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Positive Mean Currency Returns

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In this paper, we report evidence that mean currency returns are positive for both a domestic investor in a foreign currency and a foreign investor in a domestic currency. A shared currency gain creates a positive volatility factor for both. Volatility dominates other return determinants that have opposite impacts on an exchange rate and its inverse to produce positive average returns we find in excess of one percent per annum. Positive mean currency returns impact the global asset allocation of investors to accumulate to a large fraction of wealth creation over time. Currency returns are also large given the a priori *expectation of investors that they average to zero.*

Keywords: Currency Returns, Siegel Hypothesis

JEL Classification: G11, G15

I. Introduction

In this paper, we report evidence that mean currency returns are positive for both a domestic investor in a foreign currency and a foreign investor in a domestic currency despite the fact that changes in an exchange rate and its inverse relate negatively so that a gain to one is a loss to the other. In testing this provocative hypothesis, we find currency returns have a positive volatility-factor from a shared gain in opposing currencies (Siegel, 1972; Black, 1989 and 1990). Volatility dominates other return determinants that have opposite impacts on an exchange rate and its inverse to produce positive average returns that we find in excess of one percent per annum. The shared currency gain arises from convexity of the inverse exchange rate that converts a foreign back to a domestic currency and gives investors downside protection from adverse deviations. Since both have this "put" feature, we also report evidence of positive return skewness for both domestic and foreign investors.

Whether one percent is high or low depends upon one's perspective. It is unlikely high for speculative currency strategies not often profitable after transactions costs (Burnside *et al.*, 2007; Bacchetta and van Wincoop, 2010). On the other hand, most investors earn a currency return passively in conjunction with an unhedged foreign financial or business investment. The foreign return on the primary investment compensates investors for the time value of money, asset risk, and local inflation. For investors willing to bear the transactions costs of currency exchange in any

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event for business reasons, one percent per annum beyond the primary investment influences international business decisions, global asset allocation, and currency hedging. Currency returns are also large given the *a priori* expectation of investors that they equal zero. Frankel (1993) argues that Siegel's hypothesis (Siegel, 1972) is a mathematical inconvenience that is neither economically nor empirically significant. Others argue that the paradox remains outstanding (Kritzman, 2000; Gandolfo, 2001). With the exchange rates of thirty-five major currencies, we find evidence of positive mean currency returns, positive return skewness, and a positive relation between returns and exchange rate volatility as predicted by the Siegel hypothesis.

The number of positive and negative signs in a time-series of currency returns is roughly equal. Downside protection makes negative returns less negative than positive returns when positive. To detect a small positive mean return, we test with many exchange rates over long periods to average the randomness. Results from averaging should not be confused with a certainty that does not exist for currency returns. Even with positive mean returns, there are long periods when realized returns have a negative impact on investor wealth (Engel and Hamilton, 1990).

Currency returns and exchange rates require distinct modeling. In international business investment, global asset allocation, and currency hedging, downside protection gives currency returns a positive mean for domestic and foreign investors. On the other hand, without downside protection, exchange rate modeling and forecasting require equal mean changes of opposite sign.

We organize the remainder of our paper as follows. Section II reviews the existing literature and discusses our contribution to it. Section III develops hypotheses. Section IV describes the data and research methods. Section V reports evidence of positive mean currency returns, positive return skewness, and a positive relation between returns and volatility for domestic and foreign investors. Section VI concludes with summary comments and suggestions for future research.

II. Literature Review

Our paper contributes to the literature on exchange rate determinants and predictability, which begins with Meese and Rogoff (1983) who argue that macro exchange rate models forecast no better than a random walk. On the other hand, uncovered interest parity (UIP) predicts that the exchange rate of a high interest rate currency depreciates relative to a low interest rate currency (Siegel, 1972; Solnik, 1987). Contrary to UIP and contrary to a random walk, Fama (1984) and Bacchetta and van Wincoop (2010) find that high interest rate currencies appreciate. Rather than a random walk, recent evidence documents positive persistence in currency returns. Engel and Hamilton (1990) reject the random walk model in favor of one with long predictable swings. Caporale and Gil-Alana (2012) find long memories in the $US/Euro and $US/Yen exchange rates. Booth *et al*. (1982) find positive memory during the flexible exchange period of 1973-1979. Gençay (1999) finds currency return improvements beyond a random walk with several technical trading rules.

Persistence is consistent with the argument of Bacchetta and van Wincoop (2010) that investors adjust their global financial asset portfolios slowly. There is little evidence of abnormal returns from speculative currency strategies based on UIP (Burnside *et al*., 2007; Bacchetta and van Wincoop, 2010), but return persistence suggests the possibility of profitable "momentum" investment strategies of the type weakly effective for common equities (Jegadeesh and Titman, 1993). In addition, there is evidence of abnormal profits from currency strategies based on filter rules and trend-following in long-run currency movements (Levich and Thomas, 1993a and 1993b; Engel and Hamilton, 1990). Taylor (1995) surveys the results of several inefficiency studies for currency markets. Our results indicate that rebalancing global portfolios for currency volatility improves the global asset allocation of investors.

In a panel analysis of daily exchange rates, we find that interest rate differences impact exchange rates as predicted by UIP, that currency returns are weakly persistent, and that volatility positively impacts currency returns as predicted by the Siegel hypothesis. The UIP result is contrary to Fama (1984) and Bacchetta and van Wincoop (2010) and indicates that even long trends in exchange rates may not be permanent. Only with many exchange rates over long periods can we average trends away for analysis. The volatility effect is sufficiently strong to dominate other return determinants that have opposite impacts on an exchange rate and its inverse to produce positive average returns.

In the international finance literature, we are the first to jointly test the hypotheses of positive currency returns, a volatility component to returns, and positive return skewness for both domestic investors in a foreign currency and foreign investors in a domestic currency.

III. Hypotheses

Consider the US dollar as the “domestic” and the UK pound as the “foreign” currency. Of course, one can switch these roles or use any other two currencies. Let ω_t be the pound cost of a dollar at time *t*, so that ω pounds buys one dollar: $\omega = \mathcal{L}/\$$. Today’s $\mathcal{L}/\$$ exchange rate is ω_0. If $\omega_t > \omega_0$, then the pound depreciates relative to the dollar so that a pound buys fewer dollars at *t* than 0.

A U.S. investor exchanges ω_0 pounds that cost a dollar today for $\omega_0/\widetilde{\omega}_t$ dollars at $t > 0$. Thus, the “dollar return” for a pound investment is,

$$\tilde{r}_{\mathcal{L}/\$} = \omega_0/\widetilde{\omega}_t - 1, \tag{1}$$

which is positive or negative as the pound appreciates ($\omega_t < \omega_0$) or depreciates ($\omega_t > \omega_0$) and is before the pound return on a U.K. financial or business investment that the U.S. investor also earns.

The dollar cost of a pound, 1/ω, in Equation (1) converts a pound back to a dollar and gives the U.S. pound investor downside protection from adverse currency deviations. Convexity of the inverse exchange rate (that is, 1/ω is a convex function of ω) means that a one percent increase in the pound cost of a dollar (a pound depreciation) decreases the dollar cost of a pound by less than one percent. For example, suppose that the pound cost of a dollar is ω_0=0.65 and that it depreciates by 1%, so that, ω_t=0.65*1.01 = 0.6565. Substitute these amounts into Equation (1) to find that the U.S. investor’s loss is less than 1%. A similar example shows that a U.K. investor in dollars has downside protection from a dollar depreciation. equations (8) and (9) formalize this phenomenon below.

A. The Null Hypothesis: The Cost of Carry Model

The cost of carry model says that if the pound interest rate exceeds the dollar interest rate ($r_{\mathcal{L}}$>$r_{\$}$.), then we expect the pound to depreciate (*dω/ω*>0). If real interest rates are the same in the two interest rates, so that pound inflation is greater, then UIP says that the pound depreciates so that goods and service costs between the two currency jurisdictions remains the same. With risk-neutrality (at least with respect to exchange rates), we expected the exchange rate change to equal the difference in the interest rates,

$$d\omega/\omega = (r_{\mathcal{L}} - r_{\$})dt + \sigma d\tilde{z}, \tag{2}$$

where $d\tilde{z}$ is a normally-distributed Gauss-Weiner increment with mean zero and variance dt so that the instantaneous variance of percentage changes in the exchange rate is $\sigma^2 dt$. Equation (2) is the pound return for dollars.

Similarly, we expect the dollar cost of a pound, $1/\omega_t$, to increase, $\frac{d(1/\omega)}{(1/\omega)}>0$, and the dollar to depreciate when the dollar interest rate exceeds the pound interest rate ($r_\$ > r_£$),

$$\frac{d(1/\omega)}{(1/\omega)} = (r_\$ - r_£)dt - \sigma d\tilde{z} \quad (3)$$

Equation (3) is the dollar return for pounds. Both the interest rate difference and the perturbation, $d\tilde{z}$, have opposite impacts on the pound cost of a dollar (ω) and the dollar cost of a pound (1/ω).

There are several empirical implications of the cost of carry model. First, if mean currency return is positive for a domestic investor in a foreign currency (Equation 3), then it is negative for the foreign investor in the domestic currency (Equation 2). Second, because the perturbation $d\tilde{z}$ has a normal distribution and is, thus, symmetric, neither the foreign return in a domestic currency nor the domestic return in the foreign currency is skewed. Further, even if the foreign return on the domestic currency has a positive skew due to $d\tilde{z}$, then the domestic return in the foreign currency has a negative skew due to $-d\tilde{z}$ and vice versa. Finally, there is no association between mean return and either the foreign return in a domestic currency or the domestic return in the foreign currency ($r_£ - r_\$$ and $r_\$ - r_£$, respectively) and currency volatility, σ^2dt.

We statistically reject all of these hypotheses in testing.

B. The Alternative Siegel Hypothesis

Presume that the exchange process ω_t follows a geometric Brownian motion,

$$\frac{d\omega}{\omega} = \mu dt + \sigma d\tilde{z} \quad (4)$$

Equation (4) is the pound return for dollars from the perspective of the U.K. investor. If there is a risk-premium for exchange rate risk, then it is contained within the parameter μ.

The inverse exchange rate, that is, the dollar cost of a pound, $1/\omega_t$, also follows a geometric Brownian motion. With Ito's lemma and Equation (4),

$$\frac{d(1/\omega)}{(1/\omega)} = -\mu dt + \sigma^2 dt - \sigma d\tilde{z} \quad (5)$$

Equation (5) is the dollar return for pounds from the perspective of the U.S. investor.

The pound return for dollars and the dollar return for pounds relate to one another in equations (4) and (5) because of stochastic calculus and not because of any pricing differences between U.S. and U.K. investors. Rather, the exchange rate between pounds and dollars is priced in a single currency market and highlights the fact that at this stage we do not presume risk-neutrality. If a risk premium has a positive impact on the expected return for a U.K. investor in dollars (μ is greater than otherwise), then it has a negative impact on the expected return for a U.S. investor in pounds (-μ is more negative than otherwise).

Add equations (4) and (5) to find that the sum of percentage changes in the pound cost of a dollar, ω, and the dollar cost of a pound, 1/ω, calculates volatility,

$$\frac{d\omega}{\omega} + \frac{d(1/\omega)}{(1/\omega)} = \sigma^2 dt > 0 \quad (6)$$

The sum of the foreign investor's return in the domestic currency and the domestic investor's return in the foreign currency is positive and riskless. Every instant, there is positive riskless currency gain that depends solely on volatility, σ^2, which is the Siegel (1972) paradox that Kritzman (2000) identifies as a prominent finance puzzle. The reason that the currency gain is positive and riskless is that any exchange deviation, $\sigma d\tilde{z}$, is to the detriment of the domestic investor in the foreign currency or vice versa. Convexity of the inverse exchange rate gives the injured investor downside protection, which is equal for the opposite party in the vice versa case. Because one or the other gets the same protection, the gain in aggregate is riskless and, thus, we can *calculate* realized currency volatility, σ^2, on the right of Equation (6).

Because the currency gain in Equation (6) is non-stochastic (it depends upon *dt* only), it is a component of the drift μdt in equations (4) and (5), which means that it is shared between the domestic investor in the foreign currency and the foreign investor in the domestic currency. The perturbation $\sigma d\tilde{z}$ is normally distributed (symmetric, in particular) and, thus, downside protection accrues half the time to the U.S. pound investor and half the time to the U.K. dollar investor. This sharing is consistent with the observation that the number of positive and negative signs in a time-series of currency returns is roughly equal. It is also within the arbitrage bounds of McCulloch (1975) and Roper (1975).

With risk-neutrality (at least with respect to exchange rates) and UIP, the drift μ is the difference in interest rates plus half the currency gain,

$$\mu = r_{£} - r_{\$} + ½\,\sigma^2 \tag{7}$$

Substitute Equation (7) into equations (4) and (5) to find the percentage changes in the pound cost of a dollar, ω, and the dollar cost of a pound, 1/ω,

$$\frac{d\omega}{\omega} = (r_{£} - r_{\$})dt + ½\,\sigma^2 dt + \sigma d\tilde{z}, \tag{8}$$

$$\frac{d(1/\omega)}{(1/\omega)} = (r_{\$} - r_{£})dt + ½\,\sigma^2 dt - \sigma d\tilde{z} \tag{9}$$

The interest-rate differential, $(r_{\$} - r_{£})$, and the random increment, $d\tilde{z}$, have opposite impacts on the pound cost of a dollar, ω and the dollar cost of a pound, $1/\omega$, but volatility, σ^2, impacts both positively and by the same amount: $½\,\sigma^2 dt$. Equation (9) is the domestic investor's return on a foreign currency and Equation (8) is the foreign investor's return on a domestic currency. The only distinction in pricing between the foreign cost of a domestic currency (ω) and the domestic cost of a foreign currency (1/ω) is that both the foreign and the domestic investor expect downside protection from adverse currency deviations in the amount $½\,\sigma^2 dt$, which is common in the drifts of equations (8) and (9). Downside protection increases with volatility, $\sigma^2 dt$.

C. Empirical Predictions of the Siegel Hypothesis

We investigate three empirical implications of the Siegel hypothesis. First, one of the interest rate differences in equation (8) or (9) is positive and the other negative. However, if volatility, σ^2, is sufficiently great, it offsets the negative differential and, in this case, mean currency return is positive for both for a domestic investor in a foreign currency (Equation 9) and a foreign investor in a domestic currency (Equation 8).

Second, over a *dt* holding-period, volatility, σ^2, is constant so that currency returns in equations (8) and (9) are normally distributed and, thus, without skewness. However, if volatility varies over time (that is, 0 to *t*), then a time-series of measured returns each with a *dt* holding period is positively skewed. When volatility is temporally low, not only is expected return low but, also, the likelihood of especially negative returns is low because low volatility does not allow them (or high positive returns either but we are concerned with negative returns in this instance). On the other hand, when volatility is high, not only is expected return high but, also, the likelihood of exceptionally high positive returns is high because high volatility promotes them (with high expected return, we are interested in positive returns). Muted negative returns when expected return is low and accentuated positive returns when expected return is high represents downside protection from adverse currency deviations and imparts a positive skewness to a time-series of currency returns. Thus, we expect positive return skewness both for a domestic investor in a foreign currency (Equation 9) and a foreign investor in a domestic currency (Equation 8).

Third, downside protection from adverse currency deviations takes form in equations (8) and (9) as a positive relation with volatility. Thus, we expect a positive relation between currency returns and volatility, $\sigma^2 dt$, for both a foreign investor in a domestic currency and a domestic investor in a foreign currency.

D. Cost of Carry Versus the Siegel Hypothesis

The cost of carry model does not incorporate the shared currency gain and, thus, without downside protection and with homogeneous expectations, exchange rate forecasting with equations (2) and (3) is alike for a foreign and a domestic investor. On the other hand, the currency return processes in equations (8) and (9) are distinct (even inversely) because both a domestic and a foreign investor have downside protection. This protection manifests itself as drift terms that are not the negative of one another. We present mutually supporting and consistent empirical results that strongly favor the Siegel hypothesis over the cost of carry model (the null hypothesis), which supports our contention that currency returns contain downside protection. The shared currency gain in Equation (6) is the source of this better empirical support.

Our results are important even if one is interested in an exchange rate process for forecasting rather than a currency return process for investing. The exchange rate drift parameters in equations (2) and (3) are a subset of the currency return drift parameters in equations (8) and (9). Estimating the impact of interest rate differences in equations (2) and (3) on percentage exchange rate changes has a missing variable bias without the volatility factor in equations (8) and (9). Only a currency return process permits unbiased tests of UIP and other asset-pricing hypotheses.

IV. Data and Research Methods

Our tests use thirty-four daily exchange rates listed in Table 1 for widely traded currencies versus the US dollar between January 4, 1971 and December 31, 2014 from the U.S. Federal Reserve's release H.10 available from Wharton's Research Data Service (WRDS) for noon New York buying rates for cable transfers in foreign currencies. We construct a set of 584 exchange rate time-series and a second set of 584 inverse exchange rate time-series. There are 35*34/2-11=584 exchange rate pairs (an exchange rate and its inverse). The "11" in this calculation is the number of former European currencies that stopped trading at year-end 1998 with the introduction of the euro.[1] We calculate the bulk of these 584 exchange rate pairs as cross-rates from Table 1. Using the currencies in Table 1, we match the first currency ($US as domestic) with each subsequent currency down to the euro (as foreign). Then, with the second currency (AUD as domestic) we match with each subsequent currency down to the euro again. We continue in a like manner until complete.

The purpose of this exchange rate and inverse exchange rate construction is to give no preference to any currency in our study. We report all results for both domestic investors in a foreign currency and foreign investors in a domestic currency. Essentially identical results in

[1] The Greek drachma traded until 2000 when Greece joined the euro-zone but the drachma/euro series is too short to be useful for testing.

paired testing is strong evidence for the Siegel hypothesis when the cost of carry model suggests that exchange rate determinants have opposite impacts for domestic and foreign investor returns. We recognize cross-sectional residual dependence across exchange rates with methodologies we discuss below. Equation (1) calculates daily currency returns (with the identity of currencies appropriately adjusted).

Table 1: Exchange Rates

	Country and Currency	Data Beginning	Data Ending
1	Australia (AUD/US$)	01-04-1971	12-31-2014
2	Brazil (Real/US$)	01-02-1995	12-31-2014
3	Canada (Can$/US$)	01-04-1971	12-31-2014
4	People's Republic of China (Yuan/US$)	01-02-1981	12-31-2014
5	Denmark (Krone/US$)	01-04-1971	12-31-2014
6	Hong Kong (Dollar/US$)	01-02-1981	12-31-2014
7	India (Rupee/US$)	01-02-1973	12-31-2014
8	Japan (Yen/US$)	01-04-1971	12-31-2014
9	South Korea (Won/US$)	04-13-1981	12-31-2014
10	Malaysia (Ringgit/US$)	01-04-1971	12-31-2014
11	Mexico (New Peso/US$)	11-08-1993	12-31-2014
12	New Zealand (NZ Dollar/US$)	01-04-1971	12-31-2014
13	Norway (Krone/US$)	01-04-1971	12-31-2014
14	Singapore (Dollar/US$)	01-02-1981	12-31-2014
15	South Africa (Rand/US$)	01-04-1971	12-31-2014
16	Sri Lanka (Rupee/US$)	01-02-1973	12-31-2014
17	Sweden (Krona/US$)	01-04-1971	12-31-2014
18	Switzerland (Franc/US$)	01-04-1971	12-31-2014
19	Taiwan (Dollar/US$)	10-03-1983	12-31-2014
20	Thailand (Baht/US$)	01-02-1981	12-31-2014
21	United Kingdom (Pound/US$)	01-04-1971	12-31-2014
22	Venezuela (Bolivar/US$)	01-02-1995	12-31-2014
23	Austria (Schilling/US$)	01-04-1971	12-31-1998
24	Belgium (Franc/US$)	01-04-1971	12-31-1998
25	Finland (Markka/US$)	01-04-1971	12-31-1998
26	France (Franc/US$)	01-04-1971	12-31-1998
27	Germany (D Mark/US$)	01-04-1971	12-31-1998
28	Greece (Drachma/US$)	04-13-1981	12-29-2000
29	Ireland (Pound/US$)	01-04-1971	12-31-1998
30	Italy (Lira/US$)	01-04-1971	12-31-1998
31	Netherlands (Guilder/US$)	01-04-1971	12-31-1998
32	Portugal (Escudo/US$)	01-02-1973	12-31-1998
33	Spain (Pesata/US$)	01-02-1973	12-31-1998
34	European Monetary Union (Euro/US$)	01-04-1999	12-31-2014

V. Results

A. Positive Mean Currency Returns

We describe the first set of 584 exchange rates for reporting in the first column of Table 2 as the domestic (D) return on a foreign currency (F), $\tilde{r}_{(F|D)_{k,t}}$, and the set of 584 inverse exchange rates for the second column as the foreign return on a domestic currency, $\tilde{r}_{(D|F)_{k,t}}$. The subscripts $(F|D)_{k,t}$ and $(D|F)_{k,t}$ represent the k'th of 584 exchange rates (and inverse rates) at trading day t for the domestic investor in the foreign currency$(F|D)$ and the foreign investor in the domestic currency $(D|F)$. There are 11,081 daily returns between January 1971 and December 2014. The total number of currency returns over all days and over all exchange rates is 3,908,487, which is less than 11,081×584 because not all exchange rates have a full time-series.

The upper panel of Table 2 reports pooled averages of currency returns $\tilde{r}_{(F|D)_{k,t}}$ and $\tilde{r}_{(D|F)_{k,t}}$ over all 3,908,487 days, the time-series average of the 11,081 cross-sectional average daily currency returns, and the cross-sectional average of the 584 time-series average daily currency returns. Consistent with the hypothesis that mean currency returns are positive, all six average currency returns are positive and all but one is statistically significant.

The cost of carry model says that if the currency return of a domestic investor in a foreign currency is positive, then the foreign investor return in the domestic currency is negative, which means currency returns are *always* of opposite sign. Thus, even though one of the mean returns in Table 2 is insignificant statistically, it still supports the Siegel hypothesis beyond its *t*-statistic because it is positive when the inverse mean return is also positive (and significant). Further, if an exchange rate trends greatly over a time series (from perturbations in equations 8 and 9), then the temporal average return for the domestic investor in the foreign currency and the foreign investor in the domestic currency are of opposite sign. Thus, to assess the impact of downside protection on currency returns we average away long trends with many exchange rates over long periods. In so doing, we find 95 of 584 exchange rates for which the temporal mean daily return for a domestic investor in a foreign currency and its inverse pair are both positive.

Since our choice of a currency return for the Foreign/Domestic rather than the Domestic/Foreign column is arbitrary (and vice versa), a reasonable interpretation of the paired results in Table 2 is that an investor is equally likely to have a currency return from either column. While we cannot combine tests because the columns are not statistically independent, we can combine columns to better gauge average currency returns. The annualized average of the 3,908,487 pooled foreign/domestic and domestic/foreign currency returns ($\tilde{r}_{(F|D)_{k,t}}$ and $\tilde{r}_{(D|F)_{k,t}}$) is 251.8*(0.000042+0.000047)/2 = 1.12% per annum (251.8 is the average number of trading days per annum from 1971 to 2014). The temporal average of 11,081 cross-sectional average currency returns is 251.8*(0.000035+0.000058)/2 = 1.17% per annum. The cross-sectional average of 584 temporal average currency returns is 251.8*(0.000085+0.000027)/2 = 1.4% per annum. In each case, the average currency return is more than one percent per annum.

Table 2: Daily Currency Returns for Thirty Five Currencies

	Foreign/Domestic			Domestic/Foreign		
	Pooled	Cross-Sectional	Time Series	Pooled	Cross-Sectional	Time Series
Average	0.000042	0.000035	0.000085	0.000047	0.000058	0.000027
Standard Error	0.000005	0.000025	0.000013	0.000005	0.000026	0.000014
t-statistics for average	8.08	1.37	6.73	8.87	2.21	1.98
% Positive	48.8%	49.8%	59.9%	49.2%	51.0%	53.8%
Minimum	-0.7024	-0.0466	-0.0005	-0.7049	-0.0464	-0.0009
Maximum	2.3892	0.1833	0.0016	2.3604	0.1825	0.0013
Observations	3,908,487	11,081	584	3,908,487	11,081	584
Skewness	72.915	0.027	4.319	73.661	0.033	1.740
Standard Error		0.005381	0.509281		0.005381	0.473787
t-statistics for skewness		5.03	8.48		6.06	3.67
% Positive		52.3%	64.0%		52.8%	56.7%
Minimum		-5.8303	-53.1896		-15.2823	-35.8860
Maximum		15.4629	49.4461		6.4468	67.0005

Notes: The left panel reports returns for 584 exchange rates as the domestic (D) return on the foreign currency (F), $\tilde{r}_{(F|D)_{k,t}}$. The right column reports returns for the second set of 584 exchange rates as the foreign (F) currency return on the domestic (D) currency, $\tilde{r}_{(D|F)_{k,t}}$. There are 11,081 daily currency returns between January 1971 and December 2014. The total number of currency returns over all days and over all exchange rates is 3,908,487. The cross-sectional average of currency returns are $\bar{r}_{(F|D)_t} = \sum_{k=1}^{N_t} \tilde{r}_{(F|D)_{k,t}}/N_t$ and $\bar{r}_{(D|F)_t} = \sum_{k=1}^{N_t} \tilde{r}_{(D|F)_{k,t}}/N_t$, t=1,2,…,11,081. The upper and lower panel report, respectively, the temporal average and the temporal skewness of these cross-sectional averages (skewness is the sum of cubed deviations from the mean over the time-series divided by the cube of the standard deviation times one minus the number of days 11,081-1). The time-series average of currency returns for exchange rate k=1,2,…,584 are $\bar{r}_{(F|D)_k} = \sum_{k=1}^{T_k} \tilde{r}_{(F|D)_{k,t}}/T_k$ and $\bar{r}_{(D|F)_k} = \sum_{k=1}^{T_k} \tilde{r}_{(D|F)_{k,t}}/T_k$. The upper and lower panel report, respectively, the cross-sectional average and the cross-sectional skewness of these temporal averages.

B. Positively Skewed Currency Returns

Our second hypothesis is that currency returns are positively skewed because of downside protection for both a domestic investor in a foreign currency and a foreign investor in a domestic currency.

The lower panel of Table 2 reports skewness[2] of $\tilde{r}_{(F|D)_{k,t}}$ and $\tilde{r}_{(D|F)_{k,t}}$ over all 3,908,487 daily currency returns, skewness of the 11,081 cross-sectional average daily currency returns, and skewness of the 584 time-series average currency returns.

Each skewness measure is positive and statistically significant. Averaging over exchange rates and over time removes the negative relation in equations (4) and (5) between the domestic return on a foreign currency, $\tilde{r}_{(F|D)_{k,t}}$, and the foreign return on a domestic currency, $\tilde{r}_{(D|F)_{k,t}}$ that arises from the drift μ and the random increment $\sigma d\tilde{z}$ that otherwise induce skewness of opposite sign. Since volatility is the only positive determinant of both returns, our interpretation of positive skewness is that it arises from volatility. Evidence of positive return skewness is supporting evidence also for positive average currency returns because the source of both is downside protection from adverse currency deviations.

C. A Positive Relation Between Currency Returns and Volatility

Our third hypothesis is that the relation between currency returns and return volatility is positive for domestic investors in a foreign currency and foreign investors in a domestic currency. The panel analysis below accounts for cross-sectional correlation in exchange rates.

Table 3: One Month Maturity Riskless Interest Rates

	Data Beginning	**Data Ending**
US Dollar 1Month Deposit (FT/TR) - Middle Rate	01-02-1975	12-31-2014
TR Australian Dollar 1 Month Deposit - Middle Rate	09-27-1988	12-31-2014
BRL Cash Deposit 1 Month (TP) - Middle Rate	06-30-2006	12-31-2014
Canadian Dollar 1 Month Deposit (FT/TR) - Middle Rate	01-02-1975	12-31-2014
Chi Interbank 1 Month - Offered Rate	01-09-2002	12-31-2014
Danish Krone 1 Month Deposit (FT/TR) - Middle Rate	06-14-1985	12-31-2014
Hong Kong Interbank 1 Month - Offered Rate	06-04-1990	12-31-2014
Inr 1 Month Mibor Avg Fix-Fbil - Middle Rate	12-01-1998	12-31-2014
Japanese Yen 1 Month Deposit (FT/TR) - Middle Rate	08-01-1978	12-31-2014
South Korea Ibk. 1 Month Seoul - Offered Rate	07-26-2004	12-31-2014
Malaysia Deposit 1 Month - Middle Rate	07-15-1982	12-31-2014
Tr Mx (Mxd) 1 Month Irs 130M - Middle Rate	07-17-2003	12-31-2014
Tr New Zealand $ 1 Month Deposit - Middle Rate	09-27-1988	12-31-2014

[2] Skewness is the sum of cubed current return deviations from the mean divided by the product of the sample size less one times the cube of the sample standard deviation. For example, for $\tilde{r}_{(F|D)_{k,t}}$, skewness is $sk_{(F|D)} =$ $\left(\sum_j^{3,908,487}\left(\tilde{r}_{(F|D)_j} - \bar{r}_{(F|D)}\right)^3 / (3,908,487-1) * \sigma^3_{(F|D)}\right)$, where, $\sigma_{(F|D)} = \sqrt{\left(\sum_j^{3,908,487}\left(\tilde{r}_{(F|D)_j} - \bar{r}_{(F|D)}\right)^2 / (3,908,487-1)\right)}$

Table 3: One Month Maturity Riskless Interest Rates: Continues

	Data Beginning	Data Ending
TR Norwegian Krone 1 Month Deposit - Middle Rate	01-09-1995	12-31-2014
Singapore Dollar 1 Month Deposit (TR/TP) - Middle Rate	01-04-1988	12-31-2014
S African Rand 1 Month Deposit (TR/TP) - Middle Rate	04-01-1997	12-31-2014
Sri Lanka Interbank 1 Month - Middle Rate	01-03-2000	12-31-2014
Tr Swedish Kro 1 Month Deposit - Middle Rate	01-09-1995	12-31-2014
Swiss Franc 1 Month Deposit (FT/TR) - Middle Rate	01-02-1975	12-31-2014
Taiwan Deposit 1 Month - Middle Rate	08-08-1989	12-31-2014
Thailand Interbank 1 Month (Bb) - Offered Rate	01-07-1992	12-31-2014
U.K. Sterling 1 Month Deposit (FT/TR) - Middle Rate	01-02-1975	12-31-2014
Venezuela 30-Day Deposit Rate - Middle Rate	01-02-1997	12-31-2014
Oe 1 Month Vibor Delayed See Eibor 1 Month - Offered	06-10-1991	12-31-1998
Bg Eu- Franc 1 Month Deposit (FT/TR) - Middle Rate	06-05-1978	12-31-1998
Fn 1 Month Intbk Delayed See Eibor1 Month - Offered	01-02-1987	12-31-1998
Fr Eu-Franc 1 Month Deposit (FT/TR) - Middle Rate	01-02-1975	12-31-1998
Bd Eu-Mark 1 Month Deposit (FT/TR) - Middle Rate	01-02-1975	12-31-1998
Greece Deposit 1 Month - Middle Rate	01-25-1994	12-29-2000
Ir 1 Month Intbk Delayed See Eibor 1 Month - Offered	01-20-1984	12-31-1998
It Eu-Lira 1 Month Deposit (FT/TR) - Middle Rate	06-09-1978	12-31-1998
Netherland Euro-Gldr 1 Month (Icap/TR) - Middle Rate	01-09-1995	12-31-1998
Pt Eu-Escudo 1 Month Deposit (FT/TR) - Middle Rate	11-16-1992	12-31-1998
Es Eu-Peseta 1 Month Deposit (FT/TR) - Middle Rate	04-02-1992	12-31-1998
Euro 1 Month Deposit (FT/TR) - Middle Rate	01-04-1999	12-31-2014

We investigate three primary currency return determinants: interest rate differences between currencies of an exchange rate, lagged currency returns, and currency-volatility. For all currencies in Table 1, we retrieve local one-month maturity interest rates from Datastream (Thomson Financial). Table 3 gives a short description of each rate and the beginning and end-dates for each. Because even the longest interest-rate time-series is shorter than for the exchange rates in Table 1, the panel regression for currency returns in Table 4 has fewer daily observations than in Table 2.

Table 4: Panel Analysis of Daily Currency Returns with Two-Way Clustered SE

Explanatory Variable	Domestic Return on a Foreign Currency, $\tilde{r}_{F\|D}$		Foreign Return on a Domestic Currency, $\tilde{r}_{D\|F}$	
Lagged Currency Return	-0.4285 (-1.70)	-0.4286 (-1.70)	-0.1153 (-2.29)	-0.1153 (-2.29)
Dummy Variate for First Sub-Period times Lagged Currency Return	0.4310 (1.71)	0.4312 (1.71)	0.1182 (2.23)	0.1182 (2.23)
Interest Rate Differential	-0.0442 (-2.86)	-0.0493 (-2.87)	-0.0347 (-3.46)	-0.0387 (-3.48)
Dummy Variate for First Sub-Period times Interest Rate Differential		0.0505 (2.59)		0.0399 (2.76)
Currency Volatility	0.7072 (2.75)	0.7073 (2.75)	0.5479 (5.65)	0.5479 (5.65)
Dummy Variate for First Sub-Period times Currency Volatility		-1.1604 (-0.54)		0.9046 (0.42)
R^2	24%	24%	18%	18%
Pooled Daily Observations	1,774,013			

Notes: Coefficient *t*-statistics in parentheses use robust two-way clustered standard-errors. The lagged currency return adjusts for autocorrelation. Currency volatility adjusts for heteroscedasticity. $\tilde{r}_{(F|D)_{k,t}}$ is the return on foreign currency F in a domestic-currency D. $\tilde{r}_{(D|F)_{k,t}}$ is the return on a domestic currency in foreign currency. The interest rate differential, $\Delta i_{(F|D)_{k,t}}$ is the difference in riskless interest rates (foreign minus domestic, i_F-i_D, in the F/D case and i_D-i_F in the D/F case). Currency-volatility for day *t* is from Equation (6). The panel of data is k=1,2,..,584 exchange rates and up to t=1,2,…,10,051 trading-days from January 1975 to December 2014. The first sub-period is January 1975 to December 1991.

To test for return persistence, we use lagged currency return as an explanatory variable. In addition, to test for a differential in return persistence between earlier and later sub-periods (January 1975-December 1991 and January 1992-December 2014) and the Pukthuanthong-Le *et al*. (2007) hypothesis that the efficiency of currency markets has improved over time, we include a dummy variable for the first sub-period times lagged currency return as an explanatory variable. As a test of UIP, we include the contemporaneous interest rate differential as a third explanatory variable. When the domestic (D) return on a foreign currency (F), $\tilde{r}_{(F|D)_{k,t}}$, is the dependent variable, the interest rate differential is the foreign less the domestic interest rate and, thus, UIP predicts that the coefficient on the interest rate differential should be negative. When the foreign interest rate is high, the foreign currency depreciates to generate a negative return for a domestic investor. Alternatively, when the dependent variable is the foreign currency return on a domestic currency, $\tilde{r}_{(D|F)_{k,t}}$, the interest rate differential is the domestic less the foreign interest rate and, again, the test of UIP is that the coefficient on the interest rate differential is negative. Currency volatility (daily return variance) calculated with Equation (6) is the final explanatory variable. Equations (8) and (9) indicate that a volatility factor prevents a missing-variable mis-specification in our test of the economic determinants of currency returns.

We regress currency returns on lagged currency return, the interest rate differential, and currency-volatility. For the domestic return on a foreign currency, the regression is,

$$\tilde{r}_{(F|D)_{k,t}} = \alpha_1 \cdot \tilde{r}_{(F|D)_{k,t-1}} + \alpha_2 \cdot \left(d \cdot \tilde{r}_{(F|D)_{k,t-1}}\right) + \alpha_3 \cdot \Delta i_{(F|D)_{k,t}} + \alpha_4 \cdot \sigma^2_{(F|D)_{k,t}} + \varepsilon_{k,t}, \quad (10)$$

where $\tilde{r}_{(F|D)_{k,t}}$ is the return on foreign currency F in units of a domestic currency D for the k'th exchange rate, k=1,2,…,584, $\tilde{r}_{(F|D)_{k,t-1}}$ is the lagged currency return, d is a dummy variable that takes a value of one if the return is in the first sub-period January 1975 to December 1991, $\Delta i_{(F|D)_{k,t}}$ is the difference in riskless interest rates (foreign minus domestic) associated with the k'th exchange rate, $\sigma^2_{(F|D)_{k,t}}$ is currency-volatility for period t.

The coefficient α_1 measures return-persistence in the sub-period January 1992 to December 2014. The sum of coefficients $\alpha_1+\alpha_2$ measures return-persistence for January 1975 to December 1991. Equivalently, the parameter α_2 measures the differential in return-persistence between the first and second sub-periods. The regression for the foreign return on a domestic currency is equivalent to Equation (10) but with *F/D* rather than *D/F*.

Because the null hypothesis is that currency markets are informationally efficient, our expectation is that both α_1 and α_2 are zero: the return for currencies that have recently appreciated or depreciated is the same and this is true regardless of the sub-period. UIP predicts that α_3 should be negative: currency returns for high interest rate currencies should be negative. Equations (8) and (9) predict that α_4 should be positive because volatility increases currency returns.

D. Panel Regression Results for the Relation Between Currency Returns and Volatility

Table 4 reports panel regression estimates of the model in Equation (10). Petersen (2009) shows that *t*-statistics calculated with two-way clustered standard-errors account for times-series residual dependence and are robust to heteroscedasticity.

The estimate of α_1 is negative and weakly statistically significant (at 10%) for both the foreign return on a domestic currency, $\tilde{r}_{(D|F)}$ and the domestic return on a foreign currency, $\tilde{r}_{(F|D)}$. Rather than positive persistence, this is evidence of a daily reversal in currency returns for the second sub-period (January 1992-December 2014). The estimate of α_2 is positive and weakly statistically significant (at 10%) for the foreign return on a domestic currency, $\tilde{r}_{(D|F)}$ and the domestic return on a foreign currency, $\tilde{r}_{(F|D)}$. Since, $\alpha_1+\alpha_2$ is close to zero, this is evidence that daily return reversals did not exist in the first sub-period (January 1975-December 1991).

The estimate of α_3 is negative for both the domestic return on a foreign currency, $\tilde{r}_{(F|D)}$, and the foreign return on a domestic currency, $\tilde{r}_{(D|F)}$, and in both cases the estimate is statistically significant. Consistent with UIP, higher interest rates in one currency jurisdiction relative to another is associated with a depreciation in the exchange rate of the former relative to the latter.

The estimate of α_4 is positive and statistically significant for the domestic return on a foreign currency, $\tilde{r}_{(F|D)}$, and the foreign return on a domestic currency, $\tilde{r}_{(D|F)}$, which is consistent with the hypothesis that there is a positive relation between currency returns and currency volatility. This result is consistent with our argument that a positive volatility-factor is the source of positive returns and positive return skewness we report in Table 2.

Beyond relations in Equation (10), the second set of panel regressions in Table 4 test for differential relations between the two sub-periods (January 1975-December 1991 and January 1992-December 2014) for currency returns versus interest rate differences and return volatility.

The evidence is that in the second sub-period (January 1992-December 2014), the interest rate difference has the impact predicted by UIP, whereas, in the first sub-period (January 1975-December 1991), there is no relation. This set of results is consistent with the hypothesis of Pukthuanthong-Le *et al*. (2007) that the informational efficiency of exchange rate markets has improved in recent years.

There is no evidence of a sub-period difference in the relation between currency returns and volatility, which is supporting evidence for the Siegel hypothesis. Relations between currency returns and lagged currency returns and currency returns and interest rate differences depend upon exchange rate pricing by individuals in currency markets that possibly change over time with their skill and understanding. On the other hand, the Siegel hypothesis arises from downside protection from adverse currency deviations due to convexity of the inverse exchange rate. Since this is a mechanistic rather than a pricing phenomenon, we do not expect the relation between currency returns and volatility to change over time.

VI. Conclusion

In this paper, we report evidence that currency returns are positive for both a domestic investor in a foreign currency and a foreign investor in a domestic currency. A positive relation between currency returns and volatility generates positive average returns in excess of one percent per annum. Volatility as a return factor arises from downside protection from adverse deviations that global investors in opposing currencies share from convexity of the inverse exchange rate.

Frankel (1993) argues that the Siegel paradox is a mathematical inconvenience that is neither economically nor empirically significant. We present mutually supporting and consistent empirical results that strongly favor the Siegel hypothesis over the cost of carry model for exchange rates. Sharing the currency gain between a domestic and a foreign investor captures downside protection from adverse currency deviations and is the source of better empirical support.

Is the Siegel hypothesis economically significant? We believe that a one percent currency return beyond a primary foreign investment is enough to influence international business decisions, global asset allocation, and currency hedging. If the performance of a globally diversified financial-asset portfolio improves using currency volatility as a predictor of future unhedged currency returns, then the Siegel hypothesis is economically significant.

The analysis and methods of our paper have application beyond currencies when the holding period rate return on an asset requires an inverse function. Examples including a barrel of oil/$US or an ounce of gold/$US. Because the value of a bond is the discounted value of fixed future coupons and par-value at the yield to maturity, bond owners have downside protection from interest rate deviations that adversely impact the yield.

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