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Research article

Uncovered interest rate parity: A gravity-panel approach

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ABSTRACT

This paper investigates the validity of uncovered interest rate parity (UIRP) which establishes a proportional relationship between interest rate and expected nominal exchange rate differentials. This paper takes a different perspective by using a gravity panel as the methodological approach and modeling the interest rate differential as a function of the expected nominal exchange rate change. Thus, we use all possible nominal exchange rates in our sample to study the validity of the UIRP. We provide evidence in favor of UIRP which holds for a sample of high-income economies; however, this hypothesis is rejected for medium-income countries.

1. Introduction

Uncovered Interest Rate Parity (UIRP, henceforth) is a phenomenon in which currencies tend to depreciate in countries with high interest rates. If UIRP does not hold, foreign exchange investors can earn money through carry trade operations by taking out loans in currencies with low interest rates and then making deposits in currencies with high interest rates. Many authors have signaled to market imperfections, such as asymmetric information, uncertainty, and risk-aversion, as reasons for rejecting the UIRP (Gourinchas and Tornell, 2004; Bacchetta and Van Wincoop, 2013; Boschen and Smith, 2016; Husted et al., 2018; Ismailov and Rossi, 2018). While research on this topic has increased in the last years, there is inconclusive evidence explaining the reasons for UIRP's invalidity. For this reason, there is limited empirical evidence in favor of the UIRP (Lothian and Wu, 2011; Lothian, 2016).

The objective of this paper is to empirically study the validity of UIRP by incorporating heterogeneity in exchange rate and interest rate differentials. This heterogeneity is relevant since previous research presents evidence for a reduced group of countries. The contribution of this paper is in two ways. First, we use the relationship between UIRP and the expectations hypothesis of the term structure (EHTS, henceforth) to model the long-term interest rate differential as a function of the expected nominal exchange rate change. In this way, the interest rate differential not only depends on expectations of the nominal exchange rate, but also on other interest rate determinants different to a constant risk premium. By taking advantage of the literature on long-term interest rate determinants, we include macroeconomic variables as additional determinants in our specification. Second, we use a gravity model which allows us to incorporate heterogeneity in exchange rate and interest rate differentials to our empirical specification. Under this focus, the interest rate differential is seen as the differential between an economy of origin and destination. Therefore, using a gravity panel allows us to take all possible interest rate and exchange rate differentials between the sample economies into account. It is worth noting that previous empirical literature has focused on studying the validity of UIRP in few high-income economies over long periods of time. In the same line, we also include in the analysis a sample of middle-income countries whose evidence is not abundant (Pasricha, 2006; Si et al., 2017).

Our sample includes 45 countries, of which 35 are high-income countries and 10 are middle-income countries. Our sample period goes from 1992Q2 to 2011Q4. We have a gravity panel including 990 different exchange rate and long-term interest rate differentials. The main outcome of this paper is to provide empirical evidence supporting the UIRP hypothesis. Our findings suggest that UIRP is sensitive to countries' income levels since UIRP is supported between high-income economies but absent between middle-income economies. We also provide evidence that the interest rate differential is determined by macroeconomic variables such as inflation, fiscal deficit, public debt, exchange rate regime, and levels of economic freedom.

This paper is organized as follows. Section 2 presents a literature review. In section 3, we describe our methodology. Section 4 gives a description of the data. The results and robustness checks are presented in section 5. Finally, section 6 concludes this study.

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2. Literature review

2.1. The UIRP hypothesis

There is a large amount of literature that contradicts the existence of the UIRP hypothesis by showing a non-proportional or even negative relationship between exchange and interest rate differentials. Chinn and Meredith (2004) studied the UIRP's validity using quarterly short- and long-term interest rates for G7 countries (the United States, the United Kingdom, Germany, France, Italy, Japan, and Canada). For short-term interest rates, their results showed an inverse relationship in the interest rate and the nominal exchange rate differentials. The results for long-term interest rates, however, showed a proportional relationship between the two. The authors concluded that disturbances in the foreign exchange market, together with the endogeneity of monetary policy, lead to an absence of UIRP in the short-term, while in the long-term these effects diminish their magnitude. Chinn and Quayyum (2012) tested the UIRP theory together with rational expectations theories for short- and long-term interest rates. Their results were similar for both time periods, concluding that results depend greatly upon the data used and the length of time included in the sample. Chinn and Zhang (2018) presented empirical evidence that rejects UIRP in the short term, compared to the long term where UIRP holds true.

Different methodological approaches have been used to study the UIRP providing evidence (mainly) against this hypothesis. For instance, Kirikos (1993) studied the UIRP by imposing restrictions to a vector autoregressive model for six exchange rates from 1978 to 1990 whose evidence rejects the UIRP hypothesis. Huisman et al. (1998) estimated a panel of fifteen developed countries from 1979 to 1996 to show evidence against the UIRP hypothesis except during large-forward-premium time periods. Using an IV approach to deal with measurement errors and using thirteen OECD countries from 1957 to 1997, Alexius (2001) found mixed results for these different countries; however, IV techniques seem to be useful to favor the UIRP. Chaboud and Wright (2005) used intraday data for four high-income exchange rates from 1988 to 2002 to show that the UIRP only holds during short-time periods. Ferreira and Kristoufek (2020) also rejected the UIRP hypothesis by using daily data to capture nonlinear effects through a fractal method approach for twenty-four European economies. Finally, Afat and Frömmel (2021) employed a panel approach for fifty exchange rates from 2009 to 2016 by estimating an autoregressive distributed lag approach to model time-varying risk premium whose results also rejected the UIRP.

Many authors have focused on the presence of unrealistic assumptions behind the UIRP to explain the rejection of this hypothesis. For instance, investors have expectation errors which affect their rational expectations as well as failing to have a risk-neutral behavior (Taylor, 1995; Bacchetta and Van Wincoop, 2009). Furthermore, the UIRP assumes that risk-premium does not change over time; however, there is evidence arguing the presence of a time-varying risk premium (Li et al., 2012). Other authors focused on the time period in analysis where long horizons tend to decrease the effect of temporary shocks favoring the existence of the UIRP (Lothian and Wu, 2011). Different currencies and the level of development of countries are also signaled as factors for rejecting the UIRP (Mehl and Cappiello, 2009). In addition, public policies, especially monetary policy, seem to affect the relationship behind the UIRP hypothesis. Baillie and Osterberg (2000) found that US purchases and German sales of dollars favor deviations of the UIRP. Similarly, Chinn and Zhang (2018) postulated that monetary policy encourages a negative coefficient for the UIRP hypothesis even at long time horizons. Finally, the UIRP is also considered as a condition for financial-markets integration; thus, its rejection can be interpreted as a lack of financial integration of different economies (Fratzscher, 2002).

Following the above ideas, Gourinchas and Tornell (2004) proposed a model of exchange rate determinants in which investors constantly attempt to decide whether shocks in interest rates will be temporary or permanent. They found evidence against UIRP, asserting that ineffective investment decisions are due to inventor bias about the evolution of interest rates. Bacchetta and Van Wincoop (2013) proposed a two-country model in which they did not assume that agents instantaneously incorporate new information. In this way, errors in the expected exchange rate tend to persist over time. These authors found negative parameters for the relationship between interest rate and nominal exchange rate differentials. They concluded that UIRP was absent because of the inefficient decisions made by agents operating in the foreign exchange market. Boschen and Smith (2016) supported these claims and highlighted the importance of monetary market frictions, mainly the role that information asymmetries play in risk perception. Husted et al. (2018) confirmed the previous studies, claiming that violations of the UIRP theory are mainly due to uncertainty in the financial market, but, given the lack of adequate ways to measure these variables, the causes of uncertainty have not been well addressed in empirical research. By proposing a monetary uncertainty index, their results suggest that increased uncertainty in the most important financial markets increases risk-aversion. This affects expected returns and, in turn, affects the cost of risk protection in the foreign exchange market. In the same vein, Ismailov and Rossi (2018) also used an index for monetary uncertainty. They concluded that presence or absence of UIRP depends upon the uncertainty in a financial market.

There is limited evidence showing a proportional relationship between interest rate differentials and nominal exchange rate differentials. Most of that evidence comes from research done using long-term interest rates and long time periods. Lothian and Wu (2011), for example, used two centuries, from 1800 to 2000, as their time period, including short-term and long-term interest rates from the UK, France, and the USA. They found empirical evidence supporting the UIRP. However, when they performed the same analysis for 1970–1980, a period in which the US dollar showed a strong appreciation, the coefficient became negative. The authors concluded that the relationship between interest rate differentials and nominal exchange rate differentials is sensitive to economic stability, and, therefore, results depend on the time period studied. Five years later, Lothian (2016) replicated the study and obtained similar results. He claimed that interest rate differentials diminish over long periods of time, so the controversy is not whether the hypothesis is valid or not, but rather within what time frame the hypothesis is valid. From these studies we can see that although evidence supporting UIRP has increased in the last few years, this evidence is not yet conclusive.

2.2. Long-term interest rate determinants

The study of long-term interest rates provides a group of variables which present a significant effect on interest rates. Therefore, we included these variables to model long-term interest rate differentials. One of the factors shown to impact long-term interest rates is fiscal deficit. For instance, Cebula (2014) used quarterly and annual data from 1960 to 2013 to study the effect of fiscal deficit on the long-term interest rate. They found that fiscal deficit has a negative and significant effect on the long-term interest rate. This effect is supported by different authors; see e.g., Feldstein and Eckstein (1970), Hoelscher (1986), Barth et al. (1984), Findlay (1990), Johnson (1992), and Canzoneri et al. (2002). Public debt is also found to have a significant effect on long-term interest rates. Laubach (2009) studied the relationship between long-term interest rates and public debt by using long-term forward rates and projections of the government deficit. He showed empirical evidence over thirty years of a significant relationship between the variables in analysis. Ang et al. (2008) argued that inflation rate has an impact on long-term interest rates. Specifically, they concluded that expected inflation and high-inflation risk represent the 80% variation of both short-term and long-term interest rates. In a different perspective, Sambharya and Rasheed (2015) claimed that high levels of political and economic freedom generally create a positive environment for international trade,

which has a significant impact on the behavior of real interest rates. These claims were supported by Simwaka (2010) and Staehr (2016), who added that choosing an appropriate exchange rate regime can regulate interest rate shocks. Finally, there is also evidence that economic crises influence long-term interest rates. Bean et al. (2015) and Rachel and Smith (2015) observed that during crisis periods occur changes in saving levels leading to a fall in real interest rates.

3. Methodology

The theoretic relationship between interest rate differentials and exchange rate differentials can be obtained using the EHTS and UIRP hypotheses. The EHTS hypothesis asserts that the long-term interest rate is equal to the weighted average of short-term interest rates. Using the EHTS for a foreign and domestic interest rates and assuming that UIRP holds, one can have the interest rate differentials as a function of the expected exchange rate differential (for details see Bekaert et al., 2007). Aside from the nominal exchange rates, there are other macroeconomic variables that could be considered determinants of long-term interest rate differentials as was discussed in section 2. Empirical research has revealed that inflation, public and fiscal deficit (Feldstein and Eckstein, 1970; Hoelscher, 1986; Barth et al., 1984; Findlay, 1990; Johnson, 1992; Canzoneri et al., 2002; Cebula, 2014), exchange rate regime (Simwaka, 2010; Staehr, 2016), and financial crises (Bean et al., 2015; Rachel and Smith 2015) have a significant impact on the long-term interest rates (see section 2 for details). For this reason, we include these variables in our empirical model as potential determinants for long-term interest rate differentials.

Gravity models allow us to model trade flows between two economies (origin and destination economy) controlling by their sizes and common characteristics (Tinbergen, 1962). To capture temporal and individual heterogeneity, we aim to use a panel data approach to estimate a gravity model. Since gravity controls are time-invariant, there is a challenge to estimate a gravity panel model because of the perfect collinearity between gravity controls and country-pair fixed effects. We solve this problem by estimating a gravity panel model through fixed effects vector decomposition. Following Plümper and Troeger (2007) [1], this methodology includes three stages. In the first stage, we estimate a fixed-effects data panel by using the variables that vary by individual and over time, that is:

$$\Delta \boldsymbol{r}_{ijt} = \boldsymbol{\alpha}_{ij}^{1st} + \vartheta_t^{1st} + \sum_{p=1}^{10} \varphi_p^{1st} \boldsymbol{y}_{pjt} + \sum_{p=1}^{10} \boldsymbol{\delta}_p^{1st} \boldsymbol{y}_{pjt} + \boldsymbol{\beta}_{ijt}^{1st} \Delta \boldsymbol{E}_{ijt+1} + \boldsymbol{\rho}^{1st} \boldsymbol{D}_t + \varepsilon_{ijt} \tag{1}$$

In the second step, the fixed effects α_{ij}^{1st} are decomposed into two parts – one identified and one unidentified:

$$\boldsymbol{\alpha}_{ij}^{1st} = \sum_{k=1}^{2} \boldsymbol{\theta}_k^{2nd} \boldsymbol{x}_{kij} + \boldsymbol{h}_{ij} \tag{2}$$

In the third step, the model is estimated without the individual fixed effects but including the unidentified part, h_{ij}, as obtained in the second step:

$$\Delta \boldsymbol{r}_{ijt} = \vartheta_t + \sum_{k=1}^{2} \boldsymbol{\theta}_k \chi_{kij} + \sum_{p=1}^{10} \varphi_p \boldsymbol{y}_{pit} + \sum_{p=1}^{10} \boldsymbol{\delta}_p \boldsymbol{y}_{pjt} + \boldsymbol{\beta} \Delta \boldsymbol{E}_{ijt+1} + \boldsymbol{\rho} \boldsymbol{D}_t + \boldsymbol{\psi} \boldsymbol{h}_{ij} + \boldsymbol{\varepsilon}_{ijt} \tag{3}$$

where ψ is the parameter for the residual of the second step, which, by construction, must be equal to 1 (for details see Plümper and Troeger, 2007), Δr_{ijt} represents the long-term interest rate differential between economies i and j over time period t. Next, χ_{kij}represents the determinants of the gravity model, which are common and invariant characteristics between country pairs; common language (LANG) and distance (DIST). Macroeconomic variables that affect the long-term interest rate differentials are represented by y_{pit}. They include GPD per capita (GDPP) to measure the wealth of the economies being studied; GDP per capita growth rate (GDPPG); economic freedom indexes (EFI), which include an investment freedom index (IFI), a business freedom index (BFI), a governmental integrity index (GII), and a financial freedom index (FFI); exchange rate regime (ERR), inflation (INF), fiscal deficit (FD), and public debt (DP) for the country of origin. Those same variables for the destination country are represented by y_{pjt}. D_t is a dummy variable that includes the effect of financial crises during the sample period; it takes a value of 1 when the Asian and Subprime crises occurred and 0 otherwise. The expected nominal exchange rate differential one period ahead is represented by variable ΔE_{ijt+1}. A fixed effect by year is represented with ϑ_t, while α_{ij} is a country-pair fixed effect. θ_k is a coefficient associated with gravity controls; φ_p and δ_p are the parameters of the macroeconomic determinants for the economies of origin and destination, respectively. Parameters associated with economic crises are represented by ρ, whereas ε_{ijt} is an identical and independently distributed error term. Superscripts 1st and 2*nd* stand for coefficients in first and second stages, respectively. Finally, β is the parameter that allows us to test the validity of the UIRP hypothesis, taking a value of one if UIRP holds.

4. Data

Our sample contains 45 countries[2], classified into two groups according to income-level criteria used by the World Bank (see for example, Fantom and Serajuddin, 2016). These groups are based on Gross National Product per capita (GDPP), using 2016 as the reference year. The first group is composed of high-income countries (35), while the second group is composed of middle-incomes economies (10), i.e. upper and lower middle-income. This sample was chosen only based on the availability of information. Countries with low incomes are not included due to a lack of available data. In this study, we analyze 79 quarters from 1992Q2 to 2011Q4 (based on availability of information). As long-term interest rates, we use long-term government bond yields. We understand that long-term bond yields can be affected by heterogeneous factors across the different countries in our sample such as different tax regimes or capital controls. In this context, macroeconomic controls play a role capturing this heterogeneity across the different economies in analysis here. Furthermore, there is extensive evidence using long-term bond yields to study the UIRP hypothesis. For instance, Lothian and Wu (2011) use long-term government bond yields and high-grade corporate bond yields, Chinn and Meredith (2004) use government bond yield 10-year maturity, and Lothian (2016) uses long-term bond yields. The long-term government bond yields (IR) and the nominal exchange rates (NER), expressed in national currency (NC) as Special Drawing Rights (SDR), were retrieved from the International Monetary Fund's (IMF) International Financial Statistics in quarterly frequency (International Monetary Fund, 2013). Table 1 presents the behavior of the long-term interest rates (IR) and the nominal exchange rates (NER) for both groups of countries and Table 2 shows the main characteristics of the macroeconomic variables and gravity controls analyzed in this study (see Appendix 1 for the data source of these variables). Both tables evidence that high-income

[1] Green (2011) criticized the FEVD stating that this method is a type of random effect which could be inconsistent in the presence of correlation between the individual effects and additional variables in the model. Plümper and Tröger (2011) replied this criticism stating that this issue would only be valid in the presence of an infinite sample.

[2] The countries were chosen based on data availability.

Table 1. Descriptive statistics for Long-term interest rates (IR) and nominal exchange rates (NEM).

Country	IR (%)			NEM (NC/SDR)		
	Mean	Standard Deviation	Coefficient of Variation	Mean	Standard Deviation	Coefficient of Variation
High-income economies						
Australia	6.36	1.43	0.23	2.01	0.25	0.12
Austria	4.99	1.38	0.28	16.03	0.75	0.05
Belgium	5.18	1.49	0.29	47	2.34	0.05
Canada	5.66	1.68	0.3	1.86	0.18	0.09
Cyprus	5.35	1.18	0.22	0.71	0.05	0.08
Czech Republic	4.57	1.05	0.23	38.18	7.11	0.19
Denmark	5.21	1.8	0.35	8.99	0.77	0.09
Estonia	7.85	3.04	0.39	18.84	1.69	0.09
Finland	5.45	2.35	0.43	7.12	0.57	0.08
France	4.98	1.5	0.3	7.74	0.33	0.04
Germany	4.75	1.43	0.3	2.28	0.11	0.05
Greece	9.26	6.28	0.68	374.44	56.64	0.15
Hungary	7.53	0.92	0.12	276.64	71.66	0.26
Iceland	5.67	1.54	0.27	116.91	33.53	0.29
Ireland	5.78	1.87	0.32	0.92	0.05	0.05
Italy	6.32	3.01	0.48	2,276.23	200.3	0.09
Japan	1.87	0.99	0.53	156.91	15.67	0.1
Latvia	6.46	2.65	0.41	0.81	0.06	0.08
Lithuania	6.06	2.85	0.47	4.75	0.91	0.19
Luxembourg	4.8	1.59	0.33	47	2.34	0.05
Malta	4.85	0.62	0.13	0.53	0.03	0.06
Netherlands	4.86	1.36	0.28	2.56	0.12	0.05
New Zealand	6.32	1.15	0.18	2.4	0.32	0.13
Norway	5.16	1.74	0.34	9.82	0.83	0.08
Poland	6.42	1.57	0.24	4.48	0.96	0.21
Portugal	6.48	3.03	0.47	229.09	17.56	0.08
Rep. of Korea	7.98	3.51	0.44	1,527.43	274.13	0.18
Singapore	3.21	0.84	0.26	2.26	0.14	0.06
Slovakia	5.16	1.46	0.28	48.08	7.98	0.17
Slovenia	11.41	16.76	1.47	242.37	57.13	0.24
Spain	6.00	2.66	0.44	186.89	17.69	0.09
Sweden	5.55	2.43	0.44	11	1.04	0.09
Switzerland	3.21	1.15	0.36	1.87	0.2	0.11
United Kingdom	5.57	1.72	0.31	0.88	0.07	0.08
United States	5.01	1.31	0.26	1.44	0.1	0.07
TOTAL	**5.75**	**2.32**	**0.37**	**56.75**	**22.10**	**0.11**
Middle-income economies						
Bulgaria	14.43	18.35	1.27	1.84	0.99	0.54
Honduras	16.63	8.54	0.51	21.83	6.83	0.31
Malaysia	4.84	1.53	0.32	4.8	0.72	0.15
Mexico	14.89	12.32	0.83	13.58	4.73	0.35
Philippines	13.23	2.47	0.19	60.51	15.9	0.26
Russia	7.70	1.37	0.18	29.55	17.36	0.59
Solomon Islands	7.48	4.08	0.55	8.59	3.06	0.36
Sri Lanka	15.81	0.71	0.04	121.95	41.01	0.34
Thailand	6.84	2.95	0.43	49.64	8.67	0.17
Vanuatu	8.31	0.25	0.03	166.66	11.19	0.07
TOTAL	**11.02**	**5.26**	**0.44**	**47.90**	**11.05**	**0.31**

Notes: IR, NEM, NC, and SDR stands for Long-term interest rate, nominal exchange rate, national currency, and special drawing rights, respectively.

Table 2. Descriptive statistics for macroeconomic variables by country groups.

Country group	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
	GDPP (US$)			GDPPG (%)		
High-income economies	33,883.30	14,074.80	0.42	2.31	3.33	1.44
Middle-income economies	8,907.95	6,016.82	0.68	2.14	4.55	2.12
	IFI (points)			**BFI (points)**		
High-income economies	70.06	12.25	0.17	79.00	6.87	0.09
Middle-income economies	44.78	16.17	0.36	66.83	9.29	0.14
	GII (points)			**FFI (points)**		
High-income economies	69.99	20.55	0.29	68.27	15.59	0.23
Middle-income economies	33.93	12.35	0.36	47.00	12.40	0.26
	INF (%)			**FD (% of GDP)**		
High-income economies	0.05	0.22	4.35	2.01	4.95	2.46
Middle-income economies	0.24	1.15	4.88	1.48	3.72	2.51
	DP (% of GDP)			**ERR (1–5)**		
High-income economies	55.64	35.68	0.64	1.94	1.10	0.57
Middle-income economies	46.91	29.37	0.63	2.14	1.19	0.56

Notes: GDPP, GDPPG, IFI, BFI, GII, FFI, INF, FD, DP, and EER stand for per capita GDP growth rate, investment freedom index, business freedom index, government integrity index, financial freedom index, inflation, fiscal deficit, public debt, and exchange rate regime, respectively.

Table 3. Coefficients associated with the nominal exchange rate differential (β) using fixed effects vector decomposition.

Country of origin	Country of destination					
	High-income economies			Middle-income economies		
	β	Standard error	Test $\beta = 1$	β	Standard error	Test $\beta = 1$
High-income economies	1.013***	0.167	0.010	1.186***	0.561	0.110
Middle-income economies	2.341***	0.751	3.190*	-1.373	3.216	-
Goodness-of-fit						
	Origen: High-income Destination: High-income		Origen: High-income Destination: Middle income		Origen: Middle income Destination: High-income	
Residual Stage 2	0.950***		0.843***		0.803***	
F-Statistic[a]	0.720		0.852		135.17***	
AIC	87,438.204		19,644.065		7,936.330	
First stage						
R^2	0.297		0.630		0.595	
F-Statistic[b]	266.960***		175.230***		75.760***	
Annual fixed effect	yes		yes		yes	
Country-pair fixed effect	yes		yes		yes	
Second stage						
R^2	0.058		0.044		0.102	
F-Statistic[b]	819.440***		102.86***		127.61***	
Third stage						
R^2	0.713		0.899		0.885	
F-Statistic[b]	1,493.280***		889.070***		381.02***	
Country-pair fixed effect	yes		yes		yes	

Notes: [a] and [b] corresponds to test for $\psi = 1$ and overall significance test, respectively. - stands for cases in which test $\beta = 1$ is not obtained since β -coefficient is not significant. *,**, and *** corresponds to significance at the 10%, 5%, and 1%, respectively.

countries have less variation in their characteristics as compared to middle-incomes nations.[3]

5. Results and discussion

Table 3 shows the results of the coefficients associated with nominal exchange rate β, which allows us to analyze the validity of UIRP for the different sample countries. For middle-income economies of origin and destination, the coefficient for the nominal exchange rate differential is not significant and negative. This finding supports empirical literature that rejects the UIRP hypothesis exposed in the literature-review section (Chinn and Meredith, 2004; Gourinchas and Tornell, 2004; Baccheta and van Wincoop, 2013; Chinn and Quayyum, 2012; Chinn and Zhang, 2018; Boschen and Smith, 2016; Herger, 2016; Husted et al., 2018; Ismailov and Rossi, 2018).

Contrary to the above findings, we find evidence that when the origin and destination countries belong to the high-income group, or when just one of the countries is a high-income economy, the coefficient associated with parameter β is statistically significant and equal to the unit. This

[3] Note that some specific countries present high variation over the sample period which can be driven by the presence of outliers; see for example, Slovenia which has an IR mean value of 11.41 and an IR standard deviation of 16.76.

finding suggests that the interest rate and nominal exchange rate differentials exhibit a proportional relationship, supporting the presence of UIRP. These results are in line with the scarce empirical literature that supports the UIRP theory using long-term interest rates (Lothian and Wu, 2011; Lothian, 2016).

It is worth mentioning the potential endogeneity present in the specifications of Eq. (3). Some authors have found evidence that fiscal deficit and public debt have a significant effect on determining a country's wealth, interest rates, and economic growth (Elmendorf and Mankiw, 1999; Cochrane, 2011). We deal with the potential endogeneity by using the Hausman-Taylor estimator (Hausman and Taylor, 1981). This approach distinguishes between time-variant and time-invariant variables for a random-effects estimation. This is an advantage for our approach since gravity models used both types of variables. Therefore, we estimate a Hausman-Taylor estimation using GDP per capital (GDPP), growth of GDP per capita (GDPPG), fiscal deficit (FD), public debt (PD), and nominal exchange rate differential (NER) as endogenous variables for the origin and destination economies. Table 4 presents the results of the Hausman-Taylor estimation in terms of coefficients β for each case. Our results indicate that the UIRP hypothesis is validated when the origin and destination countries are high-income and also when the origin country is high-income and the destination country has a middle-income. In both cases the null hypothesis $\beta = 1$ is not rejected.

Since the UIRP hypothesis is supported in the two cases mentioned above, it is possible to identify macroeconomic variables that influence the determination of long-term interest rate differentials. Table 5 shows the results for origin and destination countries with high-income economies. The gravity controls reflect a positive and statistically insignificant relation between sharing an official first language and long-term interest rate differentials. As for the distance variable, there is a positive and statistically significant relation between the two variables, implying that a greater distance between capital cities leads interest rate differentials to be higher. This finding could be explained by a decrease in capital flows when transaction costs involved in investing outside of a country's borders are higher. In relation to the macroeconomic determinants, we find different variables for origin and destination which have a significant impact on the long-term interest rate differential; GDPP, GDP growth rate, economic freedom indices, fiscal deficit, public debt, inflation, exchange rate regime, and financial crisis. Although magnitude and significance vary between origin and destination countries, it is possible to identify factors which affect the long-term interest rate differentials.[4] This information can be useful to access to cheaper international funding, especially for developing countries (the UIRP hypothesis is also supported in the case when high-income countries are origin economies and middle-income countries are destination economies, see Appendix 2 for details).

Table 4. Coefficients associated with the nominal exchange rate differential (β), corrected for endogeneity using the Hausman-Taylor estimator.

Country of origin	Country of destination					
	High-income economy			Middle-income economy		
	β	Standard error	Test $\beta = 1$	β	Standard error	Test $\beta = 1$
High-income economy	1.098***	0.170	0.330	1.733***	0.581	1.590
Middle-income economy	1.267	0.831	-	-2.869	2.989	-

Notes: - stands for cases in which test $\beta = 1$ is not obtained since β -coefficient is not significant. *,**, and *** corresponds to significance at the 10%, 5%, and 1%, respectively.

Table 5. Results for high-income economies.

Variable	Coefficient	Estimate	Standard error
Expected nominal exchange rate differential	β	1.098***	0.170
Gravity control			
LENG	θ_1	0.244	0.410
DIST	θ_2	-7.5E-05**	2.2E-05
Country of origin			
GDPP	φ_1	-2.4E-05	1.8E-05
GDPPG	φ_2	-0.181***	0.003
BFI	φ_3	0.967**	0.330
IFI	φ_4	-1.584***	0.145
GII	φ_5	0.975***	0.161
FFI	φ_6	-2.241***	0.122
ERR	φ_7	-0.001	0.021
INF	φ_8	0.087***	0.005
FD	φ_9	-0.056***	0.003
DP	φ_{10}	0.007***	6.4E-04
Country of destination			
GDPP	δ_1	1.0E0.4***	3.1E-05
GDPPG	δ_2	0.178***	0.003
BFI	δ_3	-0.588**	0.297
IFI	δ_4	-0.078	0.134
GII	δ_5	-1.990***	0.167
FFI	δ_6	1.661***	0.103
ERR	δ_7	-0.350***	0.024
INF	δ_8	-0.080***	0.004
FD	δ_9	0.055***	0.003
DP	δ_{10}	-0.009***	5.4E-04
Crisis	ρ	0.145***	0.023
Goodness-of-fit			
χ^2-Statistic[a]	10,538.15***		
Annual fixed effects	yes		

Notes: [a] corresponds to the overall significance test. *,**, and *** corresponds to significance at the 10%, 5%, and 1%, respectively. GDPP, GDPPG, IFI, BFI, GII, FFI, INF, FD, DP, and EER stand for per capita GDP growth rate, investment freedom index, business freedom index, government integrity index, financial freedom index, inflation, fiscal deficit, and public debt, exchange rate regime, respectively.

We perform three additional robustness checks. First, we use interpolation for our variables in annual frequency (GDPP, GDPPG, FD and PD) to model the quarterly behavior. We use three methods: the cubic method, the quadratic method, and the Denton method (see Table 6). Second, we test whether our results remain true for different future time periods of the exchange rate differentials: three, six, nine, and twelve periods ahead (see Table 7). These results mainly support the UIRP hypothesis when both origin and destination countries are high-income economies. Finally, we investigate the presence of outliers in our approach (when origin and destination countries are high-income economies). Note that despite the presence of outliers can affect the estimated coefficients in different ways (Rousseeuw and Leroy, 2003; Dehon et al., 2009), Lothian and Wu (2011) show that large interest-rates differentials are beneficial to support the UIRP hypothesis. We follow Lyu (2015) who provides a test which is efficient to detect multivariate and nonidentified outliers through a *LM* statistic distributed as χ^2 with one degree of freedom. We perform this test for each observation in our dataset detecting 169 individual outliers. We eliminate these observations from our sample and re-estimate our Hayman-Taylor model whose results provide a UIRP coefficient of 0.88 with a statistic of 0.48 (p-value of 0.49) for the null hypothesis that the UIRP coefficient is equal to the

[4] These findings are robust to the fixed-effects vector decomposition estimation. Results can be obtained from authors upon request.

Table 6. Coefficients associated with nominal exchange rates (β), corrected for endogeneity and interpolated using cubic, quadratic, and Denton methods.

Country of origin	Country of destination					
	High-income economies			Middle-income economies		
	β	Standard error	Test $\beta=1$	β	Standard error	Test $\beta=1$
Cubic method						
High-income economies	1.219***	0.171	1.640	2.542***	0.604	6.510**
Middle-income economies	1.803***	0.895	0.810	-2.476	2.695	-
Quadratic method						
High-income economies	0.726***	0.169	2.620	1.203**	0.589	0.120
Middle-income economies	0.852	0.818	-	-5.518**	2.695	4.810**
Denton method						
High-income economies	1.189***	0.169	1.260	2.293***	0.600	4.640**
Middle-income economies	1.847**	0.887	0.910	-2.216	2.660	-

Notes: - stands for cases in which test $\beta = 1$ is not obtained since β -coefficient is not significant. *,**, and *** corresponds to significance at the 10%, 5%, and 1%, respectively.

Table 7. Coefficients of nominal exchange rate differentials (β) at three, six, nine, and twelve periods ahead.

Country of origin	Country of destination					
	High-income economies			Middle-income economies		
	β	Standard error	Test $\beta=1$	β	Standard error	Test $\beta=1$
Three periods ahead						
High-income economies	1.321***	0.100	10.320**	4.341***	0.387	74.390***
Middle-income economies	2.153***	0.516	4.990**	3.919**	2.268	1.660***
Six periods ahead						
High-income economies	0.876***	0.075	2.720*	1.699***	0.324	4.650**
Middle-income economies	0.839**	0.414	0.150	3.256	2.199	-
Nine periods ahead						
High-income economies	0.922***	0.062	1.510	0.432	0.327	-
Middle-income economies	-0.140	0.387	-	-2.411	2.440	-
Twelve periods ahead						
High-income economies	0.987***	0.053	0.060	-1.041**	0.332	37.620***
Middle-income economies	-0.925**	0.391	24.230***	-14.185***	2.829	28.81***

Notes: - stands for cases in which test $\beta = 1$ is not obtained since β -coefficient is not significant. *,**, and *** corresponds to significance at the 10%, 5%, and 1%, respectively.

unit. This statistic fails to reject the null hypothesis supporting, in this way, our main finding.[5] In spite of this evidence, we believe that the effect of outliers can represent a limitation for our study which needs to be investigated in further research.

Other methodological approaches have been suggested for a panel data. Afat and Frömmel (2021) investigate the UIRP by estimating a panel vector error correction model through the autoregressive distributional lag (ARDL) specification suggested by Pesaran et al. (1999). We investigate the order of integration in our dependent variable by using the unit root test proposed by Pesaran (2007) which takes the cross-section dependence into account. We obtain a statistic of -2.551, with a p-value of 0.102 (near to reject the null hypothesis of unit root at the 10% of significance).[6] Note that our dependent variable needs to be stationary in its first difference form and nonstationary in its level form to estimate an ARDL model. We use the panel cointegration test proposed by Westerlund (2008) which provides a statistic of 1.16 (with a p-value of 0.12) which fails to reject the null hypothesis of no-cointegration.[7] This evidence implies that a vector error correction model does not seem to be appropriate for our dataset.[8] An additional method is suggested by Ferreira and Kristoufek (2020) who propose a fractal analysis to capture potential nonlinear effects between the variables under analysis. This method requires high frequency data (these authors used daily data); thus, a fractal analysis does not seem to be appropriate for our quarterly panel. However, to investigate nonlinear effects in a gravity panel approach seems to be an interesting area for future research.

Our findings can be linked to four theoretical postulates. First, our empirical results show that the UIRP is supported by a sample of high-income countries and rejected for a sample of middle-income economies. Theoretical evidence shows that more efficient investment processes decrease uncertainty (Gourinchas and Tornell, 2004; Bacchetta

[5] We also re-estimate the Hausman-Taylor model for a subsample which does not include the presence of the 0.5% upper and lower percentile values of the nominal exchange rate differential and the bond yield differential whose results support our main findings. These results can be obtained from authors upon request.

[6] The null hypothesis of unit root is rejected at the 1% level for the first difference form.

[7] Note that we have so many variables in our approach (interest-rate determinants) so we test cointegration between the interest-rate and exchange rate differentials.

[8] Note that Afat and Frömmel (2021) use the 5-year sovereign credit default swap to capture time-varying risk premium; however, this variable is available since 2008 and for a small number of countries of our sample. Therefore, we are not able to use this variable to capture changes in the risk premium over time.

and Van Wincoop, 2013; Boschen and Smith, 2016). Thus, our results suggest that high-income economies have fewer risk factors compared to investors in middle-income countries. In this way, information asymmetries are reduced favoring the proportional relationship between the interest rates differential and nominal exchange rate differential. Second, since supporting the UIRP implies integrated financial markets (Lemmen, 1996; Mansori, 2003), our results also show a higher level of financial-market integration in high-income economies compared to middle-income countries. Third, Chinn and Meredith (2004) provide a theoretical model where both short-run shocks and monetary policy drive the rejection of the UIRP; however, this effect decreases in the long run favoring the UIRP. Our approach does not use ultra-long time series (such as Lothian and Wu, 2011) which suggests that increasing the number of country differentials (interest rates and expected exchange rates) is also useful to deal with specific country disturbances during the short run. Finally, since we test the UIRP hypothesis by modeling the long-term interest differential as a function of the expected nominal exchange rate change, our results are in line with theoretical evidence using the relationship between the EHTS and the UIRP hypotheses (Bekaert et al., 2007) to provide evidence in favor of the UIRP.

6. Conclusions

Using the gravity approach as a model of determination for interest rate differentials, this study shows that Uncovered Interest Rate Parity (UIRP) exists when incorporating heterogeneity in exchange rate and interest rates. This is important because our sample period was not excessively long as in previous research supporting the UIRP hypothesis. In fact, our evidence shows that the presence of UIRP is sensitive to the economies' income level. More specifically, UIRP is supported when both country of origin and destination are high-income economies. This finding is robust to endogeneity, different leads of exchange rates, interpolation of annual controls, and eliminating outliers from the sample. Our results using middle-income economies rejects the UIRP hypothesis. Evidence shows that information asymmetries play an important role driving this result since agents are not equipped with real information about the data generation process making, in this way, infrequent and inefficient investment decisions. This phenomenon leads to an increase in risk-aversion and, therefore, higher costs of managing the portfolios. This is closely related to conclusions made by Boschen and Smith (2016), who emphasize the existence of monetary market frictions and the role that information asymmetries play in risk-perception. Similarly, Husted et al. (2018) and Ismailov and Rossi (2017) suggest that high uncertainty in monetary markets – which has repercussions on agents' decisions – significantly affects the UIRP hypothesis. Our findings suggest that these issues seem to significantly decrease for high-income countries whose evidence is found to support the UIRP hypothesis. More efficient investment processes in the foreign exchange markets allows to achieve synchronized interest rates and nominal exchange rate differentials. In this way, information asymmetries are reduced, leading to smaller differentials between the interest rates and nominal exchange rates of the two high-income economies. The advantage of our panel gravity model is that it allows us to capture different combinations of both exchange rate and interest rate differentials in our sample. This issue is of relevance since previous empirical evidence uses few high-income countries over a long time period.

We also identified macroeconomic variables that affect long-term interest rates. These variables were: GPD per capita, growth rate of GDP per capita, inflation, fiscal debt, public debt, and economic freedom. Analyzing the effects that these variables have on interest rate differentials allows policy makers to make more efficient decisions to access to lower international debt costs. That is why maintaining adequate levels of inflation, fiscal deficit, and public debt, together with efficient regulation of economic freedom, can allow countries access to lower international credit.

Future areas of research are proposed by this study. Testing the different hypotheses explaining the rejection of the UIRP for middle-income countries under our approach is an interesting future research. Specifically, our approach efficiently deals with a small number of countries and time periods which is one of the main constraints to study the UIRP hypothesis. Moreover, using alternative interest rates such high-grade corporate bond yields or short-term interest rate proxies is also a way in which our approach can be beneficial to study the UIRP hypothesis. Using nonlinear and cointegration methods are also interesting to apply to a gravity panel approach to investigate the UIRP hypothesis. Finally, the presence of outliers represents a limitation for our approach which needs to be investigated in future research. In this way, the method proposed by Baltagi and Bresson (2012) seems to be a natural starting point to analyze in detail the effect of outliers on the UIRP hypothesis. Moreover, additional approaches to test the presence and type of outliers in panel data are needed since outliers can affect estimated coefficients in different ways, having even a marginal effect on the parameters of interest (Rousseeuw and Leroy, 2003; Dehon et al., 2009).

Declarations

Author contribution statement

Gabriel Pino: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Vanessa Orellana: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data will be made available on request.

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The authors declare no conflict of interest.

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