Uncovered Interest Parity: Cross-sectional Evidence

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Abstract

This paper proposes a different empirical approach to estimate the UIP by analyzing a large number of cross-country bilateral exchange rates using cross-section analysis. Different from conventional time-series UIP, cross-sectional UIP is examined with single equation estimation and panel regression model estimation. The exchange rates analyzed here include a broad spectrum of countries: developed, developing, low inflation and high inflation countries. Based on the empirical evidence, there does not appear to be a well-publicized UIP puzzle for cross-sectional UIP, and the slope estimates remain largely between zero and one throughout the sample periods, with a few exceptions. Evidence of UIP is more clear for low inflation countries than for high inflation countries. As interest rate maturity becomes longer, UIP relationship becomes weaker.

Keywords: Uncovered interest parity, Cross-section UIP

JEL classification: F31, F41, G15

*This paper is greatly benefitted by numerous comments from my colleague, Nelson Mark.

1 Introduction

Exchange rates between national currencies–the prices of national currencies in terms of foreign currencies–are among the most important prices in international economics. Exchange rate between two national currencies is determined by the economic fundamentals of the countries involved, and its dynamics are heavily influenced by the macroeconomic policies of each country. One important potential factor determining the exchange rate is the uncovered interest parity (UIP). The UIP theory asserts forward market efficiency and states that a country's currency is expected to depreciate against a foreign currency when its interest rate is higher than the foreign country's, due to international capital arbitrage. However, as is well documented, numerous empirical tests fail to support the UIP theory, thus producing the so-called forward market anomaly. Froot and Thaler (1990) report average slope estimates of -0.88 using a survey of 75 published estimates (Froot, 1990). Among others, Backus, Gregory and Telmer (1993), Froot and Frankel (1989), and McCallum (1994) all report negative relations on the UIP condition using the currencies of major developed countries. When a country's domestic interest rate is higher than the foreign interest rate, its currency has a tendency to appreciate instead of to depreciate as predicted by the UIP theory. Eichenbaum and Evans (1995) report that contractionary shock due to U.S. monetary policy leads to persistent, significant appreciation in U.S. nominal and real exchange rates, a significant deviation from the UIP theory.

This paper presents a new insight into the UIP puzzle using a large number of bilateral cross-section UIP relationships. The UIP relationship is analyzed in two dimensions: first, single equation bilateral cross-sectional UIP, and secondly, panel regression model of UIP. There is no particular theory that UIP should be on the time-series property. UIP is traditionally estimated using time-series data because of data availability. However, it is more appropriate to consider the UIP relationship in the cross-sectional context. Foreign exchange market is in equilibrium throughout all exchange rates at any given point of time. Using monthly time-series data, the bilateral exchange rates of one country against all other countries are calculated, thus producing a large number of bilateral exchange rates at each time period.[1] At each monthly period, cross-sectional UIP is estimated for country-pair observations, and a series of UIP slope estimates are obtained for the entire sample period.

To the best of my knowledge, this paper is the first one to estimate the cross-sectional UIP and to analyze *the time-series property of the cross-sectional UIP slope estimates*. All previous UIP tests have used time-series data for a small number of currencies to estimate the time-series UIP. Cross-sectional UIP estimation is only possible if a large number of bilateral exchange rates are available. Estimation of a large number of cross-sectional UIP

[1] For 37 currencies, there are 666 bilateral cross-country exchange rates.

slope distinguishes this paper from all previous UIP tests. Based on the empirical results, the UIP relationship holds well in cross-sectional analysis, and the slope estimates remain largely between zero and one throughout the sample periods, with a few exceptions. There does not appear to be any well-publicized UIP puzzle for cross-sectional UIP.

Flood and Rose (1996) compared a flexible exchange rate regime to more fixed regime using the European Monetary System (EMS) and concluded that the UIP theory fares better under the fixed than under the flexible regime. Flood and Rose (2002) also report that the UIP theory holds well during 1990s using daily data for 23 countries. Bansal and Dahlquist (2000) examined the weekly data for 28 countries and concluded that there may exist a non-linear asymmetric relationship in UIP for positive and negative forward premiums. They found that the violation of the UIP is not pervasive and the puzzle is largely confined to the high-income countries, and in particular, when U.S. interest rates are higher than foreign rates. Chinn and Meredith (2004) found better support for UIP using long-term relationships of exchange rates and the forward premium. Alexius (2001) also considered the long-run relationship of UIP using the long-term government bond yields for 13 OECD countries and the U.S., and found that the slope estimates are generally positive. On the other hand, Chaboud and Wright (2003) used high-frequency 5 minute exchange data to investigate the daily UIP theory, and claim that UIP theory holds, but that the effect is very short-lived. Using U.S.-German data, Mark and Moh (2004) found that UIP was violated only during periods of central bank intervention.

With a few exceptions, most of the existing studies have focussed on exchange rates of major developed countries. Flood and Rose (2001) and Bansal and Dahlquist (2000) expanded their samples to include several important developing countries. However, even when the sample is expanded to include a broader spectrum of countries, tests of the UIP hypothesis have focused mainly on the exchange rates with U.S. dollar. Mark and Wu (1998) considered the cross-country rates for UIP hypothesis, but only with a few cross-country rates such as against German Mark or Japanese Yen.

The next section briefly summarizes the UIP theory, econometric model and several possible explanations on the UIP puzzle. Section 3 introduces data and presents time-series UIP results as a base model. Section 4 reports cross-section bilateral UIP estimates, single equation cross-section estimation as well as panel regression model. It also analyzes statistical properties of cross-sectional slope estimates. Section 5 summarizes the main findings of the paper.

2 The forward premium puzzle

Consider the following UIP relationship in natural log form.

$$E_t\left(s_{t+k}\right) - s_t = f_{t,k} - s_t = i_t - i_t^* \tag{1}$$

where $f_{t,k}$ is the k-period forward rate, s_t is the spot rate at time t, and both are in natural logs expressed as the domestic currency price of one unit of the foreign currency. Increase of the spot (forward) rate refers to the depreciation of the domestic currency. i_t and i_t^* are domestic and foreign k-period maturity risk-free bond yields expressed in respective currency terms. Under forward market efficiency, UIP states that the forward rate is an unbiased predictor of the future spot rate. Since $E_t\left(s_{t+k}\right)$ is unobservable at time t, assuming rational expectations for the future spot rate, the econometric model to test the UIP hypothesis uses *ex post* realized spot rate s_{t+k} for $E_t\left(s_{t+k}\right)$. The econometric model is:

$$s_{t+k} - s_t = \beta_0 + \beta_1\left(f_{t,k} - s_t\right) + \varepsilon_{t+k} \tag{2}$$

UIP theory tests forward market efficiency if the joint hypothesis of $\beta_0 = 0$ and $\beta_1 = 1$ holds, i.e., the forward rate is an unbiased predictor of future spot rate. Important question on the UIP investigation is whether the UIP relationship of Equation (2) is time-series property or cross-section property. All of the standard UIP investigation focused on the time-series estimation of Equation (2). There is no particular theory that UIP should be on the time-series property. In fact, it is more appropriate to consider that the UIP relationship of Equation (2) is the cross-section property. If there exists any arbitrage opportunity between different currencies at any point of time, then, the invisible hand will take advantage of that opportunity instantaneously.

Typically, UIP investigations have focused on the time-series estimate of slope parameter β_1 considering β_0 to be the constant risk premium. The overwhelming majority of empirical studies have found that the slope estimates are negative and often statistically significant, let alone being the unity predicted by the UIP. This anomaly has provoked numerous attempts to examine different sample periods with different exchange rates. Few of these investigations have found evidence supporting the UIP theory.

The negative slope estimate is the evidence of bias of forward rate for the future spot rate. There are several alternative explanations for the negative slope estimates. Fama (1984) first introduced the risk premium, defined as $rp = f_{t,k} - E_t\left(s_{t+k}\right)$, to explain the negative relationship between the exchange rate and the forward premium. Engel (1996) presents an excellent survey on the forward discount anomaly, focusing on the risk premium

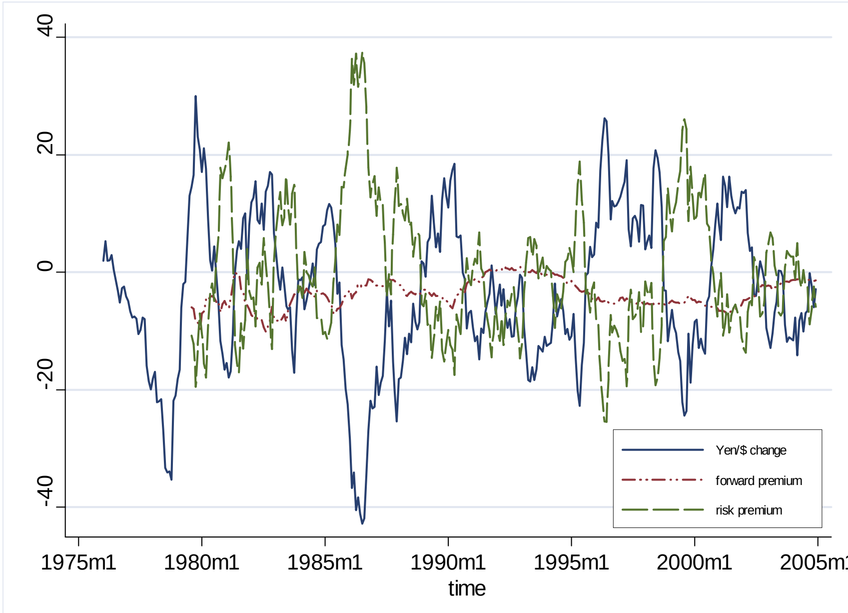

Figure 1: % change of spot rate, forward premium and risk premium

explanation. However, if the risk premium hypotheses holds for negative slope estimates, then the risk premium is negatively correlated with the expected depreciation and the variance of the risk premium should be greater than that of the exchange rate depreciation. McCallum (1994) reports that the average of the slope estimates is -4, which is typical of many other studies. This estimate implies that the standard deviation of risk premium is five times larger than that of the forward discount. The surprisingly large standard deviation of the risk premium is not well supported empirically. Figure 1 is time-series plot of one year percentage change of Japanese Yen against U.S. Dollar, one year forward premium and *ex post* (estimated) risk premium for the sample period. This is a typical time-series plot of exchange rate changes, forward premium and estimated risk premium of other developed countries. It is clear that risk premium and exchange rate changes are negatively correlated, with correlation coefficient being -0.88, but the risk premium does not appear to be significantly more volatile than the exchange rate changes.

Rogoff (1980) argues that in small samples exchange rates may have fat tails, and that the convergence to normal distribution is slow. Baillie and Bollerslev (2000) explain the forward premium anomaly as a statistical artifact due to the persistent autocorrelation in the forward premium and the small sample size of the study. They showed that forward premium is fractionally integrated (FIGARCH, fractionally integrated GARCH) and persistent, and the typical slope estimates are in fact centered around unity but widely dispersed, and converge to the true value of unity at a very slow rate. Baillie, Cecen and Han (2000) demonstrate the long-memory persistent volatility (FIGARCH) process of the German Mark-U.S. Dollar exchange rate using high and low frequency data. Mark and Wu (1998) show that the risk premium explanation is not consistent with the intertemporal asset pricing model and that the empirical data provide a weak support for the noise-trader model. Coakley and Feurtes (2001) use the exchange rate over-shooting argument as a novel solution to explain the forward premium anomaly.

Next section introduces data and starts with the time-series UIP estimation as a base model to confirm results from previous literature.

3 Time-series UIP and its puzzle

3.1 Data description

Data consist of the currencies of 36 countries and the Euro, totaling 37 currencies.[2,3] The exchange rate data comes from the IMF's International Financial Statistics (IFS). The exchange rates are the monthly rate of the national currency per U.S. Dollar from January 1975 to December 2004, total 360 monthly observations for each country. Euro country local currency exchange rates end at December 1998 and Euro rates start from January 1999 to the end of sample period, December 2004. Therefore, there is no arbitrage opportunities between Euro countries starting January 1999. International currency tradings are mostly conducted through major trading currencies such as Dollar, Euro, Yen and Pound. Many other currency exchanges are conducted indirectly through those major currencies. Therefore, bilateral exchange rates are calculated as the relative rates through U.S. Dollar exchange rates. For example, the bilateral rate between South Korea and Hong Kong is calculated as relative ratio of South Korean Won per U.S. Dollar to Hong Kong Dollar per U.S. Dollar. Since forward exchange rates are not widely available for many developing countries, interest rate differentials are used to measure the forward premium. We use four different maturities of interest rate: one month, three month, six month, and one year rates. Interest rate data come from the Datastream, which provides a wealth of detailed information on various interest rates.[4] Euro-currency rates are used for most of

[2] Countries included in our study are in alphabetic order: Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Denmark, Finland, France, Germany, Greece, Hong Kong, India, Indonesia, Ireland, Italy, Japan, Korea, Malaysia, Mexico, Netherlands, New Zealand, Norway, Peru, Philippines, Russia, Singapore, Spain, Sweden, Switzerland, Thailand, U.K., U.S., Venezuela, Euro.

[3] Among 37 national currencies, 21 (including Euro) are classifed as the developed economy currencies and 16 are currencies from the emerging and developing economies. Develpoed countries are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, U.K., U.S., and Euro.

[4] Datastream provides three different kinds of interest rates, bid rate, offer rate and middle rate whenever they are available. We use the middle rate for oru analysis.

the developed countries whenever they are available.[5] When Euro-currency rates are not available, the equivalent interbank rate is used.[6] For developing countries the interbank rates are used first, when they are available. When they are not available bank deposit rates are used. The interest rate data starts from January 1975 for most of the developed countries but there are several developing countries whose data do not start until mid or late 1990s.[7] We will start with the conventional time-series UIP analysis based on U.S. dollar exchange rates to confirm previous findings in the literature.

3.2 UIP with U.S. dollar rate

We will start with the conventional time-series UIP tests using country-by-country exchange rates per U.S. dollar. The baseline econometric model is Equation (2).

$$s_{t+k} - s_t = \beta_0 + \beta_1 (i_t - i_t^*) + \varepsilon_{t+k} \tag{3}$$

The next two tables report UIP slope estimates for the each country's exchange rate per U.S. dollar using monthly observations for each different maturities, one-, three-, six-, and 12-months. Each country has different start and end dates for different interest maturities depending on data availability. The available monthly observations start from January 1975 and ends at December 2004. Since this equation involves k period forward observations, error terms are subject to the serial correlation of $MA(k-1)$ process. To correct the serial correlation on ε_{t+k}, this equation is estimated using the Newey-West procedure to calculate the serial correlation robust standard errors. Following standard classification of countries, Table 1 and 2 report slope estimates and standard errors for developed countries and developing countries, respectively.

As we can see from these tables, many developed countries have statistically significant negative slope estimates. Japan, Canada, and the U.K. all have statistically significant negative estimates. The Euro has strong negative slope estimates, but since the Euro data starts from January 1999, its sample point consists of at most 5 year's monthly observations. Italy is a lone exception with statistically significant positive estimates for three, six and one year UIP. Finland and Spain also have positive estimates for all maturities, but these are not statistically significant. These estimates are generally in line with the findings from previous research for developed countries. For developing countries, only a few slope estimates are statistically significant. Russia and Peru have statistically significant positive

[5] Canada, Denmark, France, Germany, Italy, Japan, Switzerland, U.K., U.S., Euro.

[6] Australia, Finland, Greece, Hong Kong, New Zealand, Norway, Philippines, Russia, Singapore, Spain, Sweden

[7] Details about the interest rate data is available upon request.

Table 1: UIP slope estimates for developed countries: U.S. Dollar rate

	b1m	se(1m)	b3m	se(3m)	b6m	se(6m)	b1y	se(1y)
Australia	-1.268	0.882	-1.042	0.788	**-1.326**	0.585	**-1.380**	0.539
Austria	-0.661	1.463	-0.510	1.315	-0.539	1.042	-0.611	0.957
Belgium	-0.111	0.777	0.040	1.028	-0.283	0.555	-0.524	0.557
Canada	**-1.403**	0.495	**-0.917**	0.367	*-0.660*	0.363	-0.615	0.455
Denmark	-0.614	0.692	-0.713	0.798	-0.910	0.934	-0.865	0.994
Finland	1.366	1.193	1.462	1.150	1.426	1.134	1.087	1.038
France	-0.158	0.835	0.076	0.644	0.120	0.679	0.215	0.712
Germany	-0.549	0.922	-0.470	0.738	-0.544	0.629	-0.326	0.577
Greece	-0.969	1.058	*-0.295*	0.162	**-0.690**	0.279	**-1.290**	0.171
Ireland	1.169	0.962	0.398	0.895	0.142	1.073	**-5.410**	1.798
Italy	0.514	0.659	**1.311**	0.665	**1.725**	0.601	**1.901**	0.536
Japan	**-2.834**	0.871	**-3.007**	0.667	**-2.933**	0.599	**-2.729**	0.538
Netherlands	**-1.774**	0.797	-1.246	0.765	-1.119	0.702	-0.738	0.637
New Zealand	*-1.523*	0.808	*-1.186*	0.640	**-1.406**	0.485	**-1.406**	0.566
Norway	0.256	0.987	-0.262	0.838	-0.619	0.677	-0.689	0.641
Spain	0.964	1.183	1.246	1.064	1.005	0.990	0.925	1.127
Sweden	-1.587	1.497	*-2.224*	1.131	*-2.406*	1.273	**-2.764**	1.010
Switzerland	-1.328	0.812	-1.086	0.675	*-1.025*	0.566	**-0.954**	0.474
UK	**-1.594**	0.748	-1.270	0.775	-1.135	0.759	-0.799	0.683
Euro	**-6.443**	2.295	**-6.465**	1.732	**-6.556**	0.890	**-6.615**	0.709

Bold numbers are 5% significant and italics are 10% significant.

Standard errors are Newey-West serial correlation robust errors.

Table 2: UIP slope estimates for developing countries: U.S. Dollar rate

	b1m	se(1m)	b3m	se(3m)	b6m	se(6m)	b1y	se(1y)
Argentina	0.171	0.567	-0.194	0.344	.	.	-0.036	0.478
Brazil	-0.079	0.132	.	.	.	.	.	.
Chile	*-2.990*	1.647	*-2.528*	1.472	.	.	.	.
China	3.136	3.074	2.980	2.344	2.436	1.720	1.095	0.838
Hong Kong	-0.034	0.077	-0.037	0.052	0.005	0.030	0.028	0.016
India	0.365	0.962	-0.233	1.419	-0.799	1.682	-0.138	1.242
Indonesia	-0.291	1.796	-1.227	1.234	**-1.967**	0.539	**-1.758**	0.498
Korea	.	.	0.066	0.653	-0.546	0.615	-0.040	0.550
Malaysia	0.227	0.677	0.069	0.553	0.005	0.481	-0.031	0.389
Mexico	-0.156	0.750	-0.111	0.218	0.034	0.227	-0.005	0.180
Peru	.	.	.	.	**1.242**	0.452	**0.783**	0.283
Philippines	0.046	0.376	-0.237	0.440	-0.452	0.453	-0.691	0.448
Russia	**0.669**	0.209	**0.521**	0.216	.	.	.	.
Singapore	-1.407	1.134	*-1.347*	0.697	*-0.887*	0.513	-0.816	0.621
Thailand	0.802	1.780	0.260	1.316	.	.	-0.153	0.947
Venezuela	0.758	1.044	1.066	0.704	.	.	.	.

Bold numbers are 5% significant and italics are 10% significant.

Table 3: Rejection of UIP test for each currency: U.S. Dollar rate

Maturity	Developed countries	Developing countries	All countries
b1m	9/20 (0.45)	5/14 (0.36)	14/34 (0.37)
b3m	12/20 (0.60)	7/14 (0.50)	19/34 (0.56)
b6m	14/20 (0.70)	7/10 (0.70)	21/30 (0.70)
b1y	14/20 (0.70)	7/12 (0.58)	21/32 (0.66)

Fractions are in the parenthesis

estimates while Chile has statistically significant negative estimates for one and three month exchange rate changes.

We tested the UIP hypothesis of $H_0 : \beta_1 = 1$, and rejected the null hypothesis for 9, 12, 14 and 14 out of 20 developed countries, respectively for one-, three-, six- and twelve-month changes.[8] Test results are summarized in Table 3. The UIP hypothesis is rejected slightly more often for developed countries than developing countries. Even if we did not reject the null hypothesis for 11 out of 20 developed countries for one month exchange rate changes, this is more likely due to the large standard errors of the estimates rather than the estimates being close to one. Similar conclusions hold for all other monthly changes. These results mostly agrees to the previous literature. Table 4 is a mean and median of

[8] Rejection for one month UIP: Australia, Canada, Denmark, Japan, Netherlands, New Zealand, Switzerland, U.K., and Euro

Table 4: Summary of all slope estimates

	All countries		Developed countries		Developed excluding Euro		Developing countries	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
b1m	-0.661	-0.224	-0.927	-0.815	-0.637	-0.661	-0.216	0.006
b3m	-0.644	-0.279	-0.808	-0.611	-0.510	-0.510	-0.371	-0.153
b6m	-0.728	-0.619	-0.887	-0.675	-0.588	-0.660	-0.374	-0.452
b1y	-0.853	-0.615	-1.179	-0.769	-0.893	-0.738	-0.260	-0.040

bilateral slope estimates. Since China has fixed its exchange rates for a long period of time and Russia does not have a credible official exchange market, these two countries are excluded from the summary statistics.

It is very difficult to find any clear pattern in these figures, but the slope estimates for developed countries (either including or excluding Euro) tend to be more negative than those of developing countries. The mean slope estimates are generally more negative than those of the median, which suggests that there are more extreme negative estimates than positive ones. Since the Euro has a relatively short sample period, summary statistics are presented with and without the Euro for fair comparison. As with the previous literature, this paper also found numerous negative slope estimates for US dollar-based time-series UIP.

4 Cross-sectional UIP

4.1 Country by country bilateral cross-sectional UIP

This section will investigate the cross-section UIP relationship using bilateral exchange rates. Important question on the UIP investigation is whether the UIP relationship of Equation (2) is time-series property or cross-section property. All of the standard UIP investigation focused on the time-series estimation of Equation (2). There is no particular theory that UIP should be on the time-series property. In fact, it is more appropriate to consider that the UIP relationship of Equation (2) is the cross-section property. Foreign exchange market is in equilibrium at any given point of time throughout all exchange rates. If there exists any arbitrage opportunity between different currencies, then, the invisible hand will take advantage of that opportunity instantaneously.

The main advantage of the cross-section UIP is to overcome the single realization characteristic of time series data. We will take advantage of this feature later in the panel regression. First, we estimate the cross-sectional UIP relationship at each given point of time. In a perfect world without capital regulation, the interest rate arbitrage for exchange rate should hold at any given point of time. However, there are numerous different capital controls in different countries at different time periods, we do not expect the perfect arbitrage opportunity as theory postulates. In this analysis, we would like to investigate if the cross-section UIP produces similar results to the time-series UIP.

Cross-sectional UIP is estimated based on the Equation (2). We use the interest rate differential as the forward premium. Previous UIP studies have focussed exclusively on the time-series estimation of Equation (2) for each countries per numeraire currency exchange rate mainly due to data availability. This section focuses on the cross-sectional estimation of Equation (2) for each country-pair bilateral exchange rates for each month. The estimation equation is:

$$s_{t+k}^{i,j} - s_t^{i,j} = \beta_0 + \beta_1 \left(i_{t,k}^{i} - i_{t,k}^{j} \right) + \varepsilon_{t+k}^{i,j} \quad \text{for } t = 1975.01 \text{ to } 2004.12 \tag{4}$$

where $s_t^{i,j}$ is a natural log of country i's spot rate for one unit of country j's currency at month t and $i_{t,k}^{i}$ is k-month maturity (*k=1,3,6 and 12*) interest rate measured in k-month return rate for country i, and $\left(i_{t,k}^{i} - i_{t,k}^{j} \right)$ is expressed as the k-month period return difference. All other notations follow the same definitions from Equation (2). This equation is estimated using each currency *(i,j)* pair for 37 currencies cross-sectionally in each month from January 1975 to December 2004 for each different maturities, one-, three-, six-, and 12-months. Since data is not available for all countries from January 1975, the number of cross-sectional observations for each month estimation ranges from 21 to 561 country-pair observations. Total number of cross-sectional UIP slope estimates is 359, 357, 356 and 348 for each maturity, respectively.[9] Since this is a cross-section estimation for each time period, there is no persistent autocorrelation problem for the usual UIP estimation as argued by Baillie and Bollerslev (2000). Standard errors are estimated using White's heteroscedasticity-consistent covariance estimation.

Table 5 is a summary of cross-sectional UIP slope estimates for all sample countries for different maturities. Mean and standard errors are obtained from 359, 357, 356 and 348 cross-section slope estimates for entire sample period from January 1975 to December 2004. This table shows that even though the average slope estimates are well short of one, they are all positive and statistically significant as predicted by UIP. None of the averages is negative as is often observed in the time-series UIP slope estimates. Since we estimates the slope parameter for each month, we obtain the time-series of slope estimates, and it is interesting to examine the *time-series property* of *cross-section slope estimates*. Series of

[9] For example, for one month UIP, cross-section regression is estimated for each month starting from February 1975 to December 2004, total 359 cross-section regression estimates. For one year UIP, there are 348 cross-section regressions starting from January 1976 to December 2004.

Table 5: Cross-section UIP slope estimates

UIP Slope Estimates	Mean	Std. Error	ADF	P-P Test
1 month	0.343	0.118	-7.018	-19.141
3 month	0.561	0.076	-5.678	-8.693
6 month	0.554	0.061	-4.559	-6.519
12 month	0.653	0.052	-5.780	-4.715

Augmented Dickey Fuller test is based on the 6 lags with time trend. 1% critical value is -3.986.
Phillips-Perron statistic is calculated with time trend and default lag length of one.

slope estimates for each maturity are all stationary throughout the sample period. Figure 2 is a time-series plot for 12 month forward premium UIP slope estimates for each month, and smoothed moving average of the estimates.[10,11] Figure 2 shows that the slope estimates mostly stay above zero, with a few exceptions. General characteristics of shorter forward premium results remain similar to the one year estimates. This sample period includes all different exchange rate regimes, fixed, flexible and various intermediate regimes. These results show that there is no discernible pattern in different time periods, and there is no evidence of the claim of Flood and Rose (2002) for favorable evidence for UIP during 1990s. Since world exchange rate system has moved toward more flexible regimes in recent years, the cross-sectional UIP results do not support the regime differences studied by Flood and Rose (1996).

Figure 3 is a box plot of slope estimates for all maturities.[12] As we can observe from Table 6, estimates from the shorter premium tends to be more volatile and widely spread than those of one year estimates.

Since interest rate parity condition may not be the same for inflationary countries for fear of losing investment value due to high inflation, we divide the country characteristic based on the inflation rate for the cross-section bilateral UIP estimation.[13] We use dummy variable regression to separate high inflation countries from more moderate inflationary (and stable) countries. High inflation countries have average annual inflation rate greater than 10% over the sample period. There are 10 high inflation countries and 26 stable

[10] Moving average is calculated as the weighted average of 6 months forward and 6 months backward with equal weight.

[11] For one-, three- and six month forward premium UIP results are not presented here, but available upon request.

[12] Box plot shows the first quartile (Q_1), mdeian, and the third quartile (Q_3) in the box. Outside lines represent the upper and lower limits as $Q_3 + 1.5 \times (Q3 - Q1)$ and $Q_1 - 1.5 \times (Q3 - Q1)$. Outside the upper and lower limits are outliers.

[13] This distinction is different from the deveolped and developing country specification mostly used in the literature.

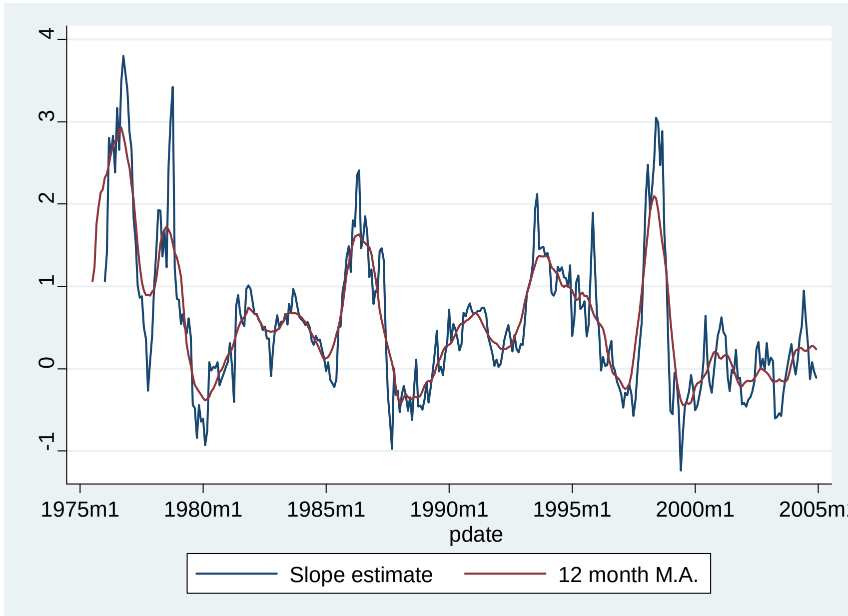

Figure 2: Cross-section UIP slope estimates for 12 month forward rate

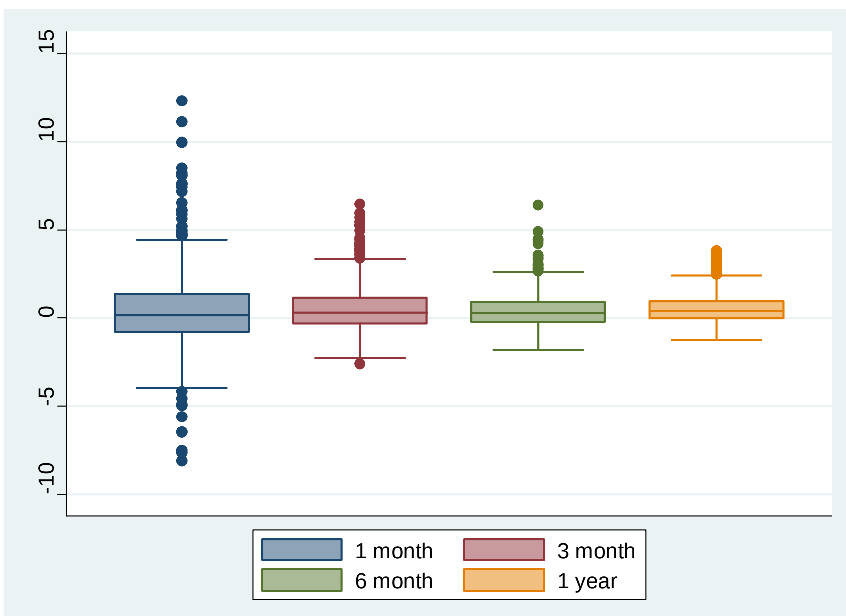

Figure 3: Box plot of slope estimates for 1-,3-,6- and 12 month forward premium

Table 6: Cross-section UIP Dummy Variable Regression Estimates

	β_0	β_1	γ_0	γ_1	$\beta_1+\gamma_1$	n
1 month	0.001 (0.030)	0.429 (0.138)	0.331 (0.177)	-0.344 (0.155)	0.207 (0.140)	191
3 month	0.005 (0.053)	0.591 (0.079)	0.938 (0.315)	-0.195 (0.082)	0.402 (0.099)	213
6 month	-0.065 (0.076)	0.498 (0.061)	3.791 (0.584)	-0.421 (0.071)	-0.046 (0.094)	210
1 year	-0.105 (0.118)	0.550 (0.048)	5.137 (1.149)	-0.126 (0.115)	0.226 (0.129)	204

Standard errors are in the parenthesis. $\beta_1 + \gamma_1$ is the sum of available estimates in the last column.

countries in the sample.[14] Estimated regression model is:

$$s_{t+k}^{i,j} - s_t^{i,j} = \beta_0 + \beta_1 \left(i_{t,k}^i - i_{t,k}^j\right) + \gamma_0 d + \gamma_1 d \left(i_{t,k}^i - i_{t,k}^j\right) + \varepsilon_{t+k}^{i,j} \quad (5)$$

where dummy variable $d = 1$ for either country i or country j being inflationary countries[15] and 0 otherwise. If one or both countries in the bilateral relationship belongs to the inflationary country, they are classified as the inflationary country UIP. Table 6 reports summary statistics for dummy variable regressions. These numbers are averages of cross-section (i, j)-pair regression slope estimates. Column 2 and column 5 report the time-series averages of cross-sectional slope estimates from Equation 5. Column 6 is the total number of cross-section slope estimates for high inflation countries ($d = 1$).

From this result, it is clear that UIP relationship becomes weaker when inflationary countries are involved. UIP slope estimates are statistically positively significant for all maturities, and the dummy variable slope (γ_1) estimates are all statistically negatively significant except for 12 month. Even though slope estimates are far below one predicted by the theory, this result shows that UIP holds qualitatively in a cross country relationship at any given time, after taking the transactions cost and capital controls across the countries into account.[16] Contrary to previous literature, UIP theory seems to hold for non-inflationary countries. However, for inflationary countries, UIP slope estimates are much closer to zero and they are statistically insignificant except for 3-month. In addition, the intercept estimates for non-inflationary countries are all statistically insignificant while those of inflationary countries are all statistically positively significant, and the intercept estimates increase as maturity increases.[17] This suggests that there is little chance

[14] They are six Latin Anmerican countries (Argentina, Brazil, Chile, Mexico, Peru and Venezuela) and Greece, Indonesia, Phillippines and Russia.

[15] High inflation countries are defined as the annual average inflation rate is more than 10% over 30 year period. There are 10 countries in the sample. Those countries are: Argentina, Brazil, Chile, Greece, Indonesia, Mexico, Peru, Philippines, Russia, and Venezuella.

[16] Transactions costs include traditional brokerage tranactions cost and other costs incurring to convert "highly controlled currencies" into more liquid currencies. There are many currencies in the sample that the official exchange rates are widely different from the parallel rates. See Reinhard and Rogoff (2004).

[17] Intercept estimates for high inflation countries are $\beta_0+\gamma_0$. Estimates and standard errors are not shown in Table 6. They are available upon request.

of arbitrage opportunity between cross-country exchange transactions for stable and non-inflationary countries. For high inflation countries, exchange rates depreciation is negligible for the interest rate differentials. It is typical that high inflation countries use high interest rate to cope with the high inflation, and their exchange rates are typically fixed or tightly managed with occasional jump (depreciation) insensitive to the interest rate differentials. Therefore, even though there may exist interest rate arbitrage opportunities for high inflation countries, they are not viewed as attractive opportunities because of the fixed exchange rates and tightly controlled capital movements.

Using cross-sectional UIP estimation, we do not encounter the UIP puzzle often observed in the time-series. We observe that the UIP slope estimates are well within the range between one and zero predicted by the theory.

4.2 Panel UIP estimation

Once we have examined single equation estimates of cross-section UIP relationship for each currency pair, we would like to estimate the panel regression model of the cross-section UIP relationship. Since we are interested in finding the robust UIP relationship regardless of country specific idiosyncratic currency pair, panel estimation is more attractive than the single equation estimation of either cross-section or time-series data. In this section, we consider two different panel structures for UIP estimation. As a base model, we first estimate the standard panel regression model with cross-section bilateral exchange rates being the panel unit. This model is an extended version of cross-section UIP model discussed in the previous section. As a robust check, we also estimate the time-series panel model. Time-series panel refers to the panel model with time (instead of bilateral cross-section) being the panel unit. This panel structure is in line with the time-series UIP model in the literature.

4.2.1 Cross-section panel estimation

Define cross-country panel regression model as following.

$$s_{t+k}^{i,j} - s_t^{i,j} = \alpha^{i,j} + \beta_1 \left(i_{t,k}^{i} - i_{t,k}^{j} \right) + \varepsilon_{t+k}^{i,j} \tag{6}$$

where $\alpha^{i,j} = \beta_0 + v^{i,j}$, is a random component of panel heterogeneity for each country pair (i,j), β_0 is a non-random intercept parameter, and $\varepsilon_{t+k}^{i,j}$ is white-noise error term. Assume that $E\left(\varepsilon_{t+k}^{i,j}\right) = E\left(v^{i,j}\right) = 0$, $E\left(\varepsilon_{t+k}^{i,j} \cdot v^{i,j}\right) = 0$, $Var\left(\varepsilon_{t+k}^{i,j}\right) = \sigma_{\varepsilon,k}^2$, and the random component $v^{i,j}$ is heteroscedastic for each country pair (i,j) with $Var\left(v^{i,j}\right) = \sigma_v^{i,j}$. Similar to the single equation UIP estimation, error term, $\varepsilon_{t+k}^{i,j}$, is $MA\left(k-1\right)$ process. Equation 6 is estimated by GLS using random effect with group heteroscedasticity and

Table 7: Cross-section Panel Regression Result

UIP Estimates	All countries		Low Inflation		High Inflation	
	β_0	β_1	β_0	β_1	β_0	β_1
1 month	-0.002	0.364	-0.007	0.433	0.222	0.211
(standard error)	(0.006)	(0.014)	(0.006)	(0.019)	(0.033)	(0.023)
Obs (groups)	81761	(586)	62924	(419)	18837	(167)
3 month	-0.013	0.390	-0.032	0.427	0.680	0.250
(standard error)	(0.010)	(0.001)	(0.010)	(0.012)	(0.060)	(0.019)
Obs (groups)	82213	(586)	66082	(446)	16131	(140)
6 month	-0.019	0.330	-0.038	0.327	3.304	-0.113
(standard error)	(0.012)	(0.009)	(0.130)	(0.010)	(0.184)	(0.032)
Obs (groups)	64468	(446)	57969	(382)	6499	(64)
1 year	-0.037	0.323	-0.104	0.321	5.100	-0.043
(standard error)	(0.018)	(0.006)	(0.020)	(0.007)	(0.220)	(0.021)
Obs (groups)	67078	(509)	56647	(408)	10431	(101)

*Groups represent total number of heterogeneity groups in each estimation

serial correlation. We estimate this model for all countries panel, and low inflation and high inflation countries panels separately. Cross-section panel regression model is similar to the conventional UIP regression model only to estimate the common UIP slope parameter for all countries. The advantage of this model is to aggregate bilateral exchange rate UIP for all countries in each panel removing all country specific characteristics and to estimate the common slope parameter. Estimation results are presented in Table 7.

Cross-section panel regression results show qualitatively similar results to the averages of the slope estimates of the bilateral cross-section regressions presented in Table 6. Estimates for slope parameters for low inflation countries are between 0.321 and 0.433, and they are all positive and statistically significant for all maturities. There is a slight tendency that UIP becomes weaker as interest maturity becomes longer. For high inflation countries, slope estimates are positively significant for short maturity UIP up to 3-month (0.211 and 0.250), and then turn to negatively significant starting 6-month UIP (-0.113 and -0.043). It is a reasonable conjecture that, for high inflation countries, UIP does not hold for long maturities for fear of losing investment value due to the uncertain exchange rate movements. Even though slope estimates are far short of one as predicted by the theory, they are at least not negative and significant different from the results often reported in the previous UIP literature. In addition, intercept estimates for high inflation countries are much larger than those of low inflation countries. Large intercept for high inflation countries represents the built-in risk premium for interest parity. These results confirm the country pair cross-section results in Table 5 and Table 6. Next sub-sections report time-series panel regression results as a robust check for the standard time-series

UIP model.

4.2.2 Time-series panel estimation

Unlike conventional panel data analysis that treats cross-sectional panel i with group specific effect (either fixed or random), in this section, we treat the time period t as a panel unit within which cross-section observations are contained. For example, there are 666 cross-section observations for each panel unit, t, from January 1975 to December 2004. Due to the data availability for each time period, time-series panel has an unbalanced panel structure. This panel structure is an extended version of the single equation time-series UIP model mostly studied in the literature, by smoothing the cross-section variations within each group (time period). Panel regression model is as following.

$$s_{t+k}^{i,j} - s_t^{i,j} = \alpha^{t+k} + \beta_1 \left(i_{t,k}^{i} - i_{t,k}^{j} \right) + \varepsilon_{t+k}^{i,j} \tag{7}$$

where $\alpha^{t+k} = \beta_0 + v^{t+k}$, is a time-varying random component within the panel unit (t) with $E\left(v^{t+k}\right) = 0$ and $Var\left(v^{t+k}\right) = \sigma_{v,k}^2$. β_0 is a non-random intercept parameter, and $\varepsilon_{t+k}^{i,j}$ is white-noise error term uncorrelated with v^{t+k} such that $E\left(v^{t+k} \cdot \varepsilon_{t+k}^{i,j}\right) = 0$ and $Var\left(\varepsilon_{t+k}^{i,j}\right) = \sigma_{\varepsilon,k}^2$. Estimation results are in Table 8. UIP theory seems to hold well for low inflation countries while those of high inflation countries do not. Intercept estimates of high inflation countries becomes bigger as interest maturity increases. Estimates for slope parameters for low inflation countries are between 0.358 and 0.577, and they are all positive and highly significant for all maturities while those of high inflation countries are positively significant for short maturity UIP up to 3-month (0.211 and 0.250), and then turn to negatively significant except for 6-month UIP (-0.134). For 6-month high inflation UIP estimation, number of observations (6499) are considerably smaller compared to other models. Even though slope estimates are far short of one as predicted by the theory, they are at least not negative and significant contrary to the results often reported in the literature. In addition, intercept estimates for high inflation countries are much larger than those of low inflation countries. Large intercept for high inflation countries represents the built-in risk premium for interest parity. These results confirm the country pair single equation cross-section results in Table 5 and Table 6.

4.2.3 Time-series panel between group estimation

We also present the estimation results of between group panel regression of Equation 7. This is a time-series UIP estimation using averages of cross-section variations of each bilateral exchange rates. This regression will show a better picture of time-series UIP

Table 8: Time-series Panel Regression Result

UIP Estimates	All countries		Low Inflation		High Inflation	
	β_0	β_1	β_0	β_1	β_0	β_1
1 month	0.002	0.480	-0.031	0.577	0.224	0.351
(standard error)	(0.032)	(0.013)	(0.036)	(0.017)	(0.157)	(0.027)
Obs (groups)	81761	(359)	62924	(359)	18837	(191)
3 month	0.023	0.490	-0.115	0.523	0.735	0.407
(standard error)	(0.046)	(0.009)	(0.054)	(0.010)	(0.258)	(0.020)
Obs (groups)	82213	(357)	66082	(357)	16131	(213)
6 month	0.061	0.350	-0.098	0.358	3.949	-0.134
(standard error)	(0.056)	(0.011)	(0.074)	(0.013)	(0.501)	(0.043)
Obs (groups)	64468	(354)	57969	(354)	6499	(210)
1 year	0.376	0.360	-0.184	0.367	5.946	0.066
(standard error)	(0.149)	(0.009)	(0.120)	(0.009)	(0.858)	(0.027)
Obs (groups)	67078	(348)	56647	(348)	10431	(204)

*Groups represent total number of time-series observations (groups)

relationship net of country-specific idiosyncratic effect. This result provides much sharper comparison between low inflation countries and high inflation countries. Slope estimates for low inflation countries are all positively significant and much closer to one between 0.674 and 0.716. Intercepts for low inflation countries are all statistically insignificant. For high inflation countries, slope estimates are either insignificant or negatively significant and the intercepts are all positively significant and much larger than those of low inflation countries. UIP holds for low inflation countries but not for high inflation countries. Again, this result confirms single equation cross-section UIP regression or cross-section panel regression UIP.

5 Conclusion

This paper investigates empirical evidence relating to the UIP puzzle. Standard UIP tests only focus on the country by country time-series UIP. We showed that there is no evidence of UIP puzzle in the cross-sectional UIP.

This paper poses an important question about the validity of existing empirical UIP results. There is no particular theory that UIP should be on the time-series property. In fact, it is more appropriate to consider that the UIP relationship in the cross-section context. If there exists any arbitrage opportunity between different currencies at each point of time, then, the invisible hand will take advantage of that opportunity instantaneously. Thus, UIP should hold.

Cross-sectional UIP slope estimates are statistically positive for all interest rate maturities, and the relationship becomes weaker as interest rate maturity becomes longer for

Table 9: Time-series Panel Between Group Regression Result

UIP Estimates	All countries		Low Inflation		High Inflation	
	β_0	β_1	β_0	β_1	β_0	β_1
1 month	0.028	0.153	-0.003	0.716	0.604	-0.243
(standard error)	(0.038)	(0.304)	(0.041)	(0.160)	(0.302)	(0.404)
Obs (groups)	81761	(359)	62924	(359)	18837	(191)
3 month	0.069	0.469	0.002	0.704	2.286	-0.703
(standard error)	(0.060)	(0.127)	(0.065)	(0.085)	(0.517)	(0.301)
Obs (groups)	82213	(357)	66082	(357)	16131	(213)
6 month	0.162	0.416	0.083	0.674	7.706	-1.024
(standard error)	(0.075)	(0.150)	(0.083)	(0.114)	(1.398)	(0.298)
Obs (groups)	64468	(354)	57969	(354)	6499	(210)
1 year	0.504	0.361	0.165	0.701	7.710	-0.188
(standard error)	(0.179)	(0.143)	(0.132)	(0.097)	(2.074)	(0.242)
Obs (groups)	67078	(348)	56647	(348)	10431	(204)

*Groups represent total number of time-series observations (groups)

low inflation countries. For high inflation countries, the slope estimates are much smaller than those of low inflation countries. This is the first paper to investigate the statistical property of cross-sectional UIP slope estimates.

In addition to the single equation cross-section estimation, we also estimated the panel regression model of UIP relation. Estimation results are qualitatively similar to those of single equation cross-section UIP model. There is no evidence of UIP puzzle, and there is a strong evidence of UIP for low inflation countries. UIP relationship becomes weaker for high inflation countries for short maturity and it became insignificant or turned negative for longer maturities.

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