47:(2)467–509 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Characterizing+predictable+components+in+excess+returns+on+equity+and+foreign+exchange+markets&journal=J.+Finance&volume=47&pages=467-509&publication_year=1992&)**

Bilson JFO. **1981**. The `speculative efficiency' hypothesis. *J. Bus.* 54:(3)435–51 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=The+%60speculative+efficiency%27+hypothesis&journal=J.+Bus.&volume=54&pages=435-51&publication_year=1981&)**

Brunnermeier MK, Nagel S, Pedersen LH. **2009**. Carry trades and currency crashes. *NBER Macroecon. Ann.* 23:313–47 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Carry+trades+and+currency+crashes&journal=NBER+Macroecon.+Ann.&volume=23&pages=313-47&publication_year=2009&)**

Burnside C. **2007**. *The cross-section of foreign currency risk premia and consumption growth risk: a comment* NBER Work. Pap. 13129 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=The+cross-section+of+foreign+currency+risk+premia+and+consumption+growth+risk%3A+a+comment&publication_year=2007&)**

Burnside C. **2011**.Carry trades and risk *The Handbook of Exchange Rates* James J, Marsh IW, Sarno L. Hoboken, NJ: Wiley Forth coming **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=The+Handbook+of+Exchange+Rates&publication_year=2011&)**

Burnside C, Eichenbaum M, Kleshchelski I, Rebelo S. **2006**. *The returns to currency speculation* NBER Work. Pap. 12489 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=The+returns+to+currency+speculation&publication_year=2006&)**

Burnside C, Eichenbaum M, Kleshchelski I, Rebelo S. **2011**. Do peso problems explain the returns to the carry trade?. *Rev. Financ. Stud.* 24:(3)853–91 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Do+peso+problems+explain+the+returns+to+the+carry+trade%3F&journal=Rev.+Financ.+Stud.&volume=24&pages=853-91&publication_year=2011&)**

Burnside C, Eichenbaum M, Rebelo S. **2007**. The returns to currency speculation in emerging markets. *Am. Econ. Assoc.* 97:(2)333–38 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=The+returns+to+currency+speculation+in+emerging+markets&journal=Am.+Econ.+Assoc.&volume=97&pages=333-38&publication_year=2007&)**

Burnside C, Eichenbaum M, Rebelo S. **2008**. Carry trade: the gains of diversification. *J. Eur. Econ. Assoc.* 6:(2-3)581–88 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Carry+trade%3A+the+gains+of+diversification&journal=J.+Eur.+Econ.+Assoc.&volume=6&pages=581-88&publication_year=2008&)**

Carhart M. **1997**. On persistence in mutual fund performance. *J. Finance* 52:(1)57–82 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=On+persistence+in+mutual+fund+performance&journal=J.+Finance&volume=52&pages=57-82&publication_year=1997&)**

Clinton K. **1988**. Transactions costs and covered interest arbitrage: theory and evidence. *J. Polit. Econ.* 96:(2)358–70 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Transactions+costs+and+covered+interest+arbitrage%3A+theory+and+evidence&journal=J.+Polit.+Econ.&volume=96&pages=358-70&publication_year=1988&)**

Engel C. **1996**. The forward discount anomaly and the risk premium: a survey of recent evidence. *J. Empir. Finance* 3:(2)123–92 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=The+forward+discount+anomaly+and+the+risk+premium%3A+a+survey+of+recent+evidence&journal=J.+Empir.+Finance&volume=3&pages=123-92&publication_year=1996&)**

Evans M. **2011**. *Exchange Rate Dynamics* Princeton, NJ: Princeton Univ. Press **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Exchange+Rate+Dynamics&publication_year=2011&)**

Fama EF. **1984**. Forward and spot exchange rates. *J. Monet. Econ.* 14:(3)319–38 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Forward+and+spot+exchange+rates&journal=J.+Monet.+Econ.&volume=14&pages=319-38&publication_year=1984&)**

Fama EF, French KR. **1993**. Common risk factors in the returns on stocks and bonds. *J. Financ. Econ.* 33:(1)3–56 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Common+risk+factors+in+the+returns+on+stocks+and+bonds&journal=J.+Financ.+Econ.&volume=33&pages=3-56&publication_year=1993&)**

Farhi E, Fraiberger SP, Gabaix X, Ranciere R, Verdelhan A. **2009**. *Crash risk in currency markets* NBER Work. Pap. 15062 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Crash+risk+in+currency+markets&publication_year=2009&)**

Farhi E, Gabaix X. **2008**. *Rare disasters and exchange rates* NBER Work. Pap. 13805 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Rare+disasters+and+exchange+rates&publication_year=2008&)**

Hansen LP. **1982**. Large sample properties of generalized method of moments estimators. *Econometrica* 50:(4)1029–54 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Large+sample+properties+of+generalized+method+of+moments+estimators&journal=Econometrica&volume=50&pages=1029-54&publication_year=1982&)**

Harvey CR, Siddique A. **2000**. Conditional skewness in asset pricing tests. *J. Finance* 55:(3)1263–95 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Conditional+skewness+in+asset+pricing+tests&journal=J.+Finance&volume=55&pages=1263-95&publication_year=2000&)**

Hodrick RJ. **1987**. *The Empirical Evidence on the Efficiency of Forward and Futures Foreign Exchange Markets* Chur, Switzerland: Harwood Acad. Publ **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=The+Empirical+Evidence+on+the+Efficiency+of+Forward+and+Futures+Foreign+Exchange+Markets&publication_year=1987&)**

Jegadeesh N, Titman S. **1993**. Returns to buying winners and selling losers: implications for stock market efficiency. *J. Finance* 48:(1)65–91 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Returns+to+buying+winners+and+selling+losers%3A+implications+for+stock+market+efficiency&journal=J.+Finance&volume=48&pages=65-91&publication_year=1993&)**

Jordà Ò, Taylor AM. **2009**. *The carry trade and fundamentals: nothing to fear but FEER itself* NBER Work. Pap. 15518 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=The+carry+trade+and+fundamentals%3A+nothing+to+fear+but+FEER+itself&publication_year=2009&)**

Jurek JW. **2008**. *Crash-neutral currency carry trades* SSRN Work. Pap. 1262934 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Crash-neutral+currency+carry+trades&publication_year=2008&)**

Lintner J. **1965**. The valuation of risk assets and the selection of risky investments in stock portfolios and capital budgets. *Rev. Econ. Stat.* 47:(1)13–37 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=The+valuation+of+risk+assets+and+the+selection+of+risky+investments+in+stock+portfolios+and+capital+budgets&journal=Rev.+Econ.+Stat.&volume=47&pages=13-37&publication_year=1965&)**

Lustig H, Roussanov N, Verdelhan A. **2009**. *Common risk factors in currency markets* SSRN Work. Pap. 1139447 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Common+risk+factors+in+currency+markets&publication_year=2009&)**

Lustig H, Verdelhan A. **2007**. The cross-section of foreign currency risk premia and consumption growth risk. *Am. Econ. Rev.* 97:(1)89–117 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=The+cross-section+of+foreign+currency+risk+premia+and+consumption+growth+risk&journal=Am.+Econ.+Rev.&volume=97&pages=89-117&publication_year=2007&)**

Mancini-Griffoli T, Ranaldo A. **2011**. *Limits to arbitrage during the crisis: funding liquidity constraints and covered interest parity* SSRN Work. Pap. 1549668 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Limits+to+arbitrage+during+the+crisis%3A+funding+liquidity+constraints+and+covered+interest+parity&publication_year=2011&)**

Meese RA, Rogoff K. **1983**. Empirical exchange rate models of the seventies: Do they fit out of sample?. *J. Int. Econ.* 14:(1-2)3–24 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Empirical+exchange+rate+models+of+the+seventies%3A+Do+they+fit+out+of+sample%3F&journal=J.+Int.+Econ.&volume=14&pages=3-24&publication_year=1983&)**

Menkhoff L, Sarno L, Schmeling M, Schrimpf A. **2011a**.Carry trades and global foreign exchange volatility *J. Finance* Forthcoming **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=J.+Finance&)**

Menkhoff L, Sarno L, Schmeling M, Schrimpf A. **2011b**. *Currency momentum strategies* Work. Pap., Cass Bus. Sch., City Univ. Lond **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Currency+momentum+strategies&)**

Mitchell M, Pulvino T. **2004**. Price pressure around mergers. *J. Finance* 59:(1)31–63 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Price+pressure+around+mergers&journal=J.+Finance&volume=59&pages=31-63&publication_year=2004&)**

Moskowitz T, Ooi YH, Pedersen LH. **2010**. *Time series momentum* Work. Pap., N. Y. Univ **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Time+series+momentum&publication_year=2010&)**

Nakamura E, Steinsson J, Barro RJ, Ursúa JF. **2010**. *Crises and recoveries in an empirical model of consumption disasters* NBER Work. Pap. 15920 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Crises+and+recoveries+in+an+empirical+model+of+consumption+disasters&publication_year=2010&)**

Okunev J, White D. **2003**. Do momentum-based strategies still work in foreign currency markets?. *J. Financ. Quant. Anal.* 38:(2)425–47 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Do+momentum-based+strategies+still+work+in+foreign+currency+markets%3F&journal=J.+Financ.+Quant.+Anal.&volume=38&pages=425-47&publication_year=2003&)**

Rafferty B. **2010**. *The returns to currency speculation and global currency realignment risk* Work. Pap., Duke Univ **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=The+returns+to+currency+speculation+and+global+currency+realignment+risk&publication_year=2010&)**

Rouwenhorst KG. **1998**. International momentum strategies. *J. Finance* 53:(1)267–84 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=International+momentum+strategies&journal=J.+Finance&volume=53&pages=267-84&publication_year=1998&)**

Sharpe WF. **1964**. Capital asset prices: a theory of market equilibrium under conditions of risk. *J. Finance* 19:(3)425–42 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Capital+asset+prices%3A+a+theory+of+market+equilibrium+under+conditions+of+risk&journal=J.+Finance&volume=19&pages=425-42&publication_year=1964&)**

Shleifer A. **1986**. Do demand curves for stocks slope down?. *J. Finance* 41:(3)579–90 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Do+demand+curves+for+stocks+slope+down%3F&journal=J.+Finance&volume=41&pages=579-90&publication_year=1986&)**

Taylor MP. **1987**. Covered interest parity: a high-frequency, high-quality data study. *Economica* 54:(216)429–38 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Covered+interest+parity%3A+a+high-frequency%2C+high-quality+data+study&journal=Economica&volume=54&pages=429-38&publication_year=1987&)**

Taylor MP. **1989**. Covered interest arbitrage and market turbulence. *Econ. J.* 99:(396)376–91 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Covered+interest+arbitrage+and+market+turbulence&journal=Econ.+J.&volume=99&pages=376-91&publication_year=1989&)**

Villanueva OM. **2007**. Forecasting currency excess returns: can the forward bias be exploited?. *J. Financ. Quant. Anal.* 42:(4)963–90 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=Forecasting+currency+excess+returns%3A+can+the+forward+bias+be+exploited%3F&journal=J.+Financ.+Quant.+Anal.&volume=42&pages=963-90&publication_year=2007&)**

Yogo M. **2006**. A consumption-based explanation of expected stock returns. *J. Finance* 61:(2)539–80 **[Google Scholar] (http://scholar.google.com/scholar_lookup?title=A+consumption-based+explanation+of+expected+stock+returns&journal=J.+Finance&volume=61&pages=539-80&publication_year=2006&)**

Article Type: Review Article

The Real Effects of Financial Markets (/content/journals/10.1146/annurev-financial-110311-101826)

Philip Bond (/search?value1=Philip+Bond&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true), Alex Edmans (/search?value1=Alex+Edmans&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true), and Itay Goldstein (/search?value1=Itay+Goldstein&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true)
Vol. 4 (2012), pp. 339–360

Climate Finance (/content/journals/10.1146/annurev-financial-102620-103311)

Stefano Giglio (/search?value1=Stefano+Giglio&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true), Bryan Kelly (/search?value1=Bryan+Kelly&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true), and Johannes Stroebel (/search?value1=Johannes+Stroebel&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true)
Vol. 13 (2021), pp. 15–36

Financialization of Commodity Markets (/content/journals/10.1146/annurev-financial-110613-034432)

Ing-Haw Cheng (/search?value1=Ing-Haw+Cheng&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true), and Wei Xiong (/search?value1=Wei+Xiong&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true)
Vol. 6 (2014), pp. 419–441

A Survey of Systemic Risk Analytics (/content/journals/10.1146/annurev-financial-110311-101754)

Dimitrios Bisias (/search?value1=Dimitrios+Bisias&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true), Mark Flood (/search?value1=Mark+Flood&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true), Andrew W. Lo (/search?value1=Andrew+W.+Lo&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true), and Stavros Valavanis (/search?value1=Stavros+Valavanis&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true)
Vol. 4 (2012), pp. 255–296

CEO Compensation (/content/journals/10.1146/annurev-financial-120209-133958)

Carola Frydman (/search?value1=Carola+Frydman&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true), and Dirk Jenter (/search?value1=Dirk+Jenter&option1=author&noRedirect=true&sortField=prism_publicationDate&sortDescending=true)
Vol. 2 (2010), pp. 75–102

+ More