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Pedro Barroso and Pedro Santa-Clara*

Abstract

We test the relevance of technical and fundamental variables in forming currency portfolios. Carry, momentum, and value reversal all contribute to portfolio performance, whereas the real exchange rate and the current account do not. The resulting optimal portfolio produces out-of-sample returns that are not explained by risk and are valuable to diversified investors holding stocks and bonds. Exposure to currencies increases the Sharpe ratio of diversified portfolios by 0.5 on average, while reducing crash risk. We argue that besides risk, currency returns reflect the scarcity of speculative capital.

I. Introduction

Currency spot rates are nearly unpredictable out of sample (Meese and Rogoff (1983)).¹ Usually, unpredictability is seen as evidence supporting market efficiency, but with currency spot rates it is quite the opposite; it presents a challenge. Because currencies have different interest rates, if the difference in interest rates does not forecast an offsetting depreciation, then investors can borrow the low-yielding currencies to invest in the high-yielding currencies (Fama (1984)). This strategy, known as the carry trade, has performed extremely well for a long period without any fundamental economic explanation. Burnside, Eichenbaum, and Rebelo (2008) show that a well-diversified carry trade attains a Sharpe ratio that is more than double that of the U.S. stock market, itself a famous puzzle (Mehra and Prescott (1985)).

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¹See also Cheung, Chinn, and Pascual (2005), Rogoff and Stavrageva (2008), and Rogoff (2009).

Considerable effort has been devoted to explaining the returns of the carry trade as compensation for risk. Lustig, Roussanov, and Verdelhan (2011a) show that the risk of carry trades across currency pairs is not completely diversifiable, so there is a systematic risk component to the strategy. They form an empirically motivated risk factor, the return of high-yielding currencies minus low-yielding currencies (HML_{FX}), close in spirit to the stock market factors of Fama and French (1992), and show that it explains the carry premium. But the HML_{FX} is itself a currency strategy, so linking its returns to more fundamental risk sources has been an important challenge for research in the currency market.

Some risks of the carry trade are well known. High-yielding currencies are known to “go up by the stairs and down by the elevator,” implying that the carry trade has substantial crash risk. Carry performs worse when there are liquidity squeezes (Brunnermeier, Nagel, and Pedersen (2008)) and increases in foreign exchange volatility (Menkhoff, Sarno, Schmeling, and Schrimpf (2012a)). Its risk exposure is time-varying, increasing in times of greater uncertainty (Christiansen, Rinaldo, and Söderlind (2011)).

Another possible explanation of the carry premium is that there is some “peso problem” with the carry trade; the negative event that justifies its returns may simply have not occurred yet (Barro (2006), Farhi and Gabaix (2007), Gourio, Siemer, and Verdelhan (2013), and Burnside, Eichenbaum, Kleshchelski, and Rebelo (2011)). Using options to hedge away the “peso risk” reduces abnormal returns, lending some support to this view, but the remaining returns depend crucially on the particular option strategy used for hedging (Jurek (2009)). Even so, the recent financial crisis was not the “peso event” needed to rationalize the carry-trade previous returns (Burnside, Eichenbaum, Kleshchelski, et al. (2011)).

Despite our improved understanding of the risk of the carry trade, the fact remains that conventional risk factors from the stock market (market, value, size, momentum) or consumption growth models do not explain its returns (Burnside, Eichenbaum, and Rebelo (2011)). Indeed, an investor looking for significant abnormal returns with respect to, say, the Fama–French (1992) factors would do very well by just dropping all equities from the portfolio and investing entirely in a passively managed currency carry portfolio instead.

Abnormal returns should not persist in a market driven by profit-maximizing investors. But the currency market has a scarcity of profit-seeking capital and, conversely, an abundance of capital-pursuing goals unrelated to profitability. This may explain the persistence of anomalies.

Unlike equity markets, profit-seeking capital in currencies had a relatively minor role during most of the floating-exchange-rate era (Jylhä and Suominen (2011)). Central banks that set domestic monetary policies and occasionally intervene in currency markets do not seek profits at all (Taylor (1982)).² Corporate and retail participants also affect market results with hedging demands not related to profitability (Hafeez and Brehon (2010)).

The relevance of actors that do not maximize profits influences the profitability of speculative currency strategies. For instance, whereas technical analysis

²When intervening, central banks stand ready to lose large amounts for extended periods of time. They typically “lean against the wind,” buying a currency that is depreciating, or vice versa.

is close to useless in equity markets (Fama and Blume (1966)), there is considerable evidence that it produces positive risk-adjusted returns in currency markets (Levich and Thomas (1993), Taylor and Allen (1992)). LeBaron (1999) finds that the effectiveness of technical trading rules is concentrated around interventions by central banks. Silber (1994) finds similar evidence in the cross section of currencies. Thus, the carry trade is not the only strategy with puzzling returns in the currency market.

Market practitioners follow other approaches, including value and momentum (Levich and Pojarliev (2011)). The benefits of combining these different approaches became apparent at the height of the financial crisis when events in the currency market assumed historical proportions.³ For instance, Deutsche Bank has three popular exchange traded funds (ETFs) that track carry, value, and momentum strategies with the currencies of the G10. From Aug. 2008 to Jan. 2009, the carry ETF experienced a severe crash of 32.6%, alongside the stock market, commodities, and high-yield bonds. But in the same period, the momentum ETF delivered a 29.4% return and the value ETF a 17.8% return. So while the carry trade crashed, a diversified currency strategy fared quite well in this turbulent period.

Coincidentally, the literature on alternative currency investments has seen major developments since 2008. Menkhoff, Sarno, Schmeling, and Schrimpf (2012b) document the properties of currency momentum; Burnside, Eichenbaum, and Rebelo (2011) examines a combination of carry and momentum; Asness, Moskowitz, and Pedersen (2013) study a combination of value and momentum in currencies (and other asset classes); and Jordà and Taylor (2012) combine carry, momentum, and the real exchange rate. Still, the core of the literature focuses on isolated strategies. Very few studies examine combinations of strategies, and virtually none examines an empirical optimum combination of these strategies.

Most of the studies on currency strategies focus on simple portfolios. This choice is understandable, as there is substantial evidence indicating that these tend to outperform out-of-sample (OOS), more complex optimized portfolios (DeMiguel, Garlappi, and Uppal (2009), Jacobs, Müller, and Weber (2014)). However, this is exactly because optimized portfolios are a closer reflection of the uncertainties faced by investors in real time. Namely, they have to deal with the choice of what signals to use, how to weigh each signal, and how to address measurement error and transaction costs. This should be particularly relevant in alternative investment classes, when there is no *a priori* reason to believe that sorting assets by a given characteristic should produce excess returns.

To study the risk and return of currency strategies in a more realistic setting, we use the parametric portfolio policies approach of Brandt, Santa-Clara, and Valkanov (2009) and test the relevance of different variables in forming currency portfolios.

First, we use a pre-sample test to study which characteristics matter for investment purposes. We test the relevance of the interest rate spread (and its sign), momentum, and three proxies for value: long-term value reversal, the real

³Melvin and Taylor (2009) provide a vivid narrative of the major events in the currency market during the crisis.

exchange rate, and the current account. Including all characteristics simultaneously in the test allows us to see which are relevant and which are subsumed by others. Then we conduct a comprehensive OOS exercise with 16 years of monthly returns to minimize forward-looking bias.⁴

We find that the interest rate spread, momentum, and value reversal create economic value for investors, whereas fundamentals such as the current account and the real exchange rate do not. The strategy combining the relevant signals increases the Sharpe ratio relative to an equal-weighted carry portfolio from 0.57 to 0.86, OOS and after transaction costs. This is a 0.29 gain, about the same as the Sharpe ratio of the stock market in the same period.

Transaction costs matter in currency markets. Taking transaction costs into account in the optimization further increases the Sharpe ratio to 1.06, a total gain of 0.49 over the equal-weighted carry benchmark. The gains in certainty equivalent are even more impressive, as the optimal diversified strategy substantially reduces crash risk.

In the Internet Appendix (available at www.jfqa.org) we show that the risk factors recently proposed to explain carry returns do not explain the returns of the optimized portfolio. So, although these risk factors may have some success in explaining carry returns, they struggle to justify our optimal currency strategy.

Addressing a largely unexplored topic, we study the optimal combination of currency strategies with stock market factors and bonds.⁵ We find that including currency strategies in an optimized portfolio increases the Sharpe ratio by 0.51 on average, OOS. Furthermore, adding currency strategies consistently reduces fat tails and left skewness. This contradicts crash-risk explanations for returns in the currency market.

Finally, we regress the returns of the optimal strategy on the level of speculative capital in the market. We find evidence that the expected returns of the strategy decline as the amount of hedge fund capital increases. This suggests that the returns we document constitute an anomaly that is gradually being arbitrated away by hedge funds, as knowledge of the relevant currency characteristics spreads and more capital is used in exploiting them, a result consistent with the adaptive markets hypothesis (Lo (2004)).

Our paper is structured as follows: In Section II we explain the implementation of parametric portfolios of currencies. Section III presents the empirical analysis. Section III.A describes the data and the variables used in the optimization. Sections III.B and III.C present the investment performance of the optimal portfolios in and out of sample, respectively. In Section IV we assess the value of currency strategies for investors holding stocks and bonds. Section V discusses possible explanations for the abnormal returns of the strategy, including insufficient speculative capital early in the sample.

⁴However, an OOS exercise does not eliminate forward-looking bias completely. After all, would we be conducting the same exercise in the first place if there were no indications in the literature that momentum and value worked in recent years?

⁵Kroencke, Schindler, and Schrimpf (2011) show that there are benefits of investing in currencies for investors with internationally diversified holdings of stocks.

II. Optimal Parametric Portfolios of Currencies

We optimize currency portfolios from the perspective of a U.S. investor in the forward exchange market. The investor can agree at time t to buy currency i forward at time $t + 1$ for $1/F_{t,t+1}^i$, where $F_{t,t+1}^i$ is the price of US\$1 expressed in foreign currency units (FCUs). Then at time $t + 1$ the investor liquidates the position, selling the currency for $1/S_{t+1}^i$, where S_{t+1}^i is the spot price of US\$1 in FCUs. The return (in U.S. dollars) of a long position in currency i in month t is

$$(1) \quad r_{t+1}^i = \frac{F_{t,t+1}^i}{S_{t+1}^i - 1}.$$

This is a zero-investment strategy, as it consists of positions in the forward market only. We use 1-month forwards throughout, as is standard in the literature.⁶ Therefore all returns are monthly, and there are no inherited positions from month to month. This also avoids path dependency when we include transaction costs in the analysis.

We optimize the currency strategies using the parametric portfolio policies approach of Brandt et al. (2009). This method models the weights of assets as a function of their characteristics. The implicit assumption is that the characteristics convey all relevant information about the assets' conditional distribution of returns. The weight on currency i at time t is

$$(2) \quad w_{i,t} = \frac{\theta^T x_{i,t}}{N_t},$$

where $x_{i,t}$ is a $k \times 1$ vector of currency characteristics, θ is a $k \times 1$ parameter vector to be estimated, and N_t is the number of currencies available in the data set at time t . Dividing by N_t keeps the policy stationary (see Brandt et al. (2009)). We do not place any restriction on the weights, which can be positive or negative, reflecting the fact that in the forward exchange market there is no obvious nonnegativity constraint.

The strategies we examine consist of an investment of 100% in the U.S. risk-free asset, yielding RF_t^{US} , and a long-short portfolio in the forward exchange market. For a given sample, θ uniquely determines the parametric portfolio policy, and the corresponding return each period will be

$$(3) \quad r_{p,t+1} = \text{RF}_t^{\text{US}} + \sum_{i=1}^{N_t} w_{i,t} r_{t+1}^i.$$

The problem an investor faces is optimizing an objective function by picking the best possible θ for the sample:

$$(4) \quad \max_{\theta} \mathbb{E}_t [U(r_{p,t+1})].$$

We use power utility as the objective function:

$$(5) \quad U(r_p) = \frac{(1 + r_p)^{1-\gamma}}{1 - \gamma},$$

⁶Burnside et al. (2008), Burnside, Eichenbaum, and Rebelo (2011), Burnside, Eichenbaum, Kleshchelski, et al. (2011), and Menkhoff et al. (2012a), (2012b).

where γ is the coefficient of relative risk aversion (CRRA).⁷ The main advantage of this utility function is that it penalizes kurtosis and skewness, as opposed to mean-variance utility, which focuses only on the first two moments of the distribution of returns. So our investor dislikes crash risk and values characteristics that help reduce it, even if these do not add to the Sharpe ratio.

The main restriction imposed on the investor's problem is that θ is kept constant across time. This substantially reduces the chances of in-sample overfitting, as only a $k \times 1$ vector of characteristics is estimated. The assumption that θ does not change allows its estimation using the sample counterparts:

$$(6) \quad \hat{\theta} = \arg \max_{\theta} \frac{1}{T} \sum_{t=0}^{T-1} U \left(\text{RF}_t^{\text{US}} + \sum_{i=1}^{N_t} \left(\frac{\theta^T x_{i,t}}{N_t} \right) r_{t+1}^i \right).$$

For statistical inference purposes, Brandt et al. (2009) show that we can use either the asymptotic covariance matrix of $\hat{\theta}$ or bootstrap methods.⁸

For the interpretation of results, it is important to note that equation (6) optimizes a utility function and not a measure of the distance between forecasted and realized returns. Therefore θ can be found relevant for one characteristic even if it conveys no information at all about expected returns. The characteristic may just be a predictor of a currency's contribution to the overall skewness or kurtosis of the portfolio, for example. Conversely, a characteristic may be found irrelevant for investment purposes even if it does help in forecasting returns because it may forecast both higher returns and higher risk for a currency, offering a trade-off that is irrelevant for the investor's utility function.

Transaction costs are relevant to assess the performance of an investment strategy (Lesmond, Schill, and Zhou (2004)). So one valid concern is whether the gains of combining momentum with carry persist after taking into consideration transaction costs. Fortunately, parametric portfolio policies can easily incorporate transaction costs that vary across currencies and over time. This is a particularly appealing feature of the method, because transaction costs varied substantially as foreign exchange trading shifted toward electronic crossing networks.

To address this issue we optimize:

$$(7) \quad \hat{\theta} = \arg \max_{\theta} \frac{1}{T} \sum_{t=0}^{T-1} U \left(\text{RF}_t^{\text{US}} + \sum_{i=1}^{N_t} \left(\frac{\theta^T x_{i,t}}{N_t} \right) r_{t+1}^i - \sum_{i=1}^{N_t} \left| \frac{\theta^T x_{i,t}}{N_t} \right| c_{i,t} \right),$$

where $c_{i,t}$ is the transaction cost of currency i at time t , which we calculate as:

$$(8) \quad c_{i,t} = \frac{F_{i,t,t+1}^{\text{ask}} - F_{i,t,t+1}^{\text{bid}}}{F_{i,t,t+1}^{\text{ask}} + F_{i,t,t+1}^{\text{bid}}}.$$

⁷ Bliss and Panigirtzoglou (2004) estimate γ empirically from risk aversion implicit in 1-month options on the Standard & Poor's (S&P) and the Financial Times Stock Exchange (FTSE) and find a value very close to 4. We adopt this value and keep it throughout. The most important measures of economic performance of the strategy are scale invariant (Sharpe ratio, skewness, kurtosis), so the specific choice of CRRA utility is not of crucial importance.

⁸ We use bootstrap methods for standard errors in the empirical part of this paper, as these are slightly more conservative and do not rely on asymptotic results.

This is one-half of the bid–ask spread as a percentage of the mid-quote. This assumes the investor buys (sells) a currency in the forward market at the ask (bid) price, and the forward is settled at the next month's spot rate.⁹

For a given month and currency, transaction costs are proportional to the absolute weight put on that particular currency. This absolute weight is a function of all the currency characteristics as seen in equation (2), so transaction costs depend crucially on the time-varying interaction between characteristics. One example is the interaction between momentum and other characteristics. As Grundy and Martin (2001) show for stocks, the way momentum portfolios are built guarantees time-varying interaction with other stock characteristics. For instance, after a bear market, winners tend to be low-beta stocks, and the reverse for losers. So the momentum portfolio, long in previous winners and short in previous losers, will have a negative beta. The opposite holds after a bull market. The same applies for currencies; after a period when carry experiences high returns, high-yielding currencies tend to have positive momentum. In this case, momentum reinforces the carry signal and results in larger absolute weights and thus higher transaction costs. However, after negative carry returns the opposite happens: High-yielding currencies have negative momentum. So momentum partially offsets the carry signal, resulting in smaller absolute weights, and actually reduces the overall transaction costs of the portfolio. This means the transaction costs of including momentum for an extended period of time in a diversified portfolio policy will be lower than what one finds when examining momentum in isolation, as in Menkhoff et al. (2012b).

III. Empirical Analysis

Combining value reversal and momentum with the carry trade considerably mitigated the crash of the carry trade in the last quarter of 2008. Although this is easy to point out *ex post*, the relevant question is whether investors in the currency market had reasons to believe in the virtue of diversifying their investment strategy before the 2008 crash. For example, Levich and Pojarliev (2011) examine a sample of currency managers and find that they explored carry, momentum, and value strategies before the crisis but shifted substantially across investment styles over time. In particular, right before the height of the financial crisis in the last quarter of 2008, most currency managers were heavily exposed to the carry trade, neutral on momentum, and investing *against* value. This raises the question of whether the benefits of diversification were as clear before the crisis as they later became apparent.

To address this issue we conduct two tests: i) a pre-sample test with the first 20 years of data up to 1996 to determine which characteristics were relevant at that time, and ii) an OOS experiment since 1996 in which the investor chooses the weight to put on each signal using only historical information available up to each moment in time.

⁹This overstates transaction costs. Mancini, Rinaldo, and Wrampelmeyer (2013) document that effective costs in the spot market are less than half those implied by bid–ask quotes. Also, maintained positions in the forward market can be rolled over for a considerably smaller cost.

Section III.A explains the data sources and the variables used in our optimization. In Section III.B we conduct the pre-sample test with the sample from Feb. 1976 to Feb. 1996. In Section III.C we conduct the OOS experiment of portfolio optimization using only the relevant variables identified in the pre-sample test.

A. Data

We use data on exchange rates, the forward premium, and the real exchange rate for the eurozone and the 27 member countries of the Organisation for Economic Co-Operation and Development (OECD). The countries in the sample are: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, South Korea, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

Most studies in the recent literature on currency returns use broader samples of countries, including many emerging economies (e.g., Burnside, Eichenbaum, Kleshchelski, et al. (2011), Lustig et al. (2011a), (2011b)). But this raises possible issues of selection bias. It may also be hard to point out the exact time when an emerging country's currency first became an eligible asset to invest. To avoid these issues, we restrict ourselves to OECD members, the "developed countries club."¹⁰

The exchange rate data are from Datastream. They include spot exchange rates at monthly frequency from Nov. 1960 to Dec. 2011 and 1-month forward exchange rates from Feb. 1976. As in Burnside, Eichenbaum, Kleshchelski, et al. (2011), we merge two data sets of forward exchange rates (against the U.S. dollar and the Great British Pound (GBP)) to have a comprehensive sample of returns in the forward market in the floating-exchange-rate era.¹¹

We calculate the real exchange rates of each currency against the U.S. dollar using the spot exchange rates and the Consumer Price Index (CPI). The CPI data come from the OECD/Main Economic Indicators (MEI) online database. In the case of Australia, New Zealand, and Ireland (before Nov. 1975), only quarterly data are available. In those cases, the value of the last available period was carried forward to the next month. In the case of the eurozone, we use the Harmonized Index of Consumer Prices (HICP) from the European Central Bank instead. The series that starts in Jan. 1996 was extended back to Jan. 1988 using the weights in the HICP of the eurozone founding members.

We test the economic relevance of carry, momentum, and value proxies combined with fundamentals in a currency market investment strategy. The variables used in the optimization exercise are:

1. $SIGN_{i,t}$: The sign of the forward discount of a currency with respect to the U.S. dollar. It is 1 if the foreign currency is trading at a discount ($F_{i,t} > S_{i,t}$) and -1 if it trades at a premium. This is the carry-trade strategy examined

¹⁰We also see no reason to restrict the sample further to just the three major currencies (as some studies do) or even the G10. The assets we consider were perfectly eligible to invest, and a portfolio optimization will be of little interest if the universe of assets becomes too small.

¹¹The first data set has data on forward exchange rates (bid and ask quotes) against the GBP from 1976 to 1996, and the second data set has the same information for quotes against the U.S. dollar from 1996 to 2011.

in Burnside et al. (2008), Burnside, Eichenbaum, and Rebelo (2011), and Burnside, Eichenbaum, Kleshchelski, et al. (2011). Given the extensive study of this strategy, we adopt it as the benchmark throughout the paper.¹²

2. $FD_{i,t}$: The interest rate spread or the forward discount on the currency. We standardize the forward discount using the cross-section mean and standard deviation across all countries available at time t , $\mu_{fd,t}$, and $\sigma_{fd,t}$, respectively. Specifically, denoting the (unstandardized) forward discount as $fd_{i,t}$, we obtain the standardized discount as: $FD_{i,t} = (fd_{i,t} - \mu_{fd,t})/\sigma_{fd,t}$. This cross-sectional standardization measures the forward discount in standard deviations above or below the average across all countries. By construction, a variable standardized in the cross section will have zero mean, implying that the strategy is neutral in terms of the base currency (the U.S. dollar).¹³
3. $MOM_{i,t}$: For currency momentum we use the cumulative currency appreciation in the last 3-month period, cross-sectionally standardized. This variable explores the short-term persistence in currency returns. We use momentum in the previous 3 months because there is ample evidence for persistence in returns for portfolios with this formation period, and there are no significant gains (in fact, the momentum effect is often smaller) when considering longer formation periods (see Menkhoff et al. (2012b)). Three-month momentum was also used in Kroencke et al. (2011). Cross-sectional standardization means that momentum measures relative performance. Even if all currencies fall relative to the U.S. dollar, those that fall less will have positive momentum.
4. $REV_{i,t}$: Long-term value reversal is the cumulative real currency depreciation in the previous 5 years, standardized cross-sectionally. First we calculate the cumulative real depreciation of currency i between the basis period (h) and moment t as an index number $q_{i,h,t} = S_{i,t}CPI_{i,h-2}CPI_{t-2}^{US}/S_{i,h}CPI_{i,t-2}CPI_{h-2}^{US}$. We use a 2-month lag to ensure the CPI is known. We pick $h = t - 60$, which corresponds to 5 years. Then we standardize $q_{i,h,t}$ cross-sectionally to obtain $REV_{i,t}$. This is essentially the same as the notion of “currency value” used in Asness et al. (2013). However, we use the cumulative deviation from purchasing power parity, instead of the cumulative return as they did, to obtain a longer OOS test period. Value reversal is positive for those currencies that experienced the larger real depreciations against the U.S. dollar in the previous 5 years, and negative for the others.
5. $Q_{i,t}$: The real exchange rate standardized by its historical mean and standard deviation. As for value reversal, we compute $q_{i,h_i,t}$ with the difference that here the basis period (h_i) is the first month for which there is CPI and exchange rate data available for currency i . Then we compute

¹²Nevertheless, for a funded program, most institutional mandates for currency funds take as the benchmark just the risk-free rate (Levich and Pojarliev (2008)).

¹³Standardizing characteristics in the cross section of assets is a usual first step in the construction of parametric portfolio policies (although not a prerequisite of the method). See Brandt et al. (2009).

$Q_{i,t} = (q_{i,h_i,t} - \bar{q}_{i,t}) / \sigma_{q_{i,t}}$, where $\bar{q}_{i,t}$ is the historical average $\sum_{j=h_i}^t q_{i,h_i,j} / t$ and $\sigma_{q_{i,t}}$ is the historical standard deviation $\sigma(\{q_{i,h_i,j}\}_{j=h_i}^t)$. The real exchange rate is measured in standard deviations above or below the historical average. Historical standardization is needed because the real exchange rate is very close to a unit root process. As such, the average distance from the historical mean at each moment in time depends on the number of previous observations in the sample.¹⁴ Historical standardization ensures that the optimization does not overweight the signal for currencies with longer samples. Unlike REV, which is cross-sectionally standardized, Q is not neutral in terms of the basis currency (the U.S. dollar). It will tend to be positive for all currencies when these are undervalued against the U.S. dollar by historical standards.

6. $CA_{i,t}$: The current account of the foreign economy as a percentage of gross domestic product (GDP), standardized cross-sectionally. The optimization assumes that the previous-year current account information becomes known in April of the current year. The current account data were retrieved from the Annual Macroeconomic database of the European Commission (AMECO), where data are available on a yearly frequency from 1960 onward. Many studies examine the relation between the current account and exchange rates, justifying its inclusion as a conditional variable.¹⁵

In order to be considered for the trading strategies, a currency must satisfy three criteria: i) there must be at least 10 previous years of real exchange rate data, ii) current forward and spot exchange quotes must be available, and iii) the country must be already an OECD member in the period considered. After filtering out missing observations, there are a minimum of 13 and a maximum of 21 currencies in the sample. On average there are 16 currencies in the sample at each point in time.¹⁶

B. Pre-Sample Results

Table 1 shows the investment performance of the optimized strategies from Feb. 1976 to Feb. 1996. We use this pre-sample period to check which variables had strong enough evidence supporting their relevance back in 1996, before starting the OOS experiment.

The two versions of the carry trade (SIGN and FD) deliver similar performance, with high Sharpe ratios (0.96 and 0.99, respectively) but also with significant crash risk (as captured by excess kurtosis and left-skewness). Momentum provides a Sharpe ratio of 0.56, better than the performance of the stock market of 0.40 in the same sample. Okunev and White (2003), Burnside, Eichenbaum,

¹⁴This is not the same for every currency, as for some currencies the data start at different periods than for others.

¹⁵See, for example, Dornbusch and Fischer (1980), Obstfeld and Rogoff (2005), and Gourinchas and Rey (2007).

¹⁶These include the euro-legacy currencies.

TABLE 1
In-Sample Performance

Table 1 shows the in-sample performance of the investment strategies in the period Feb. 1976 to Feb. 1996. The optimizations use a power utility with a CRRA of 4. Max. and Min. are the maximum and the minimum 1-month return in the sample, respectively, expressed in percentage points. Mean is the annualized average return, in percentage points. The standard deviation (St. Dev.) and Sharpe ratio (SR) are also annualized, and Kurt. is excess kurtosis. The certainty equivalent (CE) is expressed in annual percentage points. It is the constant return that would provide the same utility as the series of returns of the given strategy. The first six rows show the results for a strategy based on using only one variable at a time. The seventh row shows the results for a strategy combining the four relevant signals. The last row shows the performance of a strategy combining all variables simultaneously. See description of the variables in the text.

Strategy	Max.	Min.	Mean	St. Dev.	Kurt.	Skew	SR	CE
FD	15.91	-25.39	19.23	19.47	4.48	-1.23	0.99	18.97
MOM	17.31	-11.60	8.01	14.23	1.80	0.21	0.56	11.61
REV	8.38	-11.31	3.09	8.72	2.24	-0.26	0.36	8.95
SIGN	21.29	-30.11	17.96	18.74	7.35	-0.90	0.96	18.29
CA	2.79	-3.47	0.61	3.86	1.24	-0.44	0.16	7.59
<i>q</i>	2.02	-2.32	0.12	1.79	4.44	-0.74	0.07	7.34
FD, MOM, REV, SIGN	56.83	-32.78	44.30	32.89	5.54	0.66	1.35	34.72
All	60.38	-25.56	45.28	33.70	5.10	0.60	1.34	34.85

and Rebelo (2011), and Menkhoff et al. (2012b) all document the presence of momentum in currency markets.

Financial predictors work better in our optimization than fundamentals such as the real exchange rate and the current account. Value reversal had a Sharpe ratio of 0.36.¹⁷ But the strategies using the current account and the real exchange rate as conditioning variables achieve modest Sharpe ratios (of 0.16 and 0.07), which is not at all impressive, especially as this is an in-sample optimization.¹⁸

The seventh row of Table 1 shows the performance of an optimal strategy combining the carry (both SIGN and FD) with momentum and value reversal, all of the statistically relevant variables. Already in 1996 there was ample evidence indicating that a strategy combining different variables leads to substantial gains. The Sharpe ratio of the optimal strategy is nearly 40% higher than the benchmark, and it produces a gain of 16.43 percentage points in annual certainty equivalent. Given the high Sharpe ratio of the strategy, the optimization picks endogenously high levels of leverage that translate into its very high mean returns.¹⁹

Adding fundamentals to this strategy does not improve it: The annual certainty equivalent increases by only 13 basis points. This is an insignificant gain because in-sample, any additional variable must always increase utility.²⁰

We have known since Meese and Rogoff (1983) that currency spot rates are nearly unpredictable by fundamentals, a result known as the “disconnect puzzle.”

¹⁷Value reversal is similar to the real exchange rate but it throws away the data with more than 5 years for each moment in time. We believe this is its crucial advantage in a sample where real exchange rates are not available for all currencies and for all periods simultaneously.

¹⁸We also tested these variables OOS (although, based on the in-sample evidence, the investor would choose not to consider them) and found that they did not add to the economic value of the strategy.

¹⁹The same strategy scaled ex post to have an average leverage of just 1 has a mean excess return of 5.27% with a standard deviation of 3.92%, both annualized.

²⁰We provide the results on statistical significance in the Internet Appendix. They confirm that in the pre-sample period carry, momentum, and value reversal are relevant for the optimization; fundamentals are not.

Gourinchas and Rey (2007) find that the current account forecasts the spot exchange rate of the U.S. dollar against a basket of currencies.²¹ But we find no evidence in the cross section that the current account is relevant at all for designing a profitable portfolio of currencies. This does not imply that fundamentals have no effect on exchange rates, only that expectations about future fundamentals are already embodied in present spot rates (see Engel and West (2005), Sarno and Schmeling (2014)), so that fundamental variables are subsumed by technical variables.

Concerning both carry variables (SIGN and FD), the correlation of their returns was only 0.46 from Feb. 1976 to Feb. 1996, a value that has not changed much since. So these two ways of implementing the carry trade are not identical, and the investor finds it optimal to use both. The SIGN variable assigns the same weight to a currency yielding 0.1% more than the U.S. dollar as to another yielding 5% more. In contrast, the FD variable assigns weights proportionally to the magnitude of the interest rate differential. Whenever the U.S. dollar interest rate is close to the extremes of the cross section, SIGN is very exposed to variations in its value, whereas FD is always dollar-neutral.

One word of caution on forward-looking bias is needed here. Our pre-sample test shows that as of 1996, some of the strategies recently proposed in the literature on currency returns would already be found to have a good performance. This is a necessary condition to assess if investors would want to use these variables in real time to build diversified currency portfolios. However, this does not tell us whether there were other investment variables that we do not test that would have seemed relevant in 1996 and resulted afterward in poor economic performance.

C. Out-of-Sample Results

We perform an OOS experiment to test the robustness of the optimal portfolio combining carry, momentum, and value strategies. The first optimal parametric portfolio is estimated using the initial 240 months of the sample. Then the model is reestimated every month, using an expanding window of data until the end of the sample. The OOS returns thus obtained minimize the problem of look-ahead bias. We do not use q and CA in the optimization, as these failed to pass the in-sample test with data until 1996.²²

The in-sample results also hold OOS. Table 2 shows that the model using interest rate variables, momentum, and value reversal achieves a certainty equivalent gain of 10.84% over the benchmark, with better kurtosis and skewness. Its Sharpe ratio is 1.15, a gain of 0.45 over the benchmark SIGN portfolio.

Transaction costs can considerably hamper the performance of an investment strategy. For example, Jegadeesh and Titman (1993) provide compelling evidence that there is momentum in stock prices, but Lesmond et al. (2004) find that after

²¹Gourinchas and Rey (2007) derive their result by making a different use of the current account information. Namely, they detrend it and also consider net foreign wealth.

²²Including fundamentals does not change the results much, as they receive little weight in the optimization.

TABLE 2
Out-of-Sample Performance

Table 2 shows the OOS performance of the investment strategies in the period Mar. 1996 to Dec. 2011 with different methods to deal with transaction costs. Panel A presents the results without considering transaction costs. Panel B takes transaction costs into consideration. Panel C excludes all currencies whenever the bid-ask spread is higher than the forward discount, then adjusts the forward discount by the transaction cost. All optimizations use a power utility function with a CRRA of 4, and the coefficients are reestimated each month using an expanding window of observations in the OOS period of Mar. 1996 to Dec. 2011. Max. and Min. are the maximum and the minimum 1-month return in the sample, respectively, expressed in percentage points. Mean is the annualized average return, in percentage points. The standard deviation (St. Dev.) and Sharpe ratio (SR) are also annualized, and Kurt. is excess kurtosis. The certainty equivalent (CE) is expressed in annual percentage points.

	Max.	Min.	Mean	St. Dev.	Kurt.	Skew	SR	CE
<i>Panel A. No Transaction Costs</i>								
FD	18.64	−29.20	21.38	24.33	2.15	−0.82	0.88	10.89
MOM	14.72	−10.03	4.97	13.29	0.57	0.04	0.37	4.39
REV	9.42	−9.67	1.69	9.50	1.42	0.23	0.18	2.84
SIGN	16.40	−21.21	15.01	21.37	1.95	−0.64	0.70	8.03
All	26.90	−22.88	38.02	32.98	0.12	−0.14	1.15	18.87
<i>Panel B. With Transaction Costs</i>								
FD	4.59	−10.92	2.80	7.40	5.01	−1.35	0.38	4.55
MOM	0.64	−1.33	−0.02	0.66	17.41	−2.43	−0.03	2.88
REV	0.00	0.00	0.00	0.00	18.62	2.06	0.05	2.91
SIGN	12.12	−16.30	8.89	15.70	2.14	−0.67	0.57	6.59
All	20.39	−18.31	19.20	22.20	0.54	−0.16	0.86	12.15
<i>Panel C. With $w_{i,t} = I_{(c_{i,t} < d_{i,t})}[\theta^T x_{i,t} / N_t]$</i>								
FD	12.83	−20.70	11.91	17.18	2.66	−0.89	0.69	8.35
MOM	6.67	−7.01	2.14	6.04	2.37	−0.07	0.35	4.33
REV	3.44	−3.84	−0.37	3.00	4.66	−0.16	−0.12	2.36
SIGN	18.10	−23.09	12.08	20.23	2.74	−0.76	0.60	5.98
All	26.70	−22.75	28.48	26.84	0.69	−0.16	1.06	16.69

taking transaction costs into consideration, there are few to no gains to be obtained in exploiting momentum.

Panel B of Table 2 shows the OOS performance of the strategies after taking transaction costs into consideration. Clearly transaction costs matter. The Sharpe ratio of the optimal strategy is reduced by 0.29, a magnitude similar to the equity premium, and the certainty equivalent drops from 18.87% to just 12.15%. Momentum and value reversal individually show no profitability at all after transaction costs. This suggests a simple explanation for the new evidence on currency return predictability: Investors could not exploit it due to transaction costs, hence its persistence. Unfortunately this explanation does not hold.

In our perspective, measuring the transaction costs of individual currency strategies, as is often done in the literature, is inadequate and overstates the importance of transaction costs. For example, say the stand-alone momentum strategy is not profitable after transaction costs, but a carry strategy is. Then the investor will want to follow the carry strategy. The relevant problem for the investor is not whether stand-alone momentum is exploitable after trading costs, but rather if using momentum on top of carry is beneficial after the *increase* in total transaction costs it implies. In practice, the momentum signal reinforces the carry signal for some currency periods, resulting in higher trading costs, but momentum offsets carry for other currency periods, decreasing transaction costs. A priori, there is no way of telling if a high-cost stand-alone strategy, such as momentum, actually results in increased costs for the investor. All depends on the interaction

between signals. The final row of Panel B in Table 2 illustrates our point. The strategy using all signals (even those that do not produce value individually after transaction costs) still results in substantial outperformance, increasing the certainty equivalent relative to the benchmark by 5.56 percentage points.²³

Furthermore, we find that transaction costs can be managed. In Panel C of Table 2 we adjust the optimization to currency- and time-specific transaction costs. We calculate a cost-adjusted interest-rate-spread variable: $\widehat{fd}_{i,t} = \text{sign}(fd_{i,t})(|fd_{i,t}| - c_{i,t})$ and standardize it in the cross section to get $\widehat{fd}_{i,t}$. We use this variable instead of $FD_{i,t}$ in the vector of currency characteristics $x_{i,t}$. We then model the parametric weight function as:

$$(9) \quad w_{i,t} = I_{(c_{i,t} < |fd_{i,t}|)} \left[\frac{\theta^T x_{i,t}}{N_t} \right],$$

where $I(\cdot)$ is the indicator function, with a value of 1 if the condition holds, and 0 otherwise. We maximize expected utility with this new portfolio policy, estimating θ after consideration of transaction costs.

This method effectively eliminates from the sample currencies with prohibitive transaction costs and reduces the exposure to those that have a high ratio of cost to forward discount. Other, more complex rules might lead to better results, but we refrain from this pursuit because this simple approach is enough to prove the point that managing transaction costs adds considerable value.

The procedure increases the Sharpe ratio of the diversified strategy from 0.86 to 1.06 and produces a gain in the certainty equivalent of 4.54% per year. This gain alone is higher than the momentum or value reversal certainty equivalents per se. Indeed, the performance of the diversified strategy with managed transaction costs is very close to the strategy in Panel A of Table 2 without transaction costs.

Managing transaction costs is particularly important because these currency strategies are leveraged. We define leverage as $L_t = \sum_{i=1}^{N_t} |w_{it}|$. This is the absolute value risked in the currency strategy per dollar invested in the risk-free asset. The optimal strategy has a mean leverage of 5.94 in the OOS period of Mar. 1996 to Dec. 2011. This means that for each US\$1 invested in the risk-free rate, the investor would be long US\$3 of some set of foreign currencies and short US\$3 of another set of currencies, approximately. As a result, a small difference in transaction costs can have a large impact in the economic performance of the strategy.

One concern in optimized portfolios is whether in-sample overfitting leads to unstable and erratic coefficients OOS. Timing different investment styles is specially challenging. For instance, Levich and Pojarliev (2008), (2011) find that although currency managers show some timing ability within their specific investment strategy, they shift erratically across styles without any particular skill. In the Internet Appendix we show that the coefficients of the optimal strategy are stable, leading to consistent exposure to the conditioning variables. Thus, the optimal diversified portfolio does not share this problem.²⁴

²³A strategy using only FD and SIGN achieves OOS a certainty equivalent of 6.21 percentage points. Hence momentum and reversal add value to the portfolio even after transaction costs.

²⁴In fact, some practitioners shared with us that what they are really interested in is finding a better method to shift across styles. For now our advice is simple: Do not!

We present and discuss the risk exposures of the optimal strategy in the Internet Appendix. The strategy is exposed to some of the risk factors proposed in the literature to explain currency returns. Namely, it is exposed to liquidity risk, innovations in foreign exchange volatility, innovations in stock volatility, stock market risk, and the HML_{FX} factor. On the other hand, it is not exposed to consumption-growth risk and innovations in transaction costs. Nevertheless, risk exposures are insufficient to explain the mean returns of the strategy, which are close to its risk-adjusted returns. Time-varying risk is also not relevant to explain the returns of the strategy. Generally, the results indicate that the optimal strategy exploits market inefficiencies rather than loading on factor risk premiums.

IV. Value to Diversified Investors

We assess whether the currency strategies are relevant for investors already exposed to the major asset classes. Indeed, there is no reason a priori that investors should restrict themselves to pure currency strategies, particularly when there are other risk factors that have consistently offered significant premiums as well.

The value of currency strategies to diversified investors holding bonds and stocks is a relatively unexplored topic. Most of the literature on the currency market has focused on currency-specific strategies.

We continue to assume that the investor optimizes power utility with a constant relative risk aversion of 4. The returns on wealth are now:

$$(10) \quad R_{p,t+1} = RF_t^{US} + \sum_{j=1}^M w_j F_j + \sum_{i=1}^{N_t} w_{i,t} r_{i,t+1} - \sum_{i=1}^{N_t} |w_{i,t}| c_{i,t},$$

where w_j is the (constant) weights on a set of M investable factors F expressed as excess returns, and $w_{i,t}$ depends on the characteristics and the θ coefficients that maximize utility jointly with w_j .

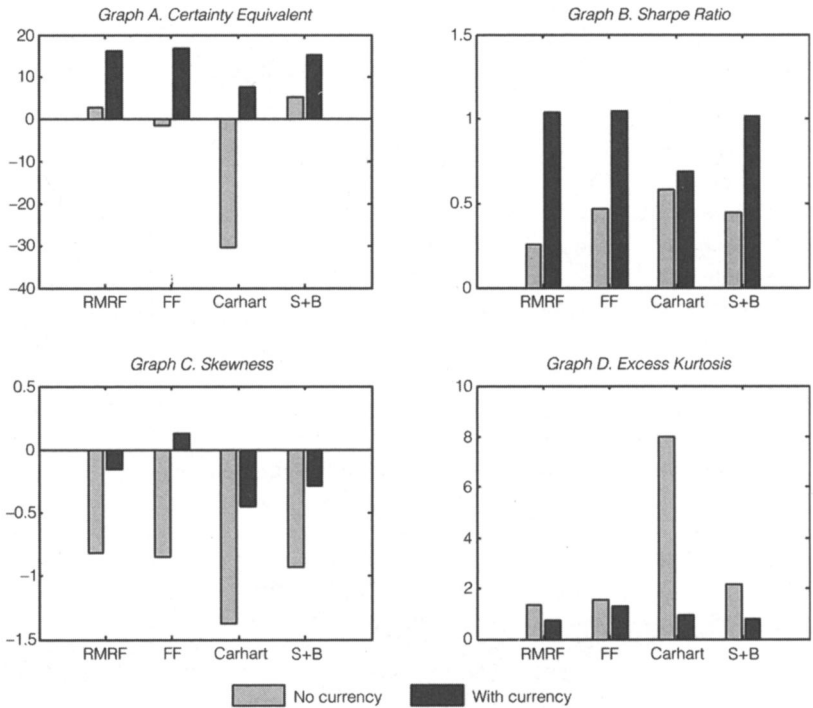
As sets of investable factors we consider the market premium (return on the stock market minus the risk-free rate (RMRF)), the Fama–French (1992) factors (RMRF, small minus big (SMB), and high minus low (HML)), and the Carhart (1997) factors consisting of the Fama–French factors and the winners-minus-losers (WML) portfolio. The currency strategy combines the interest rate spread, sign, momentum, and long-term value reversal.

Figure 1 shows the OOS performance of the optimized portfolios with and without the currency strategy.²⁵ The opportunity to invest in currencies is clearly valuable to investors. Including currencies in the portfolio always adds to the Sharpe ratio and raises the certainty equivalent. The OOS gains in certainty equivalent range are especially high for a diversified investment using the Carhart factors. This gain comes mainly from the dismal performance of stock momentum in 2009, when it experienced one of its worst crashes in history (Daniel and Moskowitz (2012), Barroso and Santa-Clara (2015)).

²⁵In the Internet Appendix we show the table with the descriptive statistics of the OOS performance.

FIGURE 1
Currencies in Diversified Portfolios

Figure 1 shows the OOS value of currency strategies for investors exposed to different background risks. Each set of columns shows the performance of an optimized portfolio with the available assets (light gray) and one that combines it with the currency strategy (dark gray). The currency strategy uses the information on the interest rate spread, sign, momentum, and reversal. The background assets are the return on the stock market minus the risk-free rate (RMRF), the Fama-French (1992) stock market factors market, size, and value (FF), these augmented with stock momentum as in Carhart (1997) (Carhart), and the return of the stock market and 10-year bonds (S+B). The OOS period is from Mar. 1996 to Dec. 2011. Results include transaction costs.



These gains are far more impressive than the gains from adding factors such as HML and SMB to the stock market. Indeed, only the inclusion of bonds improves upon the certainty equivalent of the stock market OOS. Generally, the inclusion of SMB, HML, and WML factors improves Sharpe ratios, but this increase is offset by higher drawdowns, resulting in lower certainty equivalents.

Including currencies, however, leads to substantial gains. The relevance of the interest rate spread, currency momentum, and long-term value reversal to forecast currency returns makes all conventional risk premiums seem small in comparison. Including currencies produces increases in the Sharpe ratio of approximately 0.5 on average.

One possible justification for the higher Sharpe ratios obtainable by investing in currencies is that these might entail a higher crash risk, as Brunnermeier et al. (2008) show for the carry trade. But diversified currency strategies do not conform to this explanation. Graphs C and D in Figure 1 show how complementing a portfolio policy with investments in the currency market reduces substantially the excess kurtosis and left-skewness of diversified portfolios.

Our results make it hard to reconcile the economic value of currency investing with the existence of some set of risk factors that drives returns in currencies and other asset classes. The substantial increases in Sharpe ratios combined with the lower crash risk indicate that there is either a specific set of risk factors in the currency market or that currency returns have been anomalous throughout our sample.

V. Speculative Capital

We cannot justify the profitability of our currency strategy as compensation for risk. The obvious alternative explanation is market inefficiency. This might persist due to insufficient arbitrage capital, possibly because strategies exploring the cross section of currency returns were not well known or because of barriers to entry such as specific trading platforms, bank relationships, and human capital expertise (Levich and Pojarliev (2012)). This argument is consistent with the adaptive markets hypothesis of Lo (2004). This hypothesis argues that it takes time for arbitrageurs to gather enough capital to fully exploit one source of anomalous risk-adjusted returns. As such, an anomaly can persist for some time, even if not indefinitely.

Jylhä and Suominen (2011) find that carry returns explain hedge fund returns even after controlling for the other factors proposed by Fung and Hsieh (2004), and that growth in hedge fund speculative capital is driving carry trade profits down. Neely, Weller, and Ulrich (2009) document a similar decline over time of the profitability of technical trading analysis rules in the currency market.

We run an ordinary least squares (OLS) regression of the returns of the optimal strategy on hedge fund assets under management scaled by the monetary aggregate M2 of the 11 currencies in their sample ($AUM/M2$) and new fund flows ($\Delta AUM/M2$).²⁶ The regression uses the OOS returns, after transaction costs, of the optimal strategy from Mar. 1996 to Dec. 2008 as the dependent variable. The estimated coefficients (and t -statistics in parentheses) are:

$$r_{p,t} = 0.08 - 1.47(AUM/M2)_{t-1} + 3.56(\Delta AUM/M2)_t.$$

(4.29) (-3.23) (0.36)

The R^2 of the regression is 6.5%. The new flow of capital to hedge funds is not significant in the regression, but the estimated coefficient has the correct sign. The level of hedge fund capital predicts negatively the returns of the optimal strategy. With a t -statistic of -3.23 , this provides supportive evidence that the returns of the diversified currency strategy are an anomaly that is gradually being corrected as more hedge fund capital exploits it.²⁷ This result supports the adaptive markets hypothesis of Lo (2004) in the currency market and complements the existing evidence of Neely et al. (2009) and Jylhä and Suominen (2011).

²⁶ We thank Matti Suominen for providing us the time series of $AUM/M2$. See Jylhä and Suominen (2011) for a more detailed description of the data.

²⁷ The significance of the coefficient of $AUM/M2$ is robust to the inclusion of a time variable in the right-hand side. So this result cannot be attributed to a mere trend effect.

This opens the question of whether the large returns of the strategy are likely to continue going forward. We note that in the last 3 years of our sample (2009–2011) the strategy produces a Sharpe ratio of 0.82, lower than its historical average but still an impressive performance (although not much different from the stock market in the same period).

VI. Conclusion

Diversified currency investments using the information of momentum, yield differential, and value reversal outperform the carry trade substantially. This out-performance materializes in a higher Sharpe ratio and in less severe drawdowns, as value reversal and momentum had large positive returns when the carry trade crashed. The performance of our optimal currency strategy poses a problem to peso explanations of currency returns.

Our optimal currency portfolio picks stable coefficients for the relevant currency characteristics and adds more value by dealing with transaction costs.

The economic performance of the optimal currency portfolio cannot be explained by risk factors or time-varying risk. This suggests market inefficiency or, at least, that the right risk factors to explain currency momentum and value-reversal returns have not been identified yet.

Investing in currencies significantly improves the performance of diversified portfolios already exposed to stocks and bonds. Thus, currencies either offer exposure to some set of unknown risk factors or have anomalous returns.

The most plausible explanation for the returns of our optimal diversified currency portfolio is that it constitutes an anomaly, one that is being gradually arbitrated away as speculative capital increases in the foreign exchange market. This is consistent with the adaptive markets hypothesis of Lo (2004).

By using new optimization technology on old currency data, we show that the puzzles in the currency market are too deep (and the economic performance of the resulting strategy too impressive) to support a risk-based explanation.

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