The Uncovered Interest Rate Parity Puzzle in the Foreign Exchange Market

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Abstract. This paper focuses on the theory of uncovered interest rate parity and whether interest-rate differentials have resulted in the higher interest rate currency depreciating over time. Previous literature has empirically rejected the theory indicating that higher interest rate currencies have actually appreciated relative to lower interest rate currencies. In this paper, uncovered interest rate parity is examined from 1992 to 2005 for the Pound sterling-US dollar, Pound sterling-Japanese yen and Pound sterling-Australian dollar currency pairs. A component GARCH model explicitly controls for short-term and long-term volatility and estimates positive slope coefficients, thus supporting the theory of uncovered interest rate parity and a depreciating relationship. This paper also confirms the extreme sampling hypothesis that large interest-rate differentials have a greater effect on currency movements than small differentials.

JEL classification: C58; E43; F31; G12
Keywords: Asymmetric Leverage Effect; Carry Trade; Extreme Sampling; Missed Expectations Problem; Peso Problem; Volatility Clustering

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1 Introduction

Foreign exchange trading gave rise to the theory of interest rate parity, which relates the difference between foreign and domestic interest rates with the difference in spot and future exchange rates. This parity condition states that the domestic interest rate should equal the foreign interest rate plus the expected change of the exchange rates. If investors are risk-neutral and have rational expectations, the future exchange rate should perfectly adjust given the present interest-rate differential. For example, assume the differential between one-year dollar and pound interest rates is five percent with the pound being higher. Risk neutral, rational investors would expect the pound to depreciate by five percent over one year thereby equalizing the returns on dollar and pound deposits. If the exchange rate did not adjust, then arbitrage opportunities would exist. Consequently, the current forward rate should reflect this interest-rate differential as a forward contract locks in the future exchange rate. However, assume an investor speculates the future exchange rate will depreciate by only four percent – even though the interest-rate differential and the quoted forward rate indicates the pound will depreciate by five percent. Assuming their forecast is correct, the investor could earn the entire one percent profit by not entering into a forward contract; hence, interest rate parity without a forward contract to hedge exchange rate risk is known as uncovered interest rate parity ("UIP").

If interest rate parity holds true, investors will be indifferent to interest rates in two countries whether the position is covered or uncovered as the exchange rate adjusted return will be the same. The future exchange rate should depreciate by exactly the interest-rate differential. If covered and uncovered interest rate parity both hold, this implies the forward rate is an unbiased predictor of the future spot rate. In the case of covered interest rate parity, the domestic interest rate, r_t, is represented as:

$$r_t = r_t^* + f_t - s_t \tag{1}$$

where r_t^* is the foreign interest rate, f_t is the forward rate and s_t is the current spot rate. Unlike covered interest parity with an available forward rate, UIP is more difficult to test as, "expectations of future exchange rates are not directly observable" (Isard 1996). Accordingly, UIP operates under the assumption that the current forward rate will equal the expected exchange rate plus a forecast error defined as:

$$f_t = E(s_{t+1}) + \varepsilon_{t+1} \tag{2}$$

Hence equation (1) can be rewritten as:

$$r_t = r_t^* + s_{t+1} - s_t + \varepsilon_{t+1} \tag{3}$$

or rearranged as:

$$s_{t+1} - s_t = r_t - r_t^* + \varepsilon_{t+1} \tag{4}$$

Economists assess the validity of the UIP condition by empirically estimating the parameter values of α and β in the form:

$$s_{t+1} - s_t = \alpha_0 + \beta_1(r_t - r_t^*) + \varepsilon_{t+1} \tag{5}$$

Assuming rational expectations in exchange markets and risk-neutrality amongst investors, α_0 should equal zero. This implies the absence of a constant risk premium, therefore β should equal one; in turn, this implies a perfect depreciating relationship according to UIP. UIP stipulates that as the interest-rate differential increases, the exchange rate should equally depreciate. For example, if the foreign interest rate is one percent higher than the domestic interest rate for a one-year sovereign bond, the foreign currency is expected to depreciate by one percent after one year. Interest rate parity helps balance exchange rates as this would lead to arbitrage since both domestic and foreign investors would not want to hold lower interest rate assets unless the currency is expected to appreciate.

The problem is that UIP does not hold well empirically. In fact, past research has illustrated that higher interest rate currencies actually appreciate relative to lower interest rate currencies. Economists have found that β changes drastically across sub-time intervals in both sign and value with recurrent findings that beta has an approximate value of negative one. This negative β can be interpreted as a perfect appreciating relationship, completely contradictory to UIP. This uncovered interest rate parity puzzle asserts that UIP is historically rejected using empirical evidence for various currencies across different time periods. This failure in UIP has enticed investors to capture excess returns in the foreign exchange market via carry trades – returns that can be substantial depending on the amount of leverage raised per trade. If investors believe that the expected excess return is defined as:

$$r_t - (r_t^* + s_{t+1} - s_t) > 0 \qquad (6)$$

then they will exploit this opportunity.

A more sophisticated approach to model these expected excess returns and deviations from UIP would have a profound influence across both the financial services industry and global economic policy. Possible explanations for deviations from UIP include a failure of the rational expectations assumption and the existence of a time-varying risk premium that equals the difference between the actual and expected deprecation rate. Contrary to the UIP assumption of risk-neutrality, investors are typically risk-averse, and the forward rate will equal the expected future spot rate plus a risk premium to compensate for an uncovered position (Chinn and Meredith 2005). The risk premium is suggested to be "part of the OLS residuals and its correlation with the exchange rate change causes the estimated beta coefficient to be biased"

(Ghoshray, Li and Morley 2011). Other possible explanations include the peso problem, which refers to the time when the Mexican peso "sold at a forward discount for a prolonged period prior to its widely anticipated devaluation in 1976" (Fama 1984). The forward rate became a biased predictor for data samples that included the pre-devaluation period.

In order to test the UIP hypothesis, this paper will analyze the Pound sterling-US dollar, Pound sterling-Japanese yen and Pound sterling-Australian dollar currency pairs. Excluding the Euro, these four currencies are the highest traded currencies by value in the foreign exchange market. The Euro would be favorable in analyzing UIP; however, the timeframe of this paper begins as of 1992 and the Euro was only established in 2002. This paper will examine UIP from 1992 to 2005 whereas most of the previous literature has focused on UIP immediately after the Nixon Shock when the dollar became fiat currency. In 1971, the Bretton Woods system came to an end, and by March 1976 all major currencies were floating. However, as will be discussed in the literature review, each country in the currency pairs underwent regime changes with policy shifts throughout the following years. There was a period characterized by substantial inflation, tighter monetary policy and heightened skepticism even following elections. This is suggested to have skewed previous UIP research due to a missed expectation problem as investors failed to recognize these regime shifts for an extended period of time. Previous literature attributes this as the reason beta in equation (5) is empirically negative and then turns positive during the 1990s. Consequently, the selected time frame of 1992 to 2005 should not encounter this issue.

The next section defines key terminology integrated in this paper and provides precise descriptions critical to the analysis of UIP. Section 3 reviews the literature on uncovered interest rate parity and explains how this paper will contribute to the literature. Section 4 examines the models used in analyzing UIP and details how β is calculated in each methodology. Section 5 describes the data set that is used. Section 6 illustrates the results of the regressions along with an analysis of the coefficients. Section 7 concludes.

2 Terminology

Asymmetric Leverage Effect: *Unexpected domestic exchange rate deprecation has a greater impact on short-term volatility than unexpected domestic exchange rate appreciation due to volatility clustering*

Carry Trade: *A strategy in which an investor sells a currency with a low interest rate and raises leverage to purchase a different currency with a higher interest rate in order to profit from the interest-rate differential*

Extreme Sampling: *Regressions run conditional on the absolute magnitude of a signal, specifically interest-rate differentials, being large*

Missed Expectations Problem: *When a regime or policy switch occurs but investors fail to realize it for an extended period of time*

Peso Problem: *When a sample period appears flawed as investors anticipate a future event that only materializes after the sample period has ended*

Volatility Clustering: *The cyclical process in which unexpected depreciation is more likely to be followed by higher volatility, which in turn is more likely to be accompanied by unexpected depreciation suggesting clusters of large volatilities*

3 Literature Review

3.1 Uncovered Interest-Rate Parity over the Past Two Centuries

"Uncovered Interest-Rate Parity over the Past Two Centuries" (Lothian and Wu 2005) examines the forward premium puzzle using a variety of regression methods analyzing an ultra-long time series that spans two centuries. In doing so, the authors attempt to ensure their tests will not be subject to "local features of a short sample period" (Lothian and Wu 2005). These local features include peso problems and missed expectations, by which Lothian and Wu suggest previous research has been biased. The authors recognize that many previous analyses were conducted during the 1970s and 1980s when there was a tighter monetary policy shift after a period of substantial inflation.

The authors address these common issues by using a long investment horizon and long time periods. They use an ultra-long time series from 1803 to 1999 for the US dollar-Pound sterling and French franc-Pound sterling currency pairs. This paper will instead analyze the Pound sterling-US dollar, Pound sterling-Japanese yen and Pound sterling-Australian dollar currency pairs. Previous literature calculates beta becomes positive again during the 1990s after adjusting for the problems in the 1970s and 1980s. Consequently, a selected time frame of 1992 to 2005 should not encounter these issues and instead contribute to a more focused analysis.

Lothian and Wu use multiple regression methodologies to analyze the slope coefficient including a forward premium regression of deprecation rates on nominal interest-rate differentials, rolling forward premium regression and extreme sampling regressions. First, they conduct a forward premium regression of depreciation rates on nominal interest-rate differentials using equation (5). This yields positive slope estimates over the whole period in support of UIP with beta only becoming negative during the 1980s. In fact, the slope coefficient for the francsterling currency pair is not statistically different from one and α_0 is not statistically different from zero illustrating the forward premium puzzle disappears over an ultra-long sample period.

The authors continue with a rolling forward premium regression fixing the end period of 1999 but moving the starting period progressively forward from 1802 to 1989. This regression strongly supports UIP with β becoming negative in the 1970's and 1980's similar to the base regression as a result of strong policy shifts. However, this regression was used to illustrate how these years influence the slope coefficient, and since the selected time period of 1992-2005 excludes this era, it will not be included. Lothian and Wu also conduct a sub-period analysis for robustness, which illustrates that β is volatile across sub-periods (1800-1913, 1914-1949, 1950-1999). This volatility highlights the disadvantages of using a short time-span; however, given the time period covered by this paper, this analysis will not be necessary. In addition, the authors suggest to separate small and large interest-rate differentials using a method called extreme sampling. They hypothesize that small interest-rate differentials may be tolerated in the market and would not induce any significant movement in the exchange rate (Lothian and Wu 2005). Conversely, they suggest large interest-rate differentials are less likely to continue without inducing movements in the exchange rate. By separating out the differentials based on magnitude, the results indicate that large differentials have more significant forecasting power on currency movements.

Despite the authors' contribution in supporting the validity of UIP, using an ultra-long time series spanning two centuries has multiple underlying limitations. The interest rates were acquired from multiple data sources for each individual currency, and characteristics such as maturity and interest rate classification are inconsistent across these sources. This variety of sources could skew the results, and slopes that were calculated using the regressions might not be completely accurate. Also, these findings may not be significantly insightful by not directly adjusting for historical events including two world wars, the Great Depression, the gold standard, the Bretton Woods system, and the Nixon Shock. Consistent data is available for the period between 1992 and 2005, and UIP regressions should avoid both the peso problem and missed expectations. The comparability of bonds, including maturity and classification, are vital to analyze UIP accurately and any deviation in the data can bias results. While all four countries selected in this paper did incur recessions between 1992 and 2005, market participants are assumed to have adjusted interest rates and the exchange rate to account for this.

3.2 Time-Varying Heteroskedasticity

"Uncovered Interest Parity and the Risk Premium" by Atanu Ghoshray, Dandan Li and Bruce Morley analyzes a highly cited time-varying risk premium, which the authors suggest has biased the estimated beta coefficient in previous research. Several research articles have assumed a constant risk premium, α_0, in equation (5) but Ghoshray, Li and Morley hypothesize the existence of a time-varying risk premium as proposed by Fama. The authors use a component GARCH model (CGARCH), which not only controls for time-varying heteroskedasticity but also distinguishes between long-run volatility trends and short-run deviations from that trend (Ghoshray, Li and Morley 2011).

Engle and Lee first proposed the CGARCH model, which separates long-run trends and short-term deviations, and extends it by controlling for the asymmetric leverage effect (Engle and Lee 1999). This effect states that unexpected domestic exchange rate deprecation has a greater impact on short-term volatility than unexpected domestic exchange rate appreciation. This is due to volatility clustering as unexpected depreciation is more likely to be followed by higher volatility, which in turn is more likely to be accompanied by unexpected depreciation. This cyclical process suggests clusters of large volatilities. On the other hand, unexpected appreciation is less likely to be followed by increased volatility suggesting lower tendencies of clusters of small volatilities (Ning, Wirjanto and Xu 2010). The CGARCH model can control for this asymmetric effect.

The authors conclude that the CGARCH model is significant for most countries and that it makes the β coefficient more significant than in the basic OLS model of equation (5). The model also uncovers that the permanent shocks to macroeconomic fundamentals has the greatest effect, relative to transitory short-term components. This discovery is crucial in analyzing UIP as most previous research has included a significant historical event in the data sample (e.g. financial crises). Financial crises also occur during this paper's time period of 1992 to 2005, and consequently contain changes to permanent and transitory volatility. To account for this, CGARCH controls for these events and yields an unbiased β coefficient.

Nevertheless, the main limitation in this literature is the data set, which ranges from 1986 to 2009. This time period is exposed to the peso problem and missed expectations as per Lothian and Wu's theory and also includes the beginning years of the 2008 financial crisis. The CGARCH model should, in theory, adjust for this recession by controlling for constant and heteroskedastic variances. However, there could exist a peso problem leading up to as well as during the crisis and overall the recession introduces excess volatility that may skew results. The selected time period from 1992 to 2005 should avoid this increased volatility along with the 1970s/80s peso and missed expectation problems.

4 Methodology

4.1 Forward Premium Regression

As equation (5) is the base model for UIP, the forward premium regression will be included in the scope of this paper. The results of this regression shall provide as a comparison for the other models and highlight their specific contributions towards econometric analysis of uncovered interest rate parity.

4.2 Extreme Sampling

Extreme sampling is conducted by running a regression conditional on data with large interest-rate differentials above the 90th percentile. The theory behind this methodology is that small interest-rate differentials do not have a significant impact on exchange rates as the market naturally adjusts. Large interest-rate differentials are hypothesized to greatly influence the exchange rate over time. The regression:

$$s_{t+1} - s_t = \alpha_0 + \beta^S(r_t - r_t^*) + \beta^L(r_t - r_t^* - ||dr||)I_{t\epsilon L} + \varepsilon_{t+1} \quad (7)$$

is similar to equation (5) with one added complexity. The regression separates small (S) and large (L) absolute realizations of the nominal interest-rate differential. The regression sorts the absolute values from the 90th percentile to the 99th percentile and increases the cutoff percentile, $||dr||$. $I_{t\epsilon L}$ is an indicator variable which equals one if the differential is larger than the cutoff percentile and zero otherwise. Lothian and Wu compute that β_S decreases towards zero as the percentile increases, and β_L increases towards 2.4 and 1.2 for the French franc-Pound sterling and US dollar-Pound sterling pairs, respectively. These findings indicate that large interest-rate differentials have greater forecasting power on currency movements than small interest-rate differentials. This model provides a vital understanding in analyzing the dynamic forces behind uncovered interest rate parity and will be included in the analysis.

4.3 Asymmetric CGARCH Model

The asymmetric CGARCH model incorporates an additional complexity to equation (5) by better modeling the heteroskedastic variance where σ_{t+1} represents a time-dependent standard deviation bounded by these sets of equations:

$$\sigma_{t+1}^2 = q_{t+1} + \left(\varphi_4 + \varphi_5(\varepsilon_t < 0)\right)(\varepsilon_t^2 - q_t) + \varphi_6(\sigma_t^2 - q_t) \tag{8}$$

$$q_{t+1} = \varphi_1 + \varphi_2(q_t - \varphi_1) + \varphi_3(\varepsilon_t^2 - \sigma_t^2) \tag{9}$$

where equation (9) reflects permanent volatility and equation (8) adds on transient short-term volatility. q_{t+1} is the long-run component of the conditional variance reflecting shocks to macroeconomic fundamentals. φ_1 represents constant permanent volatility and φ_2 is an autoregressive term. φ_3 shows how shocks affect the permanent component of volatility (Ghoshray, Li and Morley 2011). φ_6 is the transient risk autoregressive term while φ_4 and φ_5 represent shocks to short term volatility. $\left(\varphi_4 + \varphi_5(\varepsilon_t < 0)\right)$ adds on an asymmetric coefficient, φ_5, to help identify if there exists a leverage effect for negative residuals. $\varepsilon_{t+1} < 0$ is interpreted as an unexpected domestic exchange rate appreciation while $\varepsilon_{t+1} > 0$ is interpreted as an unexpected domestic exchange rate depreciation. The reason for distinguishing between these is due to the asymmetric effect, which suggests that past unexpected depreciation increases volatility greater than unexpected appreciation due to volatility clustering. The sign of φ_5 will be negative assuming this leverage effect holds empirically. Thus, if there is no leverage effect, then the impact of unexpected depreciation on short-term volatility is given by φ_4 (Guimarães, Kriljenko, Ishii and Karacadag 2006). By incorporating all of these factors, equation (8) controls for heteroskedasticity and consequently yields an unbiased β coefficient.

5 Data Construction

The data set consists of daily observations of Pound sterling-US dollar, Pound sterling-Japanese yen and Pound sterling-Australian dollar exchange rates as well as two-year sovereign interest rates between 1992 and 2005.* Figure 1 plots the three exchange rate series. The effect of Black Wednesday is illustrated by the sharp decrease in the exchange rates in 1992. The Pound sterling-Japanese yen rate recovers, but declines again in 1998 due to the Asian Financial Crisis. Additionally, Figure 2 plots the interest rates for each country. The United States interest rate is fairly consistent excluding the decrease in 2000 due to the Dot-com Bubble. As illustrated in Figure 2, Japan experienced depressed interest rates following the country's asset price bubble collapse referred to as the Lost Decade.

Table 1 reports the summary statistics of the exchange rates and interest rates. From 1992 to 2005, the Pound sterling appreciated relative to all three currencies. The Pound appreciated about 1.008 percent per two years against the US dollar, 0.527 percent per two years against the Japanese yen and 0.433 percent per two years against the Australian dollar. On average, the US two-year treasury rate was 1.294 percent lower than the UK gilt interest rate, the Japanese interest rate was 4.911 percent lower and the Australian interest rate was about 0.018 percent higher. Most data have close to zero kurtosis and skewness values indicating that the overall data have normally distributions and are not skewed. The only noticeable value is the kurtosis of the UK-US interest differential of 3.161, which indicates that the distribution

* Historical exchange rates and interest rates are sourced from Bloomberg

is slightly flatter than normal. This, however, is still low and should not adversely affect the results.

6 Uncovered Interest-Rate Parity Regressions

6.1 Forward Premium Regression

Based on equation (5), the forward premium regression of deprecation rates on nominal interest-rate differentials is conducted on the three currency pairs as reported in Table 2. In contrast to most previous literature, the regression slope estimates for the Pound sterling-US dollar and Pound sterling-Japanese yen are -0.340 and 0.640, respectively. These coefficients are statistically different from both zero and positive one, which does not support the UIP theory of a perfect depreciating relationship. For the Pound sterling-Australian dollar pair, the null hypothesis of β_1 = -1 cannot be rejected, thus supporting previous research in which a perfect appreciating relationship is calculated to exist. While α_0 is statistically different from zero for all three currency pairs, all of the values are very close to zero which largely supports UIP and the absence of a constant risk premium. The null hypothesis of $\beta_1 = 1$ can be rejected for the Pound sterling-Japanese yen pair; however, the value of 0.640 is positive contrary to most previous literature and within approximately two standard deviations of positive one. While all three currency pairs yielded different results, none of them confirmed the theory of a perfect depreciating relationship in which β_1 should equal positive one. This suggests that further investigation needs to be explored; regardless, these regression slopes have a high probability of supporting the UIP theory, provided that more accurate econometric analysis is explored.

6.2 Extreme Sampling

Extreme sampling is conducted by running a regression conditional on data with large interest-rate differentials above the 90th percentile. Equation (8) is run based on the different percentile criteria. Specifically, the 90th percentile of the interest-rate differential is identified and any differential below this cutoff is deemed as "small". Conversely, any differential above is classified as "large". After the regression is run, this process is repeated for increasing percentile cutoffs up to the 99th percentile. Table 3 reports the regression estimates based on these increasing percentile criteria. Each currency pair is displayed and for each estimate (β^S and β^L), the left column reports the calculated coefficient while the right column reports its standard error in parenthesis. On the right-hand side, $||dr||$ reports the cutoff interest-rate differential that corresponds to each percentile proceeded by the R^2 value.

For the Pound sterling-US dollar currency pair, the estimate for β^S progressively declines while the coefficient for β^L becomes more positive and significant. At the 90th percentile, β^S = -0.288 and is significant at the one percent level while β^L is not statistically different from zero running against the extreme sampling theory. However, similar to the findings of Lothian and Wu, β^L becomes increasingly positive and more significant. At the 99th percentile, β^L = 2.220 while β^S = -0.389, and even though β^S is still significant, β^L clearly has a greater impact on exchange rate fluctuations. Overall, α_0 for the currency pair is statistically insignificant indicating the absence of a constant risk premium, validating the UIP theory from 1992-2005 for long-term sovereign interest rates.

The Pound sterling-Japanese yen currency pair greater supports the extreme sampling hypothesis where the estimate for β^S becomes closer to zero while the coefficient for β^L becomes increasingly positive. At the 90th percentile, β^S = -0.229, which is significant at the 10% level, while β^L = 1.341, and is statistically significant at the 1% level. These findings support the extreme sampling hypothesis and β^L becomes increasingly positive as the percentile cutoff increases. At the 99th percentile, $\beta^L = 3.306$ while β^S is insignificant. β^L can be observed to have a greater impact on exchange rate fluctuations, hence it has more significant forecasting power than smaller differentials for the GBP-JPY currency pair. Similar to the GBP-USD pair, α_0 is again statistically insignificant, indicating the absence of a constant risk premium. These findings greatly support the extreme sampling hypothesis that larger interest-rate differentials have a greater effect on exchange rate fluctuations from 1992 to 2005 for long-term sovereign interest rates.

The Pound sterling-Australian dollar currency pair also supports the extreme sampling hypothesis where the estimate for β^S is near zero while the coefficient for β^L becomes increasingly positive. At the 90th percentile, both β^S and β^L are insignificant, which goes against the extreme sampling hypothesis. However, β^L becomes increasingly positive as the percentile cutoff increases and quickly becomes significant. At the 99th percentile, $\beta^L = 1.789$, which clearly supports the hypothesis and has a greater impact on exchange rate fluctuations than β^S which only equals -0.177. α_0 is again statistically insignificant indicating the absence of a constant risk premium for all three currency pairs using the extreme sampling technique.

The phenomenon of extreme sampling can be vividly captured by the graphics in Figure 3, in which the three currency pairs are plotted using a solid line for β^L and a dashed line for β^S. In all three images, the slopes for β^L greatly increases as the percentile cutoff becomes more stringent, confirming the extreme sampling hypothesis such that large interest-rate differentials have a bigger impact on currency movements. While Lothian and Wu illustrate extreme sampling using two centuries worth of inconsistent data, this paper validates the hypothesis using comparable information from the same source. As the percentiles increase the R^2 values also improve; similar to previous research, however, the overall forecasting power of interest-rate differentials on exchange rates remains extremely small. The R^2 values only equal 1.8%, 1.0% and 0.4% for the GBP-USD, GBP-JPY and GBP-AUD currency pairs, respectively.

6.3 Asymmetric CGARCH Regression

The asymmetric CGARCH model incorporates an additional complexity to equation (5) by better modeling the heteroskedastic variance. Table 4 illustrates the estimated risk-adjusted coefficients which result from an asymmetric CGARCH model versus the normal homoskedastic error assumption of equation (5). As highlighted in Table 4, the β slope coefficients for all three currency pairs are positive and significant at the 1% level. β equals 0.146 in the case of the GBP-USD pair and 0.684 in the case of the GBP-JPY pair. For the GBP-AUD currency pair, the slope coefficient is not statistically different from one directly supporting UIP. For all three currency pairs, α_0 is statistically significant at the 1% level; however, the value is near zero for all three again supporting the UIP theory. For an asymmetric effect to exist, φ_5 must be negative and significant, which would indicate that past unexpected depreciation increases volatility greater than unexpected appreciation. φ_5 is calculated to be negative for only the GBP-AUD currency pair, except the coefficient is not significant. This indicates that there is no leverage effect from 1992-2005 for long-term sovereign interest-rate differentials on exchange rate movements.

6.4 CGARCH Regression

Since the coefficient for the leverage effect is not significant, the CGARCH model is calculated again without this threshold in order to better calculate unbiased β slope coefficients. As illustrated in Table 5, β slope coefficients for all three currency pairs are still positive and significant at the 1% level. The slope coefficient for the GBP-USD and GBP-JPY pairs respectively equal 0.438 and 1.983 greatly supporting UIP, albeit not perfectly. However, the coefficient for GBP-AUD is not statistically different from positive one, indicating a perfect depreciating relationship as UIP suggests. α_0 for all three currency pairs are near zero, further supporting the absence of a constant risk premium. For the GBP-USD currency pair, φ_1 is near zero indicating extremely small constant permanent volatility, and φ_2 is very close to one, indicating that long term volatility is largely autoregressive in nature. The other two currency pairs further support this as $\varphi_2 = 1.000$ for both of them. $\varphi_1 = 0.236$ for the GBP-AUD pair; φ_1 is not statistically different from zero for the GBP-JPY pair. Furthermore, φ_3 is equal to 0.543, 0.598 and 0.710 for the GBP-USD, GBP-JPY and GBP-AUD pairs respectively, indicating shocks have had a large effect on long-term volatility similar to the findings by Ghoshray, Li and Morley. φ_5 equals 0.565, 0.644 and 0.762 for the currency pairs indicative of a strong autoregressive relationship, albeit not as perfectly correlated as long term volatility. This is expected considering short-term variance should be more volatile than in the long-term. The coefficients for φ_4 are significant but less than each individual coefficient for φ_3, which indicates that shocks have a greater lasting effect on long-term volatility than short-term volatility. Overall, the model for the CGARCH regression appears to yield more significant results when excluding the asymmetric effect. Thus, these results confirm the absence of a leverage effect from 1992 to 2005 on exchange rate fluctuations from long-term sovereign interest rates differentials and support the theory of uncovered interest rate parity.

7 Conclusion

Uncovered interest rate parity is a vital theory suggesting that countries with high nominal interest rates should experience a depreciating currency relative to countries with relatively lower interest rates. The prevailing issue is that UIP does not hold well empirically, and past research has illustrated that higher interest rate currencies actually appreciate relative to lower interest rate currencies.

The main finding of this paper is that the UIP – when calculated using the base regression model of equation (5) – falsely assumes homoskedasticity and yields biased slope coefficients. Using a CGARCH regression, long-term and short-term volatility is explicitly controlled for and the slope coefficients are calculated to be positive. These findings directly support the principle of UIP and provide validity to the theory that countries with higher interest-rate differentials experience depreciating currencies. Moreover, the CGARCH model outperforms the asymmetric CGARCH regression illustrating the absence of a leverage effect for the selected time period of 1992 to 2005. This paper also uncovers that large interest-rate differentials have a greater effect on exchange rate movements than smaller ones, which confirms Lothian and Wu's study. However the main contribution of this paper is that comparable, consistent data was utilized in confirming the extreme sampling hypothesis.

While these findings are favorable, uncovered interest rate parity does have its limitations in overall predictive performance and explanatory power. A line for further research is to directly control for monetary policy in the CGARCH model for a larger sample of currency pairs. This could validate the existence of a leverage effect, but the overall sample time period should be restricted from 1992 to 2005. This would help avoid possible peso and missed expectation problems from skewing the slope coefficient. A sub-period analysis could also be preformed across multiple timespans between 1992 and 2005 to compare this paper's findings relative to shorter time horizons. Regardless, as uncovered interest rate parity offers a theoretical bedrock for international finance and monetary policy, further research must bridge the gap between modern interest-rate differentials and future exchange rate fluctuations.

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Appendix: Exchange Rates

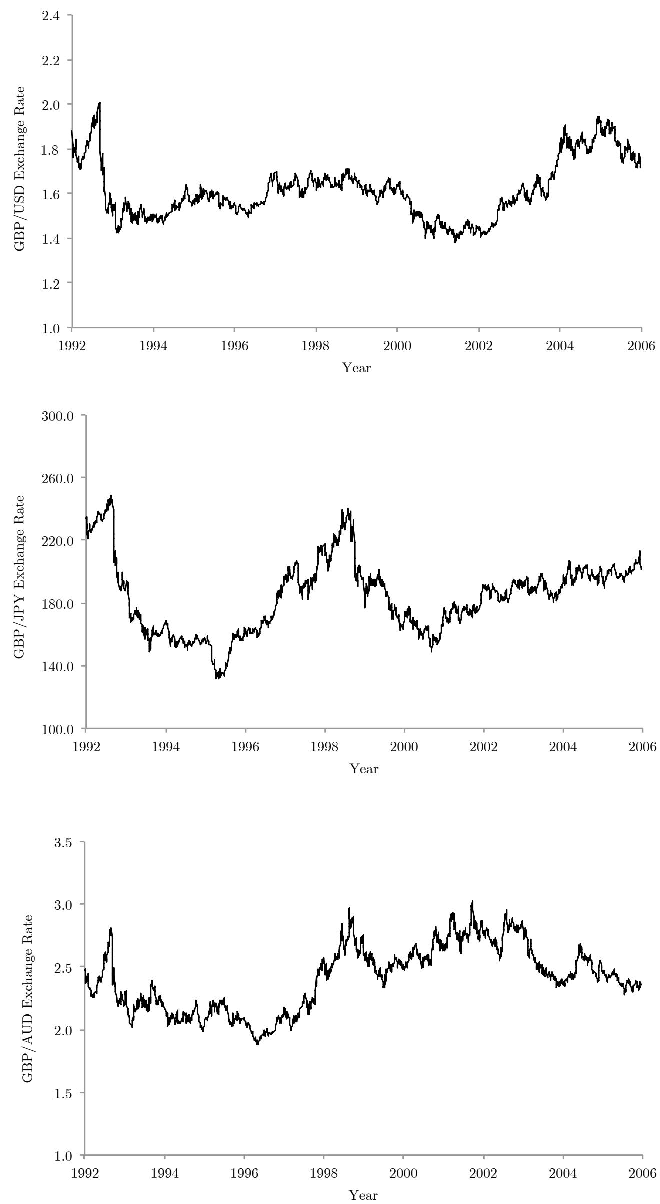

Figure 1. Exchange rates from 1992-2005 for the Pound sterling-US dollar, Pound sterling-Japanese yen and Pound sterling-Australian dollar currency pairs. Source: Bloomberg.

Appendix: Interest Rates

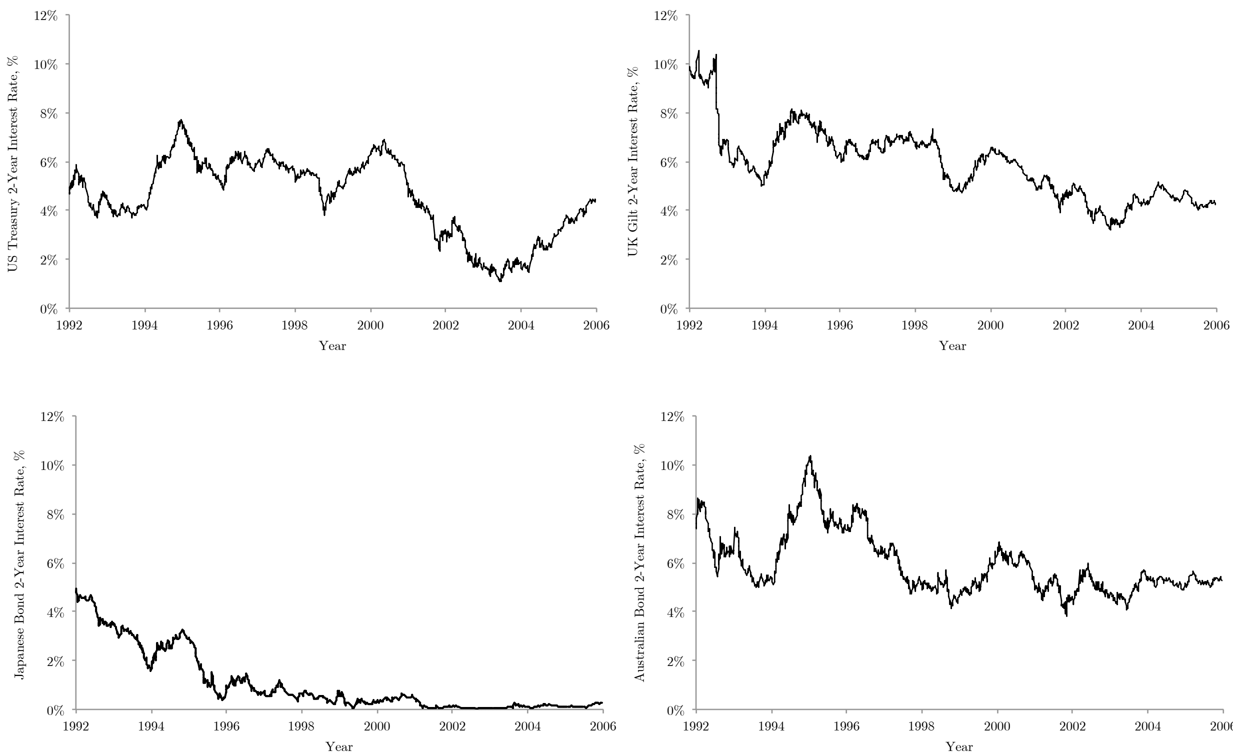

Figure 2. Nominal sovereign interest rates from 1992 – 2005 for 2 year US Treasuries, UK Gilts, Japanese and Australian Government Bonds. Source: Bloomberg.

Appendix: Extreme Sampling Regression Slopes

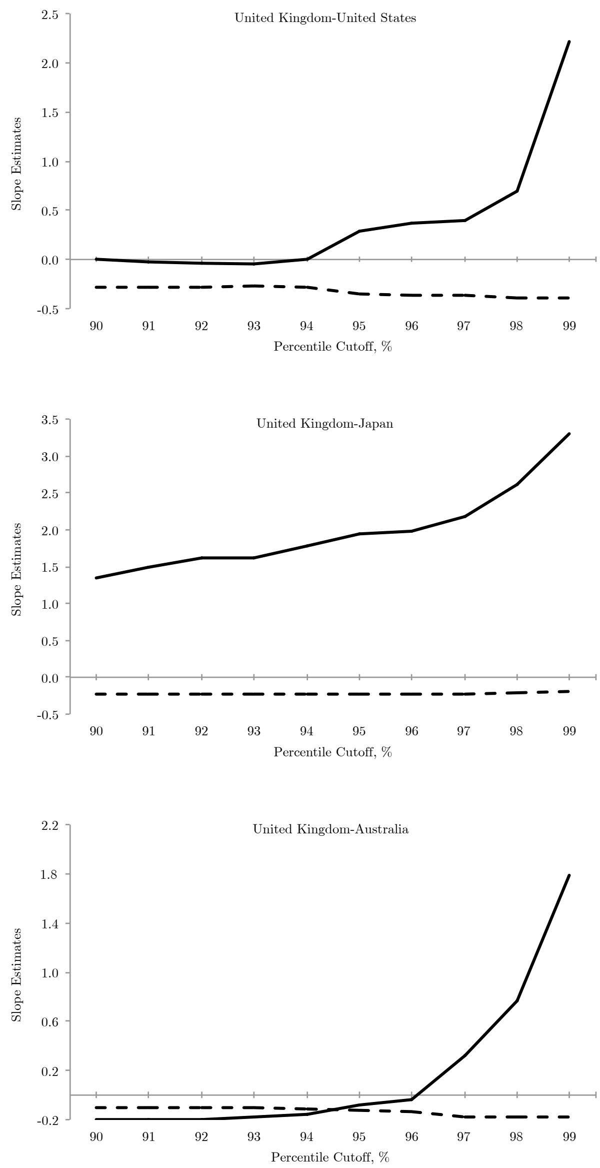

Figure 3. Regression slopes under increasing extreme sampling criteria. These results are defined by the following regression equation:

$$s_{t+1} - s_t = \alpha_0 + \beta^S(r_t - r_t^*) + \beta^L(r_t - r_t^* - ||dr||)I_{t\epsilon L} + \varepsilon_{t+1}$$

The solid lines represent estimates of β^L and the dashed lines represent estimates of β^S.

Appendix: Summary Statistics of Exchange Rates and Interest Rates

	Number of Observations = 2,933			
	ds	r	r*	*dr*
Summary A. Domestic = United Kingdom; Foreign = United States				
Mean	1.008	6.052	4.758	1.294
Standard Deviation	4.669	1.404	1.557	1.136
Skewness	-0.171	0.368	-0.702	1.394
Excess Kurtosis	-0.324	0.367	-0.446	3.161
Summary B. Domestic = United Kingdom; Foreign = Japan				
Mean	0.527	6.052	1.141	4.911
Standard Deviation	8.424	1.404	1.269	1.019
Skewness	-0.461	0.368	1.213	-0.391
Excess Kurtosis	-0.135	0.367	0.236	-0.816
Summary C. Domestic = United Kingdom; Foreign = Australia				
Mean	0.433	6.052	6.034	0.018
Standard Deviation	5.503	1.404	1.332	1.078
Skewness	0.695	0.368	0.941	0.769
Excess Kurtosis	0.252	0.367	0.249	0.910

Table 1. *ds* denotes the percentage difference between the log of the exchange rate in *t+1* (i.e. two years to coincide with the maturity of the sovereign bonds) and the log of the current spot exchange rate. *r* and *r** denote the domestic interest rate and the foreign interest rate, expressed in percentages, with *dr* representing the interest-rate differential $dr = r - r^*$.

Appendix: Forward Premium Regression

	GBP-USD		GBP-JPY		GBP-AUD	
	a_0	β_1	a_0	β_1	a_0	β_1
Estimates	0.014***	-0.340***	-0.026***	0.640***	0.005***	-1.088***
Standard Error	0.001	0.076	0.008	0.152	0.001	0.092
t-statistic	11.113	-4.490	-3.428	4.207	4.556	-11.802
p-value	0.000	0.000	0.001	0.000	0.000	0.000
R^2, *N*	0.683	2933	0.600	2933	4.537	2933

Table 2. These results are defined by the following regression equation:

$$s_{t+1} - s_t = \alpha_0 + \beta_1(r_t - r_t^*) + \varepsilon_{t+1}$$

The *t*-statistics and *p*-value are constructed based on the null hypothesis: $\alpha_0 = 0$, $\beta_1 = 0$. Data ranges from 1992 – 2005. In the last row, R-square values are displayed on the left and the number of observations on the right. * Estimated coefficient is significantly different from 0 at the 10% level, ** at 5%, and *** at 1% or lower.

Appendix: Extreme Sampling Regression

Percentile	β^S		β^L		$\|\|dr\|\|$	R^2
Summary A. Domestic = United Kingdom; Foreign = United States						
90	-0.288	(0.090)	0.005	(0.160)	2.318	0.005
91	-0.279	(0.089)	-0.022	(0.161)	2.453	0.005
92	-0.276	(0.088)	-0.036	(0.164)	2.537	0.005
93	-0.273	(0.088)	-0.045	(0.165)	2.637	0.005
94	-0.285	(0.087)	-0.004	(0.167)	2.827	0.005
95	-0.352	(0.085)	0.283	(0.176)	4.055	0.006
96	-0.367	(0.084)	0.364	(0.179)	4.196	0.006
97	-0.358	(0.082)	0.391	(0.191)	4.382	0.006
98	-0.394	(0.081)	0.691	(0.204)	4.787	0.009
99	-0.389	(0.076)	2.220	(0.351)	5.346	0.018
Summary B. Domestic = United Kingdom; Foreign = Japan						
90	-0.229	(0.122)	1.341	(0.358)	6.172	0.005
91	-0.233	(0.121)	1.493	(0.372)	6.197	0.006
92	-0.233	(0.120)	1.614	(0.384)	6.224	0.006
93	-0.224	(0.120)	1.625	(0.396)	6.244	0.006
94	-0.224	(0.120)	1.783	(0.413)	6.271	0.006
95	-0.226	(0.119)	1.945	(0.427)	6.311	0.007
96	-0.220	(0.119)	1.976	(0.438)	6.342	0.007
97	-0.222	(0.118)	2.180	(0.454)	6.368	0.008
98	-0.205	(0.117)	2.622	(0.525)	6.437	0.009
99	-0.189	(0.116)	3.306	(0.624)	6.556	0.010
Summary C. Domestic = United Kingdom; Foreign = Australia						
90	-0.100	(0.093)	-0.199	(0.211)	1.663	0.001
91	-0.102	(0.092)	-0.195	(0.213)	1.705	0.001
92	-0.103	(0.092)	-0.196	(0.218)	1.739	0.001
93	-0.107	(0.092)	-0.182	(0.221)	1.769	0.001
94	-0.113	(0.091)	-0.154	(0.223)	1.811	0.001
95	-0.125	(0.091)	-0.085	(0.227)	1.913	0.001
96	-0.133	(0.090)	-0.036	(0.234)	2.021	0.001
97	-0.181	(0.090)	0.320	(0.245)	2.121	0.002
98	-0.179	(0.086)	0.765	(0.373)	2.750	0.002
99	-0.177	(0.084)	1.789	(0.575)	3.401	0.004

Table 3. These results are defined by the following regression equation:

$$s_{t+1} - s_t = \alpha_0 + \beta^S(r_t - r_t^*) + \beta^L(r_t - r_t^* - ||dr||)I_{t\epsilon L} + \varepsilon_{t+1}$$

For each estimate (β^S and β^L), the left column reports the coefficient estimate while the right column reports its standard error in parenthesis. Note - α_0 for all currency pairs are near zero and statistically insignificant and hence are excluded from this table.

Appendix: Asymmetric CGARCH Regression

	a_0	β_1	φ_1	φ_2	φ_3	φ_4	φ_5	φ_6
Summary A. Domestic = United Kingdom; Foreign = United States								
Estimates	0.007***	0.146***	0.001	0.984***	0.600***	0.378	0.004	0.609
Standard Error	0.000	0.028	0.002	0.040	2.359	2.378	0.025	2.377
t-statistic	19.981	5.244	0.362	24.899	0.254	0.159	0.151	0.256
p-value	0.000	0.000	0.718	0.000	0.799	0.874	0.880	0.798
Summary B. Domestic = United Kingdom; Foreign = Japan								
Estimates	-0.024***	0.684***	0.004**	0.969***	0.277**	0.192***	0.156**	0.662***
Standard Error	0.003	0.062	0.001	0.012	0.110	0.051	0.078	0.027
t-statistic	-7.892	11.089	2.820	79.903	2.518	3.727	1.993	24.167
p-value	0.000	0.000	0.005	0.000	0.012	0.000	0.046	0.000
Summary C. Domestic = United Kingdom; Foreign = Australia								
Estimates	-0.007***	0.990***	1.174	1.000***	0.512	0.392	-0.001	0.603*
Standard Error	0.000	0.022	1.572	0.000	0.314	0.319	0.002	0.317
t-statistic	-27.365	44.191	0.747	-	1.631	1.226	-0.253	1.902
p-value	0.000	0.000	0.455	0.000	0.103	0.220	0.800	0.057

Table 4. These results are defined by the following regression equation:

$$s_{t+1} - s_t = \alpha_0 + \beta_1(r_t - r_t^*) + \varepsilon_{t+1}$$

where the error variance is bound by the following set of equations:

$$\sigma_{t+1}^2 = q_{t+1} + \big(\varphi_4 + \varphi_5(\varepsilon_t < 0)\big)(\varepsilon_t^2 - q_t) + \varphi_6(\sigma_t^2 - q_t)$$

$$q_{t+1} = \varphi_1 + \varphi_2(q_t - \varphi_1) + \varphi_3(\varepsilon_t^2 - \sigma_t^2)$$

The *t*-statistics and *p*-value are constructed based on the null hypothesis: $\alpha_0 = 0, \beta_1 = 0$. The t-statistic for φ_2 for UK-Australia is excluded as the value is extremely high. * Estimated coefficient is significantly different from 0 at the 10% level, ** at 5%, and *** at 1% or lower.

Appendix: CGARCH Regression

	a_0	β_1	φ_1	φ_2	φ_3	φ_4	φ_5
Summary A. Domestic = United Kingdom; Foreign = United States							
Estimates	0.006***	0.438***	0.001*	0.994***	0.543***	0.423***	0.565***
Standard Error	0.000	0.028	0.001	0.003	0.130	0.133	0.133
t-statistic	15.127	15.726	1.857	-	4.189	3.183	4.251
p-value	0.000	0.000	0.063	0.000	0.000	0.002	0.000
Summary B. Domestic = United Kingdom; Foreign = Japan							
Estimates	-0.063***	1.983***	1.576	1.000***	0.598*	0.354	0.644*
Standard Error	0.001	0.024	3.031	0.000	0.344	0.348	0.346
t-statistic	-57.331	83.287	0.520	-	1.740	1.017	1.861
p-value	0.000	0.000	0.603	0.000	0.082	0.309	0.063
Summary C. Domestic = United Kingdom; Foreign = Australia							
Estimates	-0.007***	1.021***	0.236**	1.000***	0.710***	0.229*	0.762***
Standard Error	0.000	0.022	0.101	0.000	0.121	0.131	0.127
t-statistic	-27.755	45.461	2.330	-	5.864	1.752	5.995
p-value	0.000	0.000	0.020	0.000	0.000	0.080	0.000

Table 5. These results are defined by the following regression equation:

$$s_{t+1} - s_t = \alpha_0 + \beta_1(r_t - r_t^*) + \varepsilon_{t+1}$$

where the error variance is bound by the following set of equations:

$$\sigma_{t+1}^2 = q_{t+1} + \varphi_4(\varepsilon_t^2 - q_t) + \varphi_5(\sigma_t^2 - q_t)$$

$$q_{t+1} = \varphi_1 + \varphi_2(q_t - \varphi_1) + \varphi_3(\varepsilon_t^2 - \sigma_t^2)$$

The *t*-statistics and *p*-value are constructed based on the null hypothesis: $\alpha_0 = 0, \beta_1 = 0$. The t-statistics for φ_2 are excluded as the values are extremely high. * Estimated coefficient is significantly different from 0 at the 10% level, ** at 5%, and *** at 1% or lower.