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Uncovered interest rate parity through the lens of fractal methods: Evidence from the European Union

Paulo Ferreira [a,b,c], Ladislav Kristoufek [d,*]

[a] *CEFAGE-UE, IIFA, Universidade de Évora, Évora, Portugal*
[b] *VALORIZA - Research Center for Endogenous Resource Valorization, Portalegre, Portugal*
[c] *Instituto Politécnico de Portalegre, Portalegre, Portugal*
[d] *The Czech Academy of Sciences, Institute of Information Theory and Automation, Prague, Czech Republic*

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A B S T R A C T

We study the uncovered interest rate parity in the European Union utilising the newly proposed regression frameworks based on the detrended cross-correlation analysis and the detrending moving-average cross-correlation analysis. The parity is analysed for three groups — the early Euro adopters, the later adopters, and the EU countries that are outside of the Eurozone. The main contributions of our study are twofold. First, we have analysed a large dataset that is not standard in the topical applied papers. And second, the utilised methods have allowed us to focus on possible differences between the short-term and long-term relationships between the interest rate differentials and foreign exchange rates that form the parity. Overall, the evidence for the parity is scarce, which is in hand with most of the previous studies. However, we have also uncovered some interesting patterns in the results and we provide an additional discussion of possible causes and directions for future research.

1. Introduction

The uncovered interest rate parity (UIP) is, with other interest parity conditions, a measure of financial integration [1,2]. In the context of the European Union (EU), it is expected that countries are financially integrated, mainly those which adopted the Euro as the common currency because of its benefits such as better saving allocation, reduction of costs and economic growth, among others, but also because the non-verification of financial integration in the case of the common currency adoption might imply risks such as faster crisis spread and contagion [1–3].

UIP is a relationship between interest rates and exchange rates which states that a country with higher interest rates should have a depreciating currency compared to a country with lower interest rates. In other words, an investment, independently of being made in domestic or foreign currency, should yield the same return on average, when considering the same currency. However, the empirical evidence commonly finds the opposite result: an appreciation of the exchange rate even when interest rates are higher.

This phenomenon, known as the forward premium puzzle, is commonly associated with several features such as the possibility of the rational expectations hypothesis rejection, the existence of a risk premium driving a wedge between the expected and effective exchange rate changes or econometric issues. These are usually attributed to specific issues such as the peso problem, learning processes or the existence of a carry trade problem. The peso problem occurs when agents

* Corresponding author.
E-mail address: kristouf@utia.cas.cz (L. Kristoufek).

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hope that a given phenomenon will happen but it occurs just outside the studied sample. The learning processes bring a time gap between occurring events and agents' adaptation. Finally, the existence of a carry trade means that agents have higher shares of given currency compared to others (for better understanding of these definitions, please refer to e.g. [4,5]). Menkhoff et al. [6] and Lustig et al. [7] identify the carry trade returns that arise from exploiting the forward bias can be understood as compensation for volatility risk. With a different approach, Bekaert et al. [8] claim that UIP could be currency dependent rather than horizon dependent.

In this paper, we analyse the UIP condition for the European Union using two novel regression frameworks based on fractal analysis (detrended fluctuation analysis and detrended moving average cross-correlation analysis). We aim to be innovative in two different ways: firstly, by extending the sample analysis to the new EU countries (to the best of our knowledge, there has been no study with such large sample of the EU countries); and secondly, by providing an analysis utilising new methodologies, we hope to answer whether the forward premium puzzle can be related to the choice of methodologies and sample dimensions, closely following our previous analysis on the covered interest rate parity [9]. This latter issue is confirmed by our analysis.

The remainder of the paper is organised as follows. Section 2 presents a theoretical background and a brief literature review into UIP. In Section 3, we describe the utilised methodology and the dataset. Section 4 discusses the results and Section 5 concludes.

2. Theoretical background and literature review

The uncovered interest rate parity (UIP), widely used for exchange rate models, is an indicator of the degree of asset substitutability [10]. It is uncovered because it leaves investors at risk that the future exchange rate differs from the expectations. UIP states that the domestic return is equivalent to the foreigner's return adjusted for changes in the exchange rate expectations. In other words, it is possible to write

$$(1+i_t) = (1+i_t^*)\frac{S_{t+1}^e}{S_t} \tag{1}$$

where i are the interest rates (while $*$ refers to a foreign rate), S is the spot exchange rate and S_{t+1}^e is the expected exchange rate at the end of maturity of a given asset. After the logarithmic transformation, we obtain an approximation of:

$$i_t = i_t^* + s_{t+1}^e - s_t \tag{2}$$

The expectation about the future exchange rate is an unobserved variable. The most usual way of dealing with this issue is to use the assumption of rational expectations using current data, i.e. estimating the UIP equation ex post. This implies that agents make rational use of all available information, hoping that there are no systematic errors, i.e. that the average of errors is annulled, so that:

$$\begin{aligned}\mathbb{E}(S_{t+1}) - S_{t+1} &= \varepsilon_t \\ \mathbb{E}(\varepsilon_{t+1}|I_t) &= 0\end{aligned} \tag{3}$$

where $\mathbb{E}$ is the expectations operator and I_t is the information set at time t. This implies that agents do not make any systematic errors so that there is no statistical difference between the value that the exchange rate is expected to take in the future and the value that the exchange rate will effectively take. We use this assumption in this work.

Eq. (2) can be rearranged to:

$$\Delta s_{t+1} = \alpha + \beta(i-i^*)_t + u_{t+1} \tag{4}$$

To verify the parity overall, we have the null hypothesis of $\alpha = 0$ and $\beta = 1$. There are two ways to test the hypothesis: the indirect form and the direct form. The indirect form is performed with the objective to analyse whether the forward exchange rate is a good predictor of the future spot exchange rate. Then the indirect tests should be applied utilising only the data from the foreign exchange markets [11–15]. When the objective is to analyse the degree of financial integration, as we intend in this paper, the direct form should be performed and Eq. (4) should be utilised. Even though the case can be made in favour of a more complex dynamics between exchange rates and interest rates, we follow the standard bivariate relationship here as is the case in the traditional literature on UIP [16–19].

In general, the empirical evidence suggests a paradox (puzzle): the slope parameter is estimated to be negative in several studies. Depreciation is expected when the domestic interest rate is higher than the foreign rate (and the exact amount of the spread), but the opposite is reported. There are several reviews about UIP and the referred puzzle. Works of Hodrick [20], Lewis [21], Froot & Thaler [22] or Miller [23] are some examples that cover several time spans. In the remainder of this section, we present a review of literature mostly covering the EU countries, which are of interest for our study.

In the context of the European Union studies, Gaab et al. [24] find evidence of a negative slope in Eq. (4) while studying the German mark, the British pound, and the French franc, as well as the US dollar and Swiss franc, from 1975 to mid-1984. They suggest price control and sample sensitivity as possible reasons for the referred puzzle. MacDonald & Torrance [25],

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using data for Germany, Japan, the United Kingdom and Switzerland, in relation to the USA, also reject UIP, invoking problems with the existence of a risk premium and with the irrationality in expectations. Flood & Rose [4] conclude that the UIP rejections could be due to flexible exchange rates and the deviations are explained by the existence of a peso problem. In their later study, Flood & Rose [5] compare the results of developed and developing countries, suggesting that UIP fits better during crisis times, but without any significant difference between developed and developing countries. These studies are prevalently based on a simple least squares regression.

The development of econometric techniques has given rise to several other ways of analysing the parity. With the application of the vector autoregression (VAR), Taylor [26], MacDonald & Taylor [27] and Kirikos [28] study UIP as presented in Eq. (4). None of these studies support the parity, pointing to the existence of the risk premium as the main failure and not the failure of rational expectations.

Using the error correction model (ECM), Karfakis & Parikh [29] find no evidence of UIP using American, British, German and Japanese currencies and long-maturity bonds between 1974 and 1989. Considering UIP with risk premium but in this case utilising short-term maturities, Bhatti & Moosa [30] once again find no evidence of UIP, considering several countries against the US dollar from 1972 to 1993 (some of them from the EU).

As for the other works, Marston [31] estimates a negative slope for the UIP equation for the UK, the US, Germany and France, with a sample from 1961 to 1991. The existence of a non-zero risk premium is one of the explanations advocating the UIP violation. Lemmen [1], centred on the EU countries, finds no evidence of support for UIP, even though the differentials have declined over time.

With time series and panel data, Huisman et al. [32] study the parity for 15 countries against the British Pound between January 1979 and March 1996. When the time series is used, negative and in general unstable slopes have been found. However, when applying panel data with random effects, the authors find coefficients between 0.43 and 0.55. Although parity is still not verified (since the parameter is expected to be equal to unity based on the underlying theory), the coefficients are not negative. Methodological specifics thus seem to play an important role as well. In fact, utilising other methodologies, specifically maximum likelihood estimators, Kirikos [33] concludes that parity is not rejected for Greece, Portugal and Italy between 1989 and 1998.

Applying methodologies to study the seasonality of deviations, Mansori [34] intends to evaluate the financial integration of the Central European countries that joined the European Union, comparing with countries that joined the Euro. For the Euro countries (France, the Netherlands, Spain and Italy, with pooled data), the coefficients are negative as in most cases (against Germany and the USA). For the Eastern countries that have joined the EU, the coefficients are positive (although some are not statistically different from zero). One possible explanation, which the authors indicate as unlikely, is that markets in these countries are better integrated with the world.

There are several possible reasons for this UIP failure. Since UIP turns out to be a joint hypothesis for rationality of expectations and for risk neutrality, parity failures can occur due to problems with either of these assumptions. Unfortunately, it is difficult to distinguish between them in practice. The possible non-existence of rational expectations is referred to, for example, in Taylor [26], who suggests that this can happen because agents acting in the markets are professionals and therefore have different information and motivations. The existence of the peso problem and learning processes on exchange rate regimes in force are two issues that may occur and do not imply irrational behaviour on the agents' part [27].

On the one hand, government interventions in financial markets are another possible cause of the UIP rejection [14,22,35]. On the other hand, any problem that exists with respect to the currencies under consideration leads to the possible existence of the risk premium sought by investors. The positive risk premium leads to a non-zero parity ratio discovered in interest rates (when strict parity assumption requires the value to be zero).

Other reasons for the UIP puzzle could be the non-rational expectations or the existence of risk premium that varies in time [36,37]. However, once again it is difficult to isolate the cause of the problems. In addition to these cases, Karfakis & Parikh [29] further point out that the UIP rejection might be due to possible non-linear relationship between interest rates and exchange, whereas Flood & Taylor [38] indicate that this can happen due to inefficient information processing or heterogeneity of agents' expectations.

Because most of the European Union countries have adopted a common currency, and as our approach implies the use of exchange rates, it is not possible to analyse UIP between the Eurozone countries. So, it is natural that most of the covered studies are relatively older. Nevertheless, there are several newer studies analysing wider portfolios of countries and longer samples due to better data availability. In fact, the use of longer samples is noted to have some advantages regarding the possibility of the UIP verification [39,40].

Furthermore, some studies point to a higher chance of the UIP verification for emerging economies compared to the more developed markets [41,42]. This provides further motivation for investigating the new members of the EU. The UIP relation could be also explained by non-linear movements, i.e. higher interest rate differentials could have a distinct forecasting power than smaller ones [43–45]. The use of non-linear methods might better explain UIP. Both these assertions are followed in our study where we apply non-linear methodologies not used for the UIP evaluation yet while markedly expanding the analysed dataset.

3. Methodology and data

Financial series are characteristic by some problematic properties, such as non-Gaussianity, persistence, scale dependence, and non-stationarity, that can complicate standard time series procedures [46]. The detrended fluctuation analysis (DFA) and the detrending moving average (DMA) procedures have been historically applied for studying fractal and long-range dependence properties of various datasets [47–49]. Both methods have been showed to be robust to persistence, short-range correlations and partially to heavy tails as well [50–52]. This makes them ideal for studying financial and economic series which usually suffer with these issues. Zebende [53] has approached the topic of long-range correlations and cross-correlations from a different perspective and he has introduced the correlation coefficient based on DFA and its bivariate generalisation — the detrended cross-correlation analysis (DCCA[1]) [65–67]. This DFA-based correlation coefficient approach describes the correlation profile between two series with respect to a range of studied scales, i.e. it does not describe the whole relationship between variables with a single coefficient but rather with a range of them. The idea of Zebende [53] has been used by Kristoufek [68] who introduces the DMA-based correlation coefficient with the help of the detrending moving-average cross-correlation analysis (DMCA) [69,70]. The latter method turns out to work better under the long-range dependence [71].

One step further from the correlation analysis, Kristoufek [72,73] moves DFA/DCCA and DMA/DMCA towards regression. These new estimators give estimates of the effects at different scales while keeping desirable properties such as robustness to long-term memory and/or non-stationary of the underlying series. The methods connect the ordinary least squares (OLS) estimator and the fluctuation functions of DFA/DCCA and DMA/DMCA. Building on the construction of OLS as a ratio of covariance between the series and their respective standard deviations, the DFA/DCCA and DMA/DMCA scale-specific covariance and variance can be used for re-defining the estimator so that

$$\hat{\beta}^{DFA}(s) = \frac{F^2_{XY,DFA}(s)}{F^2_{X,DFA}(s)}$$
$$\hat{\beta}^{DMA}(\lambda) = \frac{F^2_{XY,DMA}(\lambda)}{F^2_{X,DMA}(\lambda)} \quad (5)$$

where $F^2_{X,DFA}(s)$, $F^2_{XY,DFA}(s)$, $F^2_{X,DMA}(\lambda)$, $F^2_{XY,DMA}(\lambda)$ are fluctuation functions parallel to scale-specific (with scales s and λ for DFA and DMA, respectively) covariance and variance functions for DFA/DCCA and DMA/DMCA procedures, respectively. The respective s can be interpreted as scale specific effects between the impulse and response variables (for our case the interest rates differential and change in the exchange rate, respectively). More details about the theory behind and the testing procedures are provided in the original papers of Kristoufek [72,73] and the recent study of Ferreira & Kristoufek [9].

We examine the uncovered interest rate parity using interbank interest rates with maturity of 1, 3, 6 and 12 months, denominated in the currency of each country. To evaluate UIP, it is necessary to use spot exchange rates. For the countries that adopted the Euro in the first wave, it is necessary to use the exchange rates relative to a reference country. In our analysis, we utilise the German mark.[2] For the remaining countries, exchange rates relative to the Euro are used. All analysed time series have been obtained from the DataStream database.

Table 1 summarises the information for the beginning of samples. Note that to evaluate UIP, exchange rates for different moments in time need to be used. Therefore, the number of observations is different for the different considered maturities. The table is divided into three groups: the first one, composed of countries having entered in the first wave of the Euro adoption[3]; the second one, formed by the later adopting countries; and the third group, composed of the EU countries which have not entered the common currency area at the time of the analysis. All samples have been recovered with respect to the data availability. UIP can be analysed only in countries with different currencies; thence, for the first two groups, the samples end before the Euro adoption in the referred countries. This is reflected in the reduced number of observations for some countries. Regarding the last group, the samples end on the 28th March 2017. Our study thus provides and studies a considerably larger dataset that other studies focusing on the European Union member states.

4. Results

This paper estimates the uncovered interest rate parity relationship with two novel regression frameworks based on the detrended cross-correlation analysis (DCCA) and the detrending moving-average cross-correlation analysis (DMCA) for three different groups of countries with respect to their state towards the European common currency adoption. To

[1] The DCCA procedure itself has been applied in analyses of the covered interest rate parity [3,54] and in other integration studies [55–57] as well as various other fields and subfields of financial and economic analysis [58–64].

[2] Exchange rates in relation to German mark are not available, so we retrieved information from each currency exchange rate relatively to the American dollar and, with triangular parity, we calculated the corresponding exchange rate with respect to the German mark. Because transaction costs exist, it is possible to exist some differences between the real values and the calculated ones. However, since the dollar is largely used in international markets, those transaction costs are small and the deviations are minimal, which should not have great effect on the tests.

[3] As in other studies, we also evaluated the behaviour of Greece until the beginning of 1999.

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Table 1
Beginning of samples and number of observations for each maturity. The first group is composed of countries that adopted the Euro in 1999. The second group is formed by countries which adopted the Euro later. The last group is formed by non-Euro countries. For the 12-month maturity, Italian sample only begins on 25th May, 1993. The Netherlands has not got data for the 12-month maturity available. For Lithuania, the observations of the 6 and 12-month maturity is equal, because they just have information for internal interest rate available since 29th March 2009. For the 3-month maturity, there is no data available. The number of observations is equal for the different maturities because the information on interest rates is more limited compared to exchange rates. For the 6 and 12-month maturity, sample only begins on 5th October 2007. For the 12-month maturity, sample only begins on 20th March 2006. For the 12-month maturity, sample only begins on 2nd January 2003. For the 12-month maturity, sample only begins on 2nd January 2001.

Country	Date of beginning	#obs. 1M	# obs. 3M	# obs. 6M	# obs. 12M
Austria	10 June 1991	1951	1907	1842	1711
Belgium	2 November 1990	2108	2063	2000	1868
Finland	31 December 1996	497	456	391	259
France	2 November 1990	2108	2063	2000	1868
Greece	31 December 1996	497	456	391	259
Ireland	31 December 1996	497	456	391	259
Italy	1 April 1993	1478	1435	1369	1239
Netherlands	2 November 1990	2108	2063	2000	×
Portugal	31 December 1996	497	456	391	259
Spain	19 December 1991	1813	1770	1704	1573
Estonia	5 February 1999	3106	3067	3002	2870
Latvia	1 January 1999	3892	3849	3784	3553
Lithuania	1 January 1999	4153	4110	3851	3851
Slovenia	1 October 2003	843	×	843	843
Slovakia	1 January 1999	2588	2545	2480	2348
Bulgaria	17 February 2003	3862	3862	2473	2473
Croatia	1 January 1999	4737	4694	4629	2877
Czech Republic	1 January 1999	4737	4694	4629	4497
Denmark	1 January 1999	4737	4694	4629	4497
Hungary	1 January 1999	4737	4694	4629	3714
Poland	1 January 1999	4737	4694	4629	4236
Romania	1 January 1999	4737	4694	4629	4497
Sweden	1 January 1999	4737	4694	4629	4497
UK	1 January 1999	4737	4694	4629	4497

study the interest parity from short-term and long-term perspective, we opt for two specific scales.[4] For DCCA, we study the scales of 10 and 250 trading days, and for DMCA, we use 11 and 251 trading days to obtain comparable results. Note that the DMCA procedure is based on centred moving averages and it thus needs an odd number of observations in the moving average window. For the series of short length (below 1000 observations), we use 100 and 101 trading days as the long-term effect for DCCA and DMCA, respectively. Tables. 2–7 present the results for all three studied groups of countries.

Tables. 2 and 3 summarise the results for the first group – the first wave of the Euro countries – using DCCA and DMCA regressions, respectively. The evidence of UIP verification is scarce for these countries: Austria for the 1 and 3-month maturities, France and Italy for the 1-month maturity, and the Netherlands are the unique examples of the UIP verification (non-rejection), and just considering the higher scales of the DCCA and DMCA regressions. For the remaining countries, scales and methodologies, the absence of UIP verification is the rule. However, there are several interesting patterns in the results. First, the estimated beta parameters, i.e. the ones reflecting the expected depreciation relationship when the foreign interest rate increases, get closer to unity for the long-term relationship. Specifically, this is the case for Austria, Belgium, France, Italy, the Netherlands, and Spain. This suggests that UIP is closer to being true for longer scales, i.e. it takes more time for the exchange rates to adjust than expected from the UIP theory [74]. Second, for almost all the countries, the beta estimates are further from unity for higher maturities. Third, the alpha estimates, which reflect existence of risk premium in the relationship or possible violation of the rational expectations theory, are mostly significantly different from zero, specifically positive. This suggests that investors are not risk-neutral as expected from the theory but rather risk-averse and they expect to be compensated for the uncertainty they undertake when taking their positions in the interest rate and exchange rate markets [75]. Fourth, the estimated alphas are further away (more positive) for higher maturities, which could reflect further compensation of investors for longer maturities uncertainty implying higher risk premium. And fifth, the recognised forward puzzle (negative slope of the beta parameter) is uncovered for Finland, Greece, Ireland and Portugal, which is a set of countries with the lowest number of observations. Thus, the relationship might be strongly varying in time. However, we leave this issue for our further research on the topic and focus on the global properties of the uncovered interest rate parity.

The second group of countries considered in this study includes countries which adopted the Euro in later waves — Estonia, Latvia, Lithuania, Slovakia and Slovenia. Results are presented in Tables. 4 and 5. Compared to the previous group, there are fewer evident patterns in the results. However, some of these are the same, mainly the increasing beta estimates for higher scales. This is true for Estonia, Lithuania and Slovenia, leaving Latvia and Slovakia with mixed results and no

4 This is done for brevity. The complete results, i.e. the estimates for the scales in between, are available upon request.

Table 2
DCCA-based regression results for α and β, for the Eurozone founders. ** denotes rejection at a significance level of 99% and * denotes rejection at a significance level of 95%.

Country	Scale	1M		3M		6M		12M	
		α	β	α	β	α	β	α	β
AUT	10	0.0515**	0.0068**	0.0529**	−0.0063**	0.0512**	0.0013**	0.0478**	0.0045**
	250	−0.0056	1.0600	−0.0029	1.0164	0.0224**	0.5250**	0.0374	0.1894*
BEL	10	0.0553**	0.0590**	0.0525**	0.0929**	0.0520**	0.0784**	0.0479**	0.1103**
	250	0.0288**	0.5281	0.0419**	0.2793**	0.0416**	0.2475**	0.0533**	0.0189**
FIN	10	0.0324**	−0.0080**	0.0335**	0.0015**	0.0354**	0.0024**	0.0366**	0.0001**
	100	0.0303**	0.0536**	0.0334**	0.0056**	0.042	−0.1645**	0.0455**	−0.1152**
FRA	10	0.0594**	0.0631**	0.0573**	0.0856**	0.0597**	0.0156**	0.0565**	0.0246**
	250	0.0449	0.3208	0.0600**	0.0373**	0.0507**	0.1734**	0.0555**	0.0422**
GRE	10	0.1160**	0.0147**	0.1215**	1.0365**	0.1277**	−0.0782**	0.1131**	0.0463**
	100	0.1173**	−0.0211**	0.1353**	−0.2747**	0.1326**	−0.1643**	0.1525**	−0.3521**
IRE	10	0.0573**	0.0010**	0.0563**	−0.0117**	0.0530**	−0.0141**	0.0454**	−0.0127**
	100	0.0561**	0.0341**	0.0566**	−0.0183**	0.0530**	−0.0140**	0.0567**	−0.1490**
ITA	10	0.0761**	0.0492**	0.0755**	0.0442**	0.0736**	0.0645**	0.0733**	0.0582**
	250	0.0716	0.1513	0.0720**	0.1194**	0.0723**	0.0918**	0.0751**	0.0232**
NET	10	0.0531**	0.0250**	0.0524**	0.0242**	0.0505**	0.0381**	×	×
	250	0.0004	0.9574	0.0147	0.6847	0.0219	0.5355	×	×
POR	10	0.0495**	−0.0003**	0.0474**	−0.0059**	0.0446**	−0.0098**	0.0403**	−0.0108**
	100	0.0575**	−0.4806**	0.0480**	−0.0218*	0.0689**	−0.2002**	0.0421	−0.0470**
SPA	10	0.0785**	0.0520**	0.0784**	0.0241**	0.0769**	0.0131**	0.0725**	0.0136**
	250	0.0659**	0.2800**	0.0697**	0.1617**	0.0673**	0.1402**	0.0820**	−0.0848**

Table 3
DMCA-based regression results for α and β, for the Eurozone founders. ** denotes rejection at a significance level of 99% and * denotes rejection at a significance level of 95%.

Country	Scale	1M		3M		6M		12M	
		α	β	α	β	α	β	α	β
AUT	11	0.0517**	0.0025**	0.0528**	−0.0043**	0.0514**	−0.0023**	0.0482**	−0.0022**
	251	0.0036	0.8899**	0.0064**	0.8462**	0.0185**	0.5962**	0.0346**	0.2393**
BEL	11	0.0502**	0.2061**	0.0505**	0.1287**	0.0510**	0.0965**	0.0484**	0.1017**
	251	0.0228**	0.6334**	0.0394**	0.3236**	0.0440**	0.2176**	0.0507**	0.0620**
FIN	11	0.0323**	−0.0048**	0.0336**	−0.0013**	0.0359**	−0.0100**	0.0367**	−0.0032**
	101	0.0318**	0.0030**	0.0309**	0.0745**	0.0419**	−0.1613**	0.0410**	−0.0898**
FRA	11	0.0575**	0.0974**	0.0584**	0.0653**	0.0574**	0.0553**	0.0554**	0.0432**
	251	0.0342**	0.5096**	0.0513**	0.1916**	0.0512**	0.1645**	0.0534**	0.0775**
GRE	11	0.1182**	−0.0460**	0.1235**	−0.0088**	0.1259**	−0.0477**	0.1359**	−0.1845**
	101	0.1193**	−0.0651**	0.1274**	−0.0962**	0.1356**	−0.2173**	0.1412**	−0.2379**
IRE	11	0.0567**	0.0180**	0.0558**	0.0015**	0.0525**	−0.0032**	0.0427**	0.0202**
	101	0.0573**	0.0025**	0.0568**	−0.0228**	0.0543**	−0.0386**	0.0473**	−0.0360**
ITA	11	0.0761**	0.0497**	0.0750**	0.0546**	0.0737**	0.0611**	0.0734**	0.0553**
	251	0.0782**	0.0017**	0.0762**	0.0286**	0.0749**	0.0382**	0.0735**	0.0537**
NET	11	0.0537**	0.0140**	0.0519**	0.0334**	0.0505**	0.0390**	×	×
	251	0.0025	0.9202**	0.0072**	0.8158**	0.0166**	0.6260**	×	×
POR	11	0.0504**	−0.0284**	0.0486**	−0.0378**	0.0442**	0.0014**	0.0401**	−0.0054**
	101	0.0555**	−0.1749**	0.0399**	0.1974**	0.0426**	0.0400**	0.0400**	−0.003
SPA	11	0.0783**	0.0563**	0.0786**	0.0206**	0.0770**	0.0114**	0.0733**	0.0048**
	251	0.0750**	0.1158**	0.0779**	0.0322**	0.0722**	0.0748**	0.0665**	0.0746**

visible relationship between the interest rates differential and exchange rates, even though Slovakia shows some signs of the forward puzzle. The risk premium is observed for this group as well. However, its level remains quite stable in the short-run and the long-run as well as across maturities.

Finally, the last group of countries is composed of the other EU countries which keep their own currencies, with results shown in Tables. 6 and 7. As this group is quite heterogeneous, so are the results. There are only two patterns that hold across most countries in the group. First, the risk premium parameter alpha is estimated to be positive for practically all the cases and it is quite stable across maturities. And second, this premium is mostly closer to zero in the long run. However, the differences between scales are quite minor. Apart from these, the results are mixed. The depreciation effect is more visible for higher scales only for Bulgaria, Denmark, and then weakly for the Czech Republic and Hungary. The effect is also closer to zero for higher maturities.

The results reinforce the findings of previous studies, indicating that the verification of this particular parity varies for different EU countries, which denotes different degrees of financial integration across the EU. In the case of the Eurozone economies, the Central European countries are the ones with better evidence of integration, while the Southern countries have evidence against the UIP. These are very relevant results as they might help explain the difficulties of the Southern

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Table 4
DCCA-based regression results for α and β, for new Eurozone countries. ** denotes rejection at a significance level of 99% and * denotes rejection at a significance level of 95%.

Country	Scale	1M		3M		6M		12M	
		α	β	α	β	α	β	α	β
EST	10	0.0326**	0.1010**	0.0356**	0.0763**	0.0345**	0.1730**	0.0363**	0.1624**
	250	0.0212**	0.5087*	0.0229**	0.5087**	0.0246**	0.4954**	0.0078	1.0297
LAT	10	0.0349**	0.0155**	0.0417**	0.0092**	0.0459**	−0.0101**	0.0481**	0.0057**
	250	0.0365**	−0.0523**	0.0431**	−0.0506**	0.0473**	−0.0700**	0.0476**	0.0300**
LIT	10	0.0333**	−0.0028**	0.0392**	0.0004**	0.0361**	0.0141**	0.0398**	0.0291**
	250	0.0237**	0.4029***	0.0384**	0.0311**	0.0325**	0.1330**	0.0367**	0.1087**
SLK	10	0.0635**	−0.0927**	0.0618**	−0.0096**	0.0575**	0.0027**	0.0541**	−0.0114**
	250	0.0645**	−0.1207**	0.0678**	−0.1532**	0.0674**	−0.1842**	0.0531**	0.0034**
SLO	10	0.0367**	0.0083**	×	×	0.0385**	−0.0575**	0.0378**	−0.0774**
	100	0.0343*	0.1157**	×	×	0.0387**	−0.0656**	0.0336**	0.2317*

Table 5
DMCA-based regression results for α and β, for new Eurozone countries. ** denotes rejection at a significance level of 99% and * denotes rejection at a significance level of 95%.

Country	Scale	1M		3M		6M		12M	
		α	β	α	β	α	β	α	β
EST	11	0.0327**	0.0982*	0.0349**	0.1021*	0.0365**	0.1108*	0.0337**	0.2404*
	251	0.0208**	0.5212**	0.0186**	0.6547	0.0188**	0.6857**	0.0119**	0.9039
LAT	11	0.0345**	0.0343**	0.0417**	0.0079**	0.0457**	−0.0017**	0.0481**	0.0009**
	251	0.0321**	0.1369**	0.0418**	0.0065**	0.0444**	0.0526**	0.0461**	0.1190**
LIT	11	0.0340**	−0.0321**	0.0396**	−0.0126**	0.0364**	0.0051**	0.0405**	0.0105**
	251	0.0294**	0.1650**	0.0409**	−0.0603**	0.0342**	0.0768**	0.0345**	0.1640**
SLK	11	0.0617**	−0.0415**	0.0631**	−0.0395**	0.0582**	−0.0102**	0.0547**	−0.0193**
	251	0.0570**	0.0928**	0.0608**	0.0142**	0.0594**	−0.0326**	0.0550**	−0.0237**
SLO	11	0.0361**	0.0321	×	×	0.0388**	−0.0721**	0.0375**	−0.0510**
	101	0.0427**	−0.2577**	×	×	0.0393**	−0.0959**	0.0370**	−0.0172**

Table 6
DCCA-based regression results for α and β, for non-Euro countries. ** denotes rejection at a significance level of 99% and * denotes rejection at a significance level of 95%.

Country	Scale	1M		3M		6M		12M	
		α	β	α	β	α	β	α	β
BUL	10	0.0168**	0.2677**	0.0242**	0.1395**	0.0285**	0.0893**	0.0404**	0.0947**
	250	0.0081**	0.874	0.0172**	0.5691**	0.0231**	0.4726**	0.0379**	0.2289**
CRO	10	0.0431**	0.0714**	0.0489**	−0.0031**	0.0397**	0.0296**	0.0374**	0.0318**
	250	0.0544**	−0.5203**	0.0514**	−0.1215**	0.0426**	−0.1019**	0.0380**	−0.0007**
CZE	10	0.0214**	0.0057**	0.0219**	0.0024**	0.0223**	0.0047**	0.0229**	0.0007**
	250	0.0202**	0.0670**	0.0220**	0.0018**	0.0220**	0.0156**	0.0208**	0.0493**
DEN	10	0.0189**	0.0533**	0.0175**	0.1615**	0.0214**	0.0194**	0.0239**	−0.0337**
	250	0.0007	1.0049	0.0045	0.7911**	0.0140**	0.3538**	0.0248**	−0.0730**
HUN	10	0.0700**	0.0019**	0.0693**	−0.0099**	0.0679**	−0.0014**	0.0589**	−0.0143**
	250	0.0675**	0.1392**	0.0685**	0.0325**	0.0682**	−0.0237**	0.0589**	−0.0145**
POL	10	0.0595**	0.0012**	0.0596**	0.0039**	0.0591**	−0.0055**	0.0498**	−0.0037**
	250	0.0586**	0.0477**	0.0599**	−0.0115**	0.0592**	−0.0128**	0.0485**	0.0629**
ROM	10	0.1395**	−0.0077**	0.1366**	−0.0181**	0.1292**	0.0008**	0.1178**	0.0130**
	250	0.1501**	−0.8602**	0.1372**	−0.2201**	0.1273**	−0.1902**	0.1100**	−0.2021**
SWE	10	0.0207**	0.0038**	0.0216**	0.0070**	0.0226**	0.0065**	0.0242**	0.0107**
	250	0.0223**	−0.0802**	0.0235**	−0.0868**	0.0226**	0.0083**	0.0229**	0.0792**
UK	10	0.0284**	0.0043**	0.0295**	0.0069**	0.0305**	0.0038**	0.0317**	0.0125**
	250	0.0284**	0.0054**	0.0302**	−0.0312**	0.0302**	0.0235**	0.0319**	0.0017**

countries during the Eurozone crisis. For the non-Eurozone countries, the evidence of verification of the UIP is lower, which is a sign of monetary autonomy of these countries, suggesting that these countries could easily fight against asymmetric shocks. If they intend to adopt the common currency, they should ensure that the financial integration process will allow these countries to be in conditions ready to face the possibility of such shocks.

5. Discussion and conclusions

The detrended cross-correlation analysis and the detrending moving-average cross-correlation analysis regressions have been utilised in the uncovered interest rate parity study covering a wide set of the EU countries. Specifically, we have

Table 7
DMCA-based regression results for α and β, for non-Euro countries. ** denotes rejection at a significance level of 99% and * denotes rejection at a significance level of 95%.

Country	Scale	1M		3M		6M		12M	
		α	β	α	β	α	β	α	β
BUL	11	0.0172*	0.2397*	0.0232**	0.1967**	0.0286**	0.0847**	0.0416**	0.0281**
	251	0.0101**	0.7371**	0.0154**	0.6806**	0.0241**	0.4900**	0.0385**	0.1964**
CRO	11	0.0433**	0.0612**	0.0482**	0.0329**	0.0402**	0.0080**	0.0376**	0.0243**
	251	0.0551**	−0.5556**	0.0527**	−0.1866**	0.0443**	−0.1766**	0.0386**	−0.0309**
CZE	11	0.0214**	0.0069**	0.0219**	0.0036**	0.0223**	0.0048**	0.0228**	0.0022**
	251	0.0196**	0.1092**	0.0211**	0.0357**	0.0214**	0.0324**	0.0218**	0.0259**
DEN	11	0.0175	0.1279*	0.0181	0.1339	0.0224**	−0.0280**	0.0238*	−0.0310**
	251	0.0013*	0.9697	0.0031**	0.8589	0.0124**	0.4285**	0.0236**	−0.0249**
HUN	11	0.0699**	0.0070**	0.0692**	−0.0026**	0.0678**	−0.0002**	0.0589**	−0.0143
	251	0.0679**	0.1148**	0.0686**	0.0270**	0.0679**	−0.0019**	0.0589**	−0.0145**
POL	11	0.0595**	0.0012**	0.0596**	0.0020**	0.0590**	−0.0006**	0.0497**	−0.0030**
	251	0.0578**	0.0918**	0.0591**	0.0281**	0.0582**	0.0342**	0.0490**	0.0374**
ROM	11	0.1383**	0.0842**	0.1365**	−0.0009**	0.1290**	−0.0190**	0.1174**	0.0007**
	251	0.1384**	0.0784**	0.1366**	−0.0445**	0.1279**	−0.1246**	0.1125**	−0.1319**
SWE	11	0.0207**	0.0035**	0.0216**	0.0056**	0.0225**	0.0140**	0.0243**	0.0100**
	251	0.0189**	0.0954**	0.0213**	0.0206**	0.0219**	0.0431**	0.0236**	0.0422**
UK	11	0.0285**	0.0026**	0.0296**	0.0047**	0.0304**	0.0067**	0.0318**	0.0093**
	251	0.0255**	0.1103**	0.0292**	0.0242**	0.0302**	0.0247**	0.0317**	0.0187**

studied the parity for three groups — the early Euro adopters, the later adopters, and the EU countries that are outside of the Eurozone. The main contributions of our study are twofold. First, we have analysed a large dataset that is not standard in the topical applied papers. And second, the utilised methods have allowed us to focus on possible differences between the short-term and long-term relationships between the interest rate differentials and foreign exchange rates that form the parity. Overall, the evidence for UIP is scarce, which is in hand with most of the previous studies. However, we have also uncovered some interesting patterns in the results, the most important of which we now discuss.

The alpha parameters have been estimated as positive for almost all the cases. Positive alphas suggest violation of possibly two important assumption of the UIP theory — investors' risk neutrality and rational expectations. A global look at the results suggests that the former case might prevail as the risk premium increases with maturity. This should not be surprising as most economic theories assume a risk-averse economic agent rather than a risk-neutral one. However, the latter explanation of the rational expectations violation could influence the estimates of the beta parameter as argued by Ghoshray et al. [75]. This leads us to the other important finding.

The beta parameters have been mostly estimated rather far from unity. The equality suggests that changes in the interest rate differential translate perfectly into the exchange rate appreciation or depreciation. However, there are many cases when the very opposite case – negative beta – has been found. This so-called forward puzzle is present for several countries but it can hardly be identified as universal. On the contrary, the expected positive relationship between in the interest rate differentials and the exchange rates is found for majority of the studied cases (combination of a country, a scale, and a maturity). Nevertheless, most of the estimated effects are closer to zero than one.

Altogether, there are many historical reasons why the uncovered interest rate parity need not hold for our set of countries. For the Euro founders, high exchange rate volatility of the 1990s as well as the fixed exchange rate regimes before the actual Euro introduction could have played a significant role. The European Monetary System (EMS) and the crisis connected to it could have led investors to anticipate possible adjustments which did not occur during the period under analysis, which would confirm the peso problem existence. This could also be the explanation for some failures in the new Euro adopters: the quick evolution of economic systems and the necessity of adjustments could affect the UIP verification, alongside with the already identified learning processes. For the other countries, and mainly the non-Euro countries, the UIP rejection could be easily connected to the Global Financial Crisis (GFC) of the late 2000s and mainly its aftermath when most central banks adopted unorthodox monetary policies which strongly influenced the exchange rate markets but also the interest rate markets with the base interest rates close to or even below zero.

Our results also highlight that it makes sense to look at the results from a perspective of different scales as mainly the depreciation effects are visible only in the long run. In the short run, the effects are negligible. In the similar logic, the results for the Eurozone countries suggest that not only the scale (frequency) domain is interesting to look at, but also the time domain. The mixed and rather unstable results might be due to time variation in both parameters of interest. This could be due several reasons — structural breaks, other important macroeconomic variables, and fiscal and monetary policies. These will be the topics of interest of future research.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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