University of Minho
School of Economics, Management and Political Science

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Exchange rate dynamics and Purchasing Power Parity: Developed vs Developing countries

may 2026

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Conducted under the supervision of

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* as part of the double degree associated to the *International Master in Public Policies*, at University of Rennes

may 2026

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Dinâmicas das taxas de câmbio e Paridade do Poder de Compra: Países desenvolvidos vs. Países em desenvolvimento

Resumo

Existem muitas teorias que tentam explicar as flutuações das taxas de câmbio. Uma das teorias mais antigas e estudadas sobre as taxas de câmbio é a da paridade do poder de compra (PPC), que sugere que o movimento das taxas de câmbio pode ser explicado pelas variações dos níveis de preços. Apesar da PPC ter sido testada ao longo de mais de um século, não existe consenso quanto à sua validade. Deste modo, este estudo analisa as flutuações cambiais, com foco na validação da teoria da PPC, considerando simultaneamente outros determinantes da taxa de câmbio. Este estudo também analisa se a validação da PPC varia entre países desenvolvidos e países em desenvolvimento. Esta dissertação visa responder a três questões de investigação: (1) A PPC é válida? (2) A PPC é o determinante mais influente das flutuações cambiais? (3) A validação da PPC varia entre grupos de países? Para responder a estas questões, este estudo utiliza duas bases de dados com dados em painel. A base de dados principal contém dados trimestrais de dez países (cinco desenvolvidos e cinco em desenvolvimento), entre 1999 e 2023Q2 e a segunda base de dados inclui dados trimestrais de doze países da zona euro, entre 2001 e 2024. As propriedades dos dados em painel são testadas nestas bases de dados, e os resultados dos testes aplicados são utilizados para justificar a especificação do modelo. Os resultados deste estudo não indicaram evidencias que validem a PPC no longo prazo, mas indicaram uma validação parcial da PPC no curto prazo. Para além da PPC, verificou-se que a abertura comercial e o diferencial da taxa de crescimento do M3, contribuíem para a depreciação da taxa de câmbio, mas com um impacto menor do que a PPC. No entanto, a paridade descoberta de juros (PDJ) e os regimes cambiais não tiveram um impacto estatisticamente significante nesta análise. Adicionalmente, este estudo sugere que a validação da PPC é heterogénea entre grupos de países, sendo mais forte nos países em desenvolvimento. Embora os resultados sugeriram que o modelo é relevante para analisar a taxa de câmbio, também mostraram a complexidade e dificuldade em explicar os movimentos cambiais.

Palavras chave: dados em painel, fundamentos macroeconómicos, países desenvolvidos vs países em desenvolvimento, paridades de poder de compra, taxas de câmbio

Exchange rate dynamics and Purchasing Power Parity: Developed vs Developing countries

Abstract

There are many theories that try to explain exchange rate movements. One of the oldest and most studied exchange rate theories is the purchasing power parity (PPP) which suggests that exchange rate behaviour can be explained by price level movements. Despite the PPP hypothesis being tested over a century, there is no consensus regarding its validity. Therefore, this study analyses exchange rate movements, with focus on the PPP theory validation while considering other exchange rate determinants. Furthermore, the analysis assesses if support for PPP varies across developed and developing countries. This dissertation aims to answer three main questions: (1) Does PPP hold? (2) Is PPP the most influential determinant of exchange rate movements? (3) Does the validation of PPP vary across groups of countries? To answer these questions, this study uses two panel datasets. The main dataset contains quarterly data of ten countries (five developed and five developing countries) between 1999 and 2023Q2 and a second dataset that includes quarterly data of twelve countries from the Euro area between 2001 and 2024. In these datasets, panel-data properties are tested, and the test results from the main dataset are used to justify the model specification. The results of this study indicated no support for PPP validity in the long-run, but found partial support for PPP in the short-run. Besides PPP, trade openness and M3 growth rate differential were found to contribute to the exchange rate depreciation, but with less impact than PPP. However, uncovered interest parity (UIP) and exchange rate regimes did not have a statistically significant impact in this analysis. Moreover, this study suggests that the PPP support is heterogeneous across groups of countries, and its support was stronger in developing countries. Even though the results suggested that the model is relevant to analyse the exchange rate, they also showed the complexity and difficulty in explaining exchange rate movements.

Keywords: developed vs developing countries, exchange rates, panel data, macroeconomic fundamentals, purchasing power parity

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List of Abbreviations

ADF - Augmented-Dickey-Fuller

ADL - Autoregressive Distributed Lag

AIC - Akaike Information Criterion

ASEAN - Association of Southeast Asian Nations

BIC - Bayesian Information Criterion

CADF - Cross-sectionally Augmented Dickey-Fuller

CD - Cross dependence

CSD - Cross-sectional dependence

CIP - Covered interest parity

CIPS - Cross-sectionally augmented Im-Perasan-Shin

CPI - Consumer's price index

ECM - Error-connection model

FE - Fixed Effects

G20 - Group of World's Twenty Largest Economies

GDP - Gross domestic product

IMF - International Monetary Fund

MENA - Middle East and North Africa

MG - Mean Groups

NER - Nominal exchange rate

NIR - Nominal interest rate

OECD - Organisation for Economic Co-operation and Development

PMG - Pooled Mean Groups

PP - Philips-Perron

PPP - Purchasing power parity

RE - Random effects

REER - Real effective exchange rate

RER - Real exchange rate

RIR - Real interest rate

UIP - Uncovered interest parity

UK - United Kingdom

US - United States

VIF - Variance Inflation Factor

1. Introduction

1.1. Contextualisation and justification

Exchange rates play an important role in international economics as they influence economic and financial decisions beyond borders (Kaur, 2024). One of the oldest and most studied exchange rate theories is the Purchasing power parity (PPP), proposed by Cassel (1918). However, after a century of studies testing its validity, there is still no consensus. Furthermore, it is not usual to compare PPP across groups of countries and include other exchange rate determinants in PPP studies.

For these reasons, this study analyses the exchange rate behaviour, focusing on the validation of the PPP hypothesis, as well as how differences between developed and developing countries can affect its explanatory power. To this end, this dissertation estimates an empirical model that integrates PPP and other macroeconomic fundamentals, such as interest rate differentials, monetary aggregates, trade openness, and the exchange rate regimes. This dissertation contributes to the ongoing PPP debate, since it remains unsolved. Furthermore, debating PPP is relevant to analyse since price levels directly affect the economic agents' behaviour.

1.2. Research questions and objectives

This study focuses on answering three research questions. First, does PPP hold? This theory was developed a century ago, and yet no consensus was reached. Thus, an objective of this study is to contribute to the debate in the literature.

Second, is PPP the most influential determinant of exchange rate movements? Regardless of whether PPP is fully supported, with the inclusion of other exchange rate determinants, another research objective is to analyse whether PPP has the greatest impact in exchange rate movements across macroeconomic variables.

Third, does the validation of PPP vary across groups of countries? The third objective and main contribution of this study is to test whether the characteristics of developed and developing countries affect the support of PPP, and to identify which group presents stronger PPP evidence.

1.3. Brief methodological overview

To answer these research questions, this study uses two panel datasets. The main panel dataset, which contains data from ten economies (five developed countries and five developing countries) over a period of twenty-four and a half years, with data about nominal exchange rates, price levels, trade openness index, money supply, interest rates and exchange rate arrangements. In this dataset, the panel-data properties are tested, and the results from these tests define the model specification to answer all research questions. The second dataset includes data about the nominal exchange rate and price levels of twelve countries from the Euro area over a period of twenty-four years. This dataset is used to test panel-data properties, and their results represent evidence that only contributes to answer this study's first research question.

1.4. Structure of the study

This dissertation has the following structure: Section 2 presents the theoretical and empirical framework regarding exchange rates, PPP and other exchange rate determinants. Section 3 outlines the data sources, the construction of variables, and the methodological approach, explaining the tests and model specification that will be used. Section 4 presents descriptive statistics with summary statistics, evolution figures and pairwise correlations. Section 5 reveals the results of the statistical tests and estimations. Section 6 discusses the results, as well as the study's limitations and directions for future research. Finally, section 7 concludes with the summary of the main findings, emphasising the effect and significance of the exchange rate determinants analysed in this study.

2. Literature review

2.1. Exchange rates: types and regimes

2.1.1. Exchange rate types

When analysing exchange rate dynamics, studies focus on one of the exchange rate types, which are nested to the first one that will be presented by representing economic extensions from it. First, the bilateral nominal exchange rate (NER), which is the market price of currencies, expressed as the amount of domestic currency units needed to purchase a foreign one (Alam & Taib, 2013; Itskhoki, 2021). Second, the bilateral real exchange rate (RER) represents the NER adjusted to relative price levels between countries (Itskhoki, 2021). It can be expressed as:

$$Q_t \equiv \frac{S_t P_t^*}{P_t} \tag{1}$$

Where Q_t is the RER at time t, S_t is the NER, expressed as domestic currency units per foreign currency unit, P_t is the domestic price level, and P_t^* is foreign price level. Finally, the real effective exchange rate (REER) is the trade-weighted average of the bilateral real exchange rate against other currencies (Khan et al., 2002) as shown in equation 2.

$$REER_t = 100 \prod_{i=1}^{n} (RER_{it})^{w_i} \tag{2}$$

Where $REER_t$ represents the real effective exchange in time t as an index, RER_{it} is the RER against currency i, and w_i is the trade with country i as a share of the country's total international trade. It's assumed that $\sum w_i = 1$, and RER is in equilibrium on the model's base year (Khan et al., 2002).

2.1.2. Exchange rate regimes

In addition to the type of exchange rates, they can also be classified according to their regime. The choice of an exchange rate arrangement not only influences exchange rate volatility, but is also contributes to achieve national economic objectives, to achieve certain levels of market efficiency, or to attenuate the economic impact and persistence of shocks (Corzo et al., 2025; Mirdala, 2013). According to the International Monetary Fund (2024) (IMF), apart from residual cases, exchange rate regimes fall into three main categories: hard

peg, soft peg, floating. Under this de facto classification, currencies are assigned to specific subcategories based on their actual exchange rate behaviour rather than solely on declared policy intentions.

Hard pegs are characterised by requiring a near complete loss of monetary policy autonomy. They include two main arrangements: First, under no separate legal tender, a country completely loses control of its monetary policy and uses a foreign currency as its sole legal tender. Common examples include dollarisation and monetary unions. Second, a currency board involves a legislative commitment to exchange domestic currency for a specified foreign one at a fixed rate. This arrangement is supported by strict institutional constraints, such as full foreign reserves backing, which eliminates most of the traditional central bank functions.

Soft pegs represent the set of arrangements in which exchange rate are managed but retain some degree of flexibility. A conventional peg refers to a formal commitment to fix the currency to another currency or a basket of currencies, with authorities prepared to preserve the parity through direct or indirect intervention. Under this classification, exchange rate swings are restricted to small margins, usually within $\pm 1\%$ around a central rate (or $\pm 2\%$ for at least six months), even though no ongoing commitment is necessary. A stabilised arrangement also involves the currency to be pegged to a single currency or to a basket of them. However, it differs from the conventional peg as it requires that the exchange rate stability (within a $\pm 2\%$ margin for at least six months) is confirmed using statistical criteria and that is consequence of official intervention. Under a crawling peg, the exchange rate is adjusted in small amounts, either at a fixed rate (forward-looking) or in response to changes in selected macroeconomic indicators (backward-looking) such as past inflation differentials or expected to targeted inflation differentials. Craw-like arrangements represent the currencies whose exchange rate remain within narrow margins ($\pm 2\%$) around an identified trend for the at least six months. However, the minimum rate of change is usually greater than the maximum allowed under stabilised arrangements. If that's not the case, currencies can be classified under this arrangement if they change at least 1% a year and its movements are monotonic and continuous. For last pegged exchange rate within horizontal bands maintain change its value within a range of at least $\pm 1\%$ around a central fixed value or within a margin superior to 2% between its maximum and minimum values.

Floating exchange rate regimes are driven mainly by market forces, so their current and future values are determined by demand and supply fluctuations. They include two arrangements: floating and free floating regimes. Under a floating regime, exchange rates follow no predetermined path and fluctuate freely. Even if they display stability similar to stabilised or crawl-like arrangements, this stability must not be a result of authorities' intervention. Thus, they don't target a specific exchange rate level. For last, the free floating exchange rate regime is the most flexible one, in which exchange rate are almost entirely by market dynamics.

Under this regime, official intervention must be exceptionally rare (at most three times during on the last six months, with each one lasting no longer than three business day), and only occurs to address disorderly market conditions.

Table 1 presents the evolution of exchange rate regimes across countries based on the IMF's de facto classification, which complements the institutional classification previously described. It summarises how exchange rate arrangements have evolved over time by displaying the relative predominance of hard pegs, soft pegs, and floating regimes in between 2008 and 2023.

Exchange rate arrangement	**2008**	**2013**	**2018**	**2023**
Hard peg	**12.2%**	**13.1%**	**12.5%**	**13.4%**
No separate legal tender	5.3%	6.8%	6.8%	7.2%
Currency board	6.9%	6.3%	5.7%	6.2%
Soft peg	**39.9%**	**42.9%**	**46.4%**	**44.8%**
Conventional peg	22.3%	23.6%	22.4%	20.6%
Stabilised arrangement	12.8%	9.9%	14.1%	11.3%
Crawling peg	2.7%	1.0%	1.6%	1.5%
Crawl-like arrangement	1.1%	7.9%	7.8%	10.8%
Pegged exchange rate with horizontal bands	1.1%	0.5%	0.5%	0.5%
Floating	**39.9%**	**34.0%**	**34.4%**	**32.5%**
Floating	20.2%	18.3%	18.2%	16.5%
Free floating	19.7%	15.7%	16.1%	16.0%
Residual				
Other managed arrangements	8.0%	9.9%	9.4%	9.3%

Table 1 - De facto exchange rate arrangements (% of IMF members) (2008 -2023). Source: Self-compilation using data from International Monetary Fund (2014, 2024)

In recent years, pegged currencies have been the most common among IMF members, particularly soft pegs. The share of both hard and soft peg arrangements increased during this time, while the proportion of floating regimes has declined. The expansion of hard pegs is mainly driven by an increase in the number of countries adopting no separate legal tender arrangements. Similarly, the growing prevalence of soft pegs results from a nine percentage points increase in the share of crawl-like arrangements. In contrast, floating currencies lost representation as a consequence of declines in both floating and free floating currencies. Although floating regimes still accounted for 32.5% in 2023, the overall pattern suggests an increased degree of exchange rate management worldwide.

2.2. Exchange rate determinants

The purpose of this dissertation is to clarify exchange rate dynamics, with a focus on the validity of the purchasing power parity (PPP) hypothesis. The literature study takes into account other macroeconomic

factors that have been demonstrated to affect exchange rate fluctuations, even though PPP serves as the primary theoretical benchmark.

2.2.1. Purchasing power parity

PPP represents one of the oldest exchange rate determination theories, and points to a relationship between exchange rates and relative prices levels across countries, whereby identical goods should reflect the same purchasing power internationally (Kulkarni & Ishizaki, 2002; A. M. Taylor & Taylor, 2004). To PPP holds, it is assumed that the exchange rate is flexible and that there is free trade and the absence of transport costs, tariffs or other barriers. (Aslan, 2010; Kulkarni & Ishizaki, 2002; Obstfeld & Rogoff, 1995). This theory has two versions: absolute PPP, and relative PPP.

The absolute PPP goes according to the law of one price. This economic proposition states that, assuming no arbitrage, a good or a basket of goods' price should be the same across countries when they are observed in the same currency (Kyei-Mensah, 2023). Therefore, the absolute PPP states that the NER should correspond countries' price levels ratio (Kasem & Al-Gasaymeh, 2022). The following equation shows the absolute PPP:

$$S_t = \frac{P_t}{P_t^*} \tag{3}$$

Where S_t represents the NER expressed as the price of a foreign currency in terms of domestic one at time t; P_t represents the domestic price level and P_t^* the foreign price level. The absolute PPP implies that if the exchange rate equals the relative prices level, then its variation should be proportional to changes in the ratio of price levels, which consist in the relative PPP (McDermott & Cashin, 2001).

The relative PPP states that the NER variation is explained by the price level movements differentials between two countries, implying that the purchasing power between countries remains constant over time (Doğanlar et al., 2009; Kasem & Al-Gasaymeh, 2022). Therefore, the relative PPP implies that:

$$s_t = p_t - p_t^* \tag{4}$$

Where s_t, p_t and p_t^* represent the natural logarithm of NER, domestic and foreign price levels, respectively. This formula suggests that RER dynamics can be expressed as the following:

$$q_t \equiv s_t + p_t^* - p_t \tag{5}$$

Where q_t is the natural logarithm of RER at time t. If the relative PPP holds, the RER is stationary, and so its movements represent deviations from PPP (Sarno & Taylor, 2002).

Despite a century of studies trying to validate the PPP hypothesis, there's still no consensus about it. On one hand, there's literature with evidence to support PPP in different regions around the world, such as: in Middle East and North Africa (MENA) countries (Kasem & Al-Gasaymeh, 2022), in six countries of the Association of Southeast Asian Nations (ASEAN) (Aslan, 2010), in Japan (Kulkarni & Ishizaki, 2002), in Mexico (Wallace, 2017) and in 26 different currencies (Click, 1996).

On the other hand, some studies have found no evidence to support this theory in short-run (Dornbusch & Krugman, 1976; Wang, 2004; Xu, 2003) and long-run (Boundi-Chraki & Mateo Tomé, 2022; Yiheyis & Cleeve, 2016), and in some specific regions, such as, Europe (31 European countries) (not even among eurozone members) (Berka & Devereux, 2010). Even though Umoru et al. (2023) found that PPP has statistical significance to explain exchange rate movements, they concluded that PPP by itself isn't fully capable to explain exchange rate dynamics.

There're also studies with mixed results. For instance, Doğanlar et al. (2009), Kyei-Mensah (2023), Mike & Kızılkaya (2019), Nusair (2013) Wallace (2013), validated in 2 out of 10, 13 out of 15, 8 out of 12, 17 out of 18, and in 12 out of 23 economies, respectively. On a particular case, Papell (2006) results suggested a highly cyclical validation of PPP, with stronger evidence during depreciations and weaker in appreciations.

However, some empirical studies also pointed for possible issues related to PPP tests. For instance, Krugman (1978) did not fully validate the PPP, but demonstrated better results towards the hypothesis when he addressed endogeneity issues. There's also some studies that point out the long-run PPP validity may be incorrect due to severe size bias (Engel, 2000; Fischer & Porath, 2010). Moreover, The Granger causality tests between Malawi's REER and inflation rate suggested that the existence of reverse causality (Yiheyis & Cleeve, 2016).

Therefore, despite the theoretical simplicity of PPP, the lack of empirical consensus regarding its validity emphasises the need for further investigation of this topic, which motivates the present study. Furthermore, as the studies tend to either focus on individual countries or evaluate the sample as a whole, the limited attention paid to differences between groups of countries motivates the analysis of potential differences between developed and developing countries.

2.2.2. Interest rate parity

Policymakers have been focused on the relationship between exchange rates and interest rates with the objective of 'strengthening their domestic currency. Accordingly, the interest rate parity hypothesis states the

existence of a relationship between exchange rate movements and interest rate differentials. This theory has two versions: the covered interest parity (CIP) and the uncovered interest parity (UIP) (Khan et al., 2002).

The CIP states that, under perfect capital mobility, the forward premium on exchange rate must match the current differences between the domestic interest rate and the foreign one (Eaton & Turnovsky, 1983; Khan et al., 2002). Therefore, the CIP can be approximated as:

$$\frac{F_t - S_t}{S_t} \approx f_t - s_t \approx i_t - i_t^* \tag{6}$$

Where F_t is the forward exchange rate estimated at the time t, S_t is the NER, f_t and s_t are their natural logarithmic forms, respectively, and i_t and i_t^* represents the domestic nominal interest rate (NIR) and the foreign NIR.

On the other hand, despite UIP is based on the same principle as CIP, this version is formulated in terms of expected exchange rate variation instead (M. S. Khan et al., 2002; Liu & Lee, 2020; Obstfeld & Rogoff, 1995) and it's represented by the following equation:

$$E(s_{t+1} - s_t) = i_t - i_t^* \tag{7}$$

Where $E(s_{t+1} - s_t)$ represents the expected difference between the NER logarithm in time t+1 and t. Therefore, these theories suggest the existence of a relationship between exchange rate movements and interest rates differentials.

However, there is no general agreement regarding UIP validity. On one hand, Byrne & Nagayasu (2010), Khan et al. (2019), and MacDonald & Nagayasu (1999) found a cointegration relationship between RER and real interest rates on developed countries, with the former author finding evidence when using structural breaks, and the latter one finding more robust results when using long-term RIR.

On the other hand, there are studies that didn't validate UIP. One of them studied China between 1996 and 2020, and the results suggested UIP didn't hold for whole period (Liu & Lee, 2020). Another study tried to validate UIP on India, but results did not find a causal relationship between NIR differentials and NER (Shastri & Shastri, 2016).

Additionally, some suggested non-linear effects of interest rate differentials on exchange rates. For instance, in a study using five major currencies against the Swedish krona, the results suggested that on the short-run the relationship between NIR differentials and the NER is negative, but positive in the long-run (Hacker et al., 2012). Moreover, Hnatkovska et al. (2013) concluded that the relationship between NIR and NER is non-monotonic, being negative if the NIR changes are small but positive with larger increases.

2.2.3. Money supply

Money supply refers to the group of safe assets that households and businesses can use to make payments or to hold as short-term investments (Federal Reserve, 2024). This study will focus on one of the main money supply measures employed by international institutions such as the International Monetary Fund (IMF) and the Organisation for Economic Co-operation and Development (OECD): Monetary base, M1, M2, and M3.

The monetary exchange rate model predicts that an increase in the money growth differentials lead to exchange rate depreciation in the short-run (domestic currency units per foreign currency unit) (Beldjebel & Hellal, 2024; Funashima, 2020; Levin, 1997; Umoru et al., 2023). Beldjebel and Hellal (2024) and Funashima (2020) suggest that increases in money supply results in inflationary pressures which, according to the PPP, depreciate the exchange rate.

2.2.4. Openness of economies

The trade openness of an economy reflects the exposure of a country to international trade and represents the ratio of the sum of imports and exports to gross domestic product (GDP) (Holden et al., 1979). Studies regarding its effect on the exchange rate mainly suggest two results: A higher degree of trade openness decreases exchange rate volatility (AJAO, 2016; Calderón & Kubota, 2018; Hau, 2002; Moayed et al., 2022; Mpofu, 2021) and leads to real depreciation of the exchange rate (Gantman & Dabós, 2018; Glebocki Keefe & Saha, 2022; Lee & Law, 2013; Li, 2003).

Gantman & Dabós (2018) and Li (2003) suggest that an increase in trade openness can lead to two opposite effects: substitution and income effects. They suggest that lowering tariffs leads consumers to replace non-tradeable goods with cheaper imported tradable goods (substitution effects). Therefore, the shift in consumers' behaviours results in a decrease in demand and relative prices of non-tradable goods, which leads to the exchange rate depreciation. In contrast, if an increase in trade openness is a result of a reduction in tariffs, it can lead to an increase in overall welfare, resulting in increased demand for all goods (including non-tradables) and appreciating the exchange rate. However, the empirical evidence of these studies suggests that the substitution effect usually dominates, resulting in an overall depreciation.

Moreover, Li (2003) suggests that the credibility of trade reforms plays a crucial role in exchange rate movements. If the reform is credible and permanent, an increase in trade openness leads to currency depreciation. However, if the economic agents believe that this reform is temporary, they may anticipate higher future prices in non-tradeable goods and increase their consumption, leading to short-run appreciation.

3. Data and Methodology

3.1. Data

3.1.1. Data sources

To answer this study's research questions, quarterly macroeconomic data was collected from the following sources: International Monetary Fund's (IMF), International Financial Statistics, The Organisation for Economic Co-operation and Development (OECD), Australian Bureau of Statistics, the Banco de México, the Federal Reserve Economic Data from Federal Reserve Bank of Saint Louis, the Japanese Bankers Association, Trending Economics, Eulerpool and Gurufocus. From these sources, data of the NER (domestic units per United States (US) dollar; period's average), Consumer's Price Index (CPI), 3-month interbank nominal interest rate (average per period), exports, imports, GDP, M3 (percentage growth rate, period-to-period), and exchange rate arrangement were collected. The sample of the main dataset is composed of ten G20 countries, five developed countries (Australia, Canada, Japan, Korea and United Kingdom (UK)) and five developing countries (Mexico, Brazil, Turkey, China and India). They were selected because they are major players in the global economy and provided a balanced comparison between developed and developing countries. Euro area countries were excluded to avoid cases where multiple countries share the same currency. Furthermore, US will be used as the reference country for NER, CPI, interest rate, and M3 growth rate. This balanced dataset uses quarterly data between 1999Q1 and 2023Q2, resulting in 980 observations. Quarterly data was used as a compromise between capturing short-term dynamics (as well as long-term ones) and ensuring sufficient observations for panel econometric analysis.

Despite the eurozone countries' exclusion, due to their impact in global economy, they will be taken into account for a PPP complementary analysis. Therefore, a secondary dataset will be used, containing countries from Euro Area. In order to have a balanced dataset and a reasonable time period to analyse, the sample of this complementary analysis will include the former twelve Euro area countries (Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Spain, and Portugal) between 2001 and 2024. For this complementary analysis, data from Eurostat data about the Euro-US dollar NER, and price levels of these countries were collected.

3.1.2. Variables construction

For the main dataset, the gathered data was treated, converted and computed to have the necessary variables for the analysis. The variables' construction and treatment were the following:

For NER, as data was gathered in both monthly, quarterly and annually, the procedure was to only keep the quarterly data. Afterwards, the natural logarithm of NER and its variation between periods was calculated (equation 8).

$$\Delta \log(NER_{i,t}) = \log(NER_{i,t}) - \log(NER_{i,t-1}) \quad (8)$$

CPI data was originally available at the monthly frequency. Therefore, quarterly CPI was computed as an arithmetic average of monthly CPI. This index was normalised to have the first period for each country as the base one (i.e. 1999Q1=100). Moreover, the natural logarithm of CPI was calculated for all countries (including US), and inflation is measured as the first differences of the logarithm of CPI (equation 9). Also, the relative PPP indicator was computed as the log difference between domestic and US CPI as it's shown equation 10.

$$\pi_{i,t} = \log(CPI_{i,t}) - \log(CPI_{i,t-1}) \quad (9)$$

$$PPP_{i,t} = \log(CPI_{i,t}) - \log(CPI_{US,t}) \quad (10)$$

Regarding interest rates, as part of the data from some countries (Brazil, India, Japan, Turkey) was monthly, this data was converted to quarterly frequency by applying an arithmetic average of interest rates. Using this data, UIP indicator was computed by the difference between countries and US interest rate (equation 11).

$$UIP_{i,t} = i_{i,t} - i_{US,t} \quad (11)$$

Trade openness index was calculated by gathering data about exports, imports and GDP. As data about Mexico's imports and exports was monthly, they were transformed into quarterly data by applying the sum of them for each quarter. Given that, exports and imports were in billions of US dollars, while GDP was in billions of national currency units, imports and exports were converted into national currency by multiplying them with NER. Since the NER is expressed in domestic currency units per US dollar, multiplying trade flows expressed in US dollars with NER converts them into domestic currency units, ensuring consistency with GDP. Furthermore, converting these variables into domestic units avoids potential issues related to exchange rate valuation effects. Afterwards, this study computed trade openness using the ratio of the sum of exports and imports to GDP and multiplied by 100 (Equation 12).

$$Openness_{i,t} = \frac{Exports_{i,t} + Imports_{i,t}}{GDP_{i,t}} \times 100 \quad (12)$$

Regarding M3 growth rate, as Brazil's data was monthly, the data of this country was converted to quarterly data by employing an arithmetic average for each quarter. Moreover, the differential of this variable was computed by the difference between the countries analysed and US M3 growth rate (equation 13).

$$M3GD_{i,t} = M3G_{i,t} - M3G_{US,t} \tag{13}$$

This study also created a categorical variable for the exchange rate regime, for both main and specific exchange rate arrangement. For the main regime, the variable goes from a scale of one to four, with lower values corresponding to more rigid exchange rate regimes, whereas higher values indicate greater exchange rate flexibility. Similarly, the specific exchange rate arrangement order follows the same logic, but its scale goes from one to ten. The latter categorical variable also takes into account the differences between 1998 and 2009 IMF de facto classification, with the annexed table A1 explaining the classification and how the specific exchange rate arrangements between classifications were harmonised.

For the Euro Area dataset, quarterly data about NER and price levels were transformed into natural logarithms, and the natural logarithm of RER was computed as defined in equation 5.

3.2. Methodology

This section outlines the empirical strategy used to analyse exchange rate movements, with a focus on testing the validity of PPP. This study employs two complementary datasets: the first one (with five developed and five developing countries) will be used to estimate NER dynamics within a cointegration framework; while the second one with euro area data (twelve countries) will be used exclusively to test the stationarity of RER as complementary validation of PPP within a monetary union.

3.2.1. Baseline empirical model

The baseline specification is defined as:

$$\log(NER)_{it} = \beta_0 + \beta_1 PPP_{it} + \beta_2 UIP_{it} + \beta_3 OP_{it} + \beta_4 M3GD_{it} + \beta_5 SRG_{it} + \delta_t + \varepsilon_{it} \tag{14}$$

Where $\log(NER)_{it}$ is the natural logarithm of NER expressed as local currency units per US Dollar, β_0 is the intercept, PPP_{it} is the relative PPP ($p - p^*$) of country i at period t; UIP_{it} is the short-term interest rate differential ($i - i^*$), OP_{it} is the trade openness index expressed as the sum of imports and exports to GDP, $M3GD_{it}$ is the M3 money supply growth rate differential between the local and foreign economy and ε_{it} is

the error term. This model is controlled for the exchange rate regime (using the secondary exchange rate arrangement) (SRG_{it}), and for time fixed effects (δ_t).

NER is chosen as the dependent variable to allow the comparison of PPP with other macroeconomic factors. The use of RER would not allow such comparison since, as it was shown in equations 1 and 5, RER already incorporates price levels. The choice of using US as the base country is to be consistent with most studies for the base country. Also, the relative version of PPP is adopted, as it is the standard specification in empirical PPP studies.

3.2.2. Model specification strategy

As PPP is a long-run mechanism, most modern PPP studies employ tests to time-series properties. Also, the use of these tests affects the choice of model specification between a static or a dynamic model. As mentioned previously, if the PPP holds, then the RER is stationary, which implies that the NER and price levels are cointegrated (Kasem & Al-Gasaymeh, 2022; Sarno & Taylor, 2002). Therefore, to validate PPP, most studies apply one of these two strategies: test the stationarity of RER using a unit root test, or apply a unit root test to the model's variables and then test for cointegration between NER and the explanatory variables. For this study's main dataset, as NER will be used as dependent variable, this study will use a unit root test followed by a cointegration test. However, to complement the analysis, RER stationarity will be tested on the dataset with euro area countries using panel unit root tests, to test RER in a monetary union is mean-reverting, which is consistent with long-run PPP.

3.2.3. Cross-sectional dependence test

Contrarily to most studies that use time-series, the choice of the panel unit root test is affected by the existence of cross-sectional dependence (CSD). As CSD changes the statistical properties on unit root tests, disregarding it could mislead the statistical inference. Moreover, as this study is using macroeconomic data, the existence of CSD is common due to common global shocks, and trade and financial integration (Pesaran, 2004).

Therefore, to apply the appropriate panel unit root test, this study will first employ the Cross Dependence test developed by Pesaran (2004), which is adequate to small panel datasets. For each dataset, CSD will be tested prior to panel unit root analysis. In the main dataset, the CD test will be applied to individual (country) series using only the continuous variables from equation 14 and tests whether they residuals are correlated

across countries. In the Euro Area dataset, it will be applied directly to the RER series. The CD test uses the following set of hypotheses:

$$H_0: Cov(\varepsilon_{it}, \varepsilon_{jt}) = 0\ , for\ all\ t, with\ i \neq j$$

$$H_1: H_0\ is\ false$$

The CD test computes the following statistics:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{p_{ij}}\right) \tag{15}$$

Where T is the number of time periods per country, N is the number of countries, and $\widehat{p_{ij}}$ is the pair-wise correlation of the residuals between country i and country j, with $i \neq j$. If the null hypothesis is rejected, then the test suggests the presence of CSD. To the particular case in the Euro Area dataset, given the high degree of economic integration across countries, CSD is likely to exist, making second-generation panel unit root tests particularly relevant.

3.2.4. Panel unit root test

A unit root process implies non-stationarity, meaning that shocks have permanent effects on the series, and variables do not revert to a constant mean (Wooldridge, 2020). Consider the following autoregressive model:

$$x_t = \rho x_{t-1} + \varepsilon_{it} \tag{16}$$

Where x_t is a time series at time t, and ρ is the coefficient of its previous value. A unit root process is present when $\rho = 1$ meaning that the series behaves as a random walk, increasing the unpredictability of its movements. If a series has unit root, using models with non-stationary variables without correction misleads the statistical inference. Estimating a regression with non-stationary variables may result in spurious relationships, characterised by high R^2 values and statistically significant coefficients despite the absence of a meaningful economic relationship.

If the null hypothesis of the CD test is not rejected, then this study will employ first generation unit root tests, since they assume that there is no CSD. Among the unit root tests, the more commonly used are the Augmented-Dickey-Fuller (ADF) and Phillips-Perron (PP) tests (Engel, 2000; Fischer & Porath, 2010; Kasem

& Al-Gasaymeh, 2022; Kyei-Mensah, 2023; Papell, 2006). These tests are computed by using the following autoregressive model:

$$\Delta x_{i,t} = \mu_i + \alpha x_{i,t-1} + \sum_{j=1}^{k} b_j \Delta x_{i,t-j} + \varepsilon_{it} \quad (17)$$

Where $\Delta x_{i,t}$ is the series variation on country i at time t, μ_i represents the country-specific fixed effects, $x_{i,t-1}$ is the series lagged value, α is its coefficient where $\alpha = \rho - 1$ and $\sum_{j=1}^{k} b_j \Delta x_{i,t-i}$ its lagged level and k lagged first differences, which is only used in ADF tests. The choice for the appropriated lag structure will be used according to the information criterion, such as Akaike information criterion (AIC) and Bayesian information criterion (BIC) as suggested by Kyei-Mensah (2023). These tests have the following set of hypotheses:

$$H_0: \alpha = 0$$

$$H_1: \alpha < 0$$

Where the null hypothesis indicates that the series has a unit root, while the alternative hypothesis states the stationarity of the series.

However, the standard version of ADF and PP tests only apply to time-series. Therefore, in order to adapt these tests to panel data, this study will employ their Fisher version. The Fisher ADF and Fisher PP tests examine the unit root of each country for each series and use the p-value of each test in equation (14) (Barbieri, 2005):

$$P = -2 \sum_{i=1}^{N} \ln (p_i) \quad (18)$$

Where P follows a χ^2 distribution with 2N degrees of freedom and the test compares P to the critical values. This test has as null hypothesis that all-panel series have a unit root, and the alternative one is that the series is stationary at least in some panels.

However, if the null hypothesis of the CD test is rejected, there is evidence to support the existence of CSD. In this case, the analysis proceeds by employing the following second generation panel unit root test: the Cross-sectionally augmented Im-Perasan-Shin (CIPS) unit root test developed by Pesaran (2007). This test uses the following Cross-sectionally Augmented Dickey-Fuller (CADF):

$$\Delta x_{i,t} = \mu_i + \alpha_i x_{i,t-1} + \sum_{j=1}^{k} b_i \Delta x_{i,t-j} + c_i \bar{x}_{t-1} + d_i \Delta \bar{x}_t + \varepsilon_{it} \quad (19)$$

The specification includes the cross-sectional series average from the previous time period ($\bar{x}_{t-1}$), and the variation of the average cross-section at time t ($\Delta\bar{x}_t$). From this model, the CIPS statistics is obtained by calculating the average t-statistics from the coefficient of $x_{i,t-1}$.

The null hypothesis of this test is the existence of a panel unit root for all series, while alternative hypothesis states the existence of stationarity in at least some panels. This test's null hypothesis is rejected if the CIPS statistics is lower than the test's critical value (following a CADF distribution), thus supporting that the series is stationary.

These panel unit root tests will analyse the model's variables at its level and first differences, as the cointegration test requires the variables to be integrated of order one, I(1) (including the dependent one) (Kasem & Al-Gasaymeh, 2022). For the euro area dataset, this analysis will conclude at the panel unit root stage, as no NER-based dynamic model is estimated with the data from this sample.

3.2.5. Panel cointegration test

From the panel unit root tests, one of the following three outcomes is expected: all variables are stationary, there are both stationary and I(1) variables, or all of them are I(1). If all variables are stationary the empirical strategy consists in applying Fixed Effects (FE) estimators to the model in equation (18) (Baltagi, 2005). If the dependent variable is I(0) but there are I(1) variables, the non-stationary regressors will be transformed into first differences to ensure the stationarity of all variables, and the model will then be estimated using FE estimators. If the dependent variable and at least one explanatory variable is I(1), a cointegration test will be applied. The cointegration test aims to analyse the long-run relationship between variables by testing the existence of a stationary linear combination from non-stationary variables (Kasem & Al-Gasaymeh, 2022).

This study will employ the error-correction model (ECM) cointegration test developed by Westerlund (2007), which is designed for panel data, and takes into account possible heterogeneity across countries. Furthermore, if there is CSD, the analysis proceeds by employing the bootstrap version of this cointegration test. The ECM can be written as:

$$\Delta y_{i,t} = \mu_i + \alpha_i\left(y_{i,t-1} - \beta_i' X_{i,t-1}\right) + \sum_{j=1}^{p_i} b_{i,j}\,\Delta y_{i,t-j} + \sum_{j=0}^{p_i} \gamma_{i,j}\,\Delta X_{i,t-j} + \varepsilon_{it} \qquad (20)$$

Where $\Delta y_{i,t}$ is the variation of the dependent variable of country i at time t, $y_{i,t-1}$ is the dependent variable at time t-1, X is the matrix of I(1) explanatory variables that will be tested, γ_{ij} represents their short-term estimators, while β_i' is matrix of their long-term estimators, α_i is the error-correction parameter, which will

be the one parameter to be tested. Moreover, $\sum_{j=1}^{p_i} b_{i,j}\,\Delta y_{i,t-j}$ and $\sum_{j=0}^{p_i} \gamma_{i,j}\,\Delta X_{i,t-j}$ represents the lag structure of the dependent and explanatory variables, respectively. The set of hypotheses of this model is the following:

$$H_0: \alpha_i = 0$$

$$H_1: \alpha_i = \alpha < 0$$

Where the null hypothesis states no cointegration, and the alternative hypothesis states at least one vector of cointegration. If the null hypothesis is rejected, then the test suggests the presence of a cointegration relationship (Westerlund, 2007). This test will be computed for the whole panel as well as for individual countries

3.2.6. Long-run and short-run estimation

The result of the cointegration test will define if the analysis can estimate NER dynamics on both long and short-run with a dynamic model, or if it will be restricted to the short-run with a static model. If there is at least one vector of cointegration, the strategy is to use an ECM model with Pooled Mean Group (PMG) or Mean Group (MG) estimators. This approach is an extension of the Autoregressive Distributed Lag (ADL) model for panel data (Goswami & Hossain, 2013; Pesaran et al., 1999). Also, the ECM is chosen since it's capable of dealing with both I(0) and I(1) variables and mitigates concerns with endogeneity by modelling both short-run dynamics and long-run relationships (Khan et al., 2019). PMG and MG estimators rely on different assumptions. While both allow heterogeneous coefficients in the short-run, PMG assumes homogeneous long-run coefficient, while MG estimators assume heterogenous coefficients for each cross-sectional unit (Habermeier & Mesquita, 1999). This model can be represented as follows:

$$\Delta\log(NER)_{it} = \mu_i + \phi_i[\log(NER)_{it-1} - \beta'_i X_{it}] + \sum_{j=1}^{q} \lambda_{ij}\Delta\log(NER)_{it-j} + \sum_{j=0}^{p} \delta_{ij}\Delta X_{it-j} + \sum_{j=0}^{r} \Gamma_{ij}\Delta W_{it-j} + \psi_{ij} Z_{it-j} + \delta_t + \varepsilon_{it} \quad (21)$$

Where μ_i is the country-specific heterogeneous intercept, ϕ is the error-correction coefficient, X is the matrix of cointegrated variables, β' and δ are their long-run and short-run coefficients, respectively. λ is effect of the lagged dependent variable in the short run W is the matrix of I(1), non-cointegrated variables, and Γ is its effect in the short-term. Z represents the matrix of stationary variables and ψ their coefficient in the short-run. Also δ_t represent the control variable for timed fixed effects and ε_{it} is the error term. Moreover, AIC and BIC will be used to define the model's optimal lag structure.

If the null hypothesis of no cointegration cannot be rejected, the long-run relationship is not supported. Therefore, applying an error-correction model is not appropriate. In this case, all I(1) variables, including the dependent one, will be transformed into first differences, and the baseline model will be estimated using fixed effects estimators. In the framework of Fixed effects (FE) vs Random effects (RE), the Hausman test relies on the assumption of a large number of cross-sectional units, the small number of countries in this dataset (N=10) can lead to unreliable estimates. Moreover, the use of first-differenced variables could lead to the elimination of the random effects. This results in the RE model collapsing to a pooled Ordinary Least Squares model. In that case, the Hausman test becomes meaningless. Due to these potential issues, the use of FE estimators was preferred.

3.2.7. Model diagnostics and robustness

If the analysis proceeds with PMG and MG estimators, equation 21 is estimated using both estimators. As previously mentioned, the cross-sectional dimension of this dataset is small (N=10), so the Hausman test may not be reliable to test for long-run homogeneity. Therefore, the analysis will be limited to compare the long-run coefficients' magnitude across specifications. If the estimators' magnitude across PMG and MG is similar, then PMG will be preferred because it is more efficient under the long-run homogeneity assumption.

Following the model estimation, the statistical significance of its coefficients is assessed using individual and global significance tests. To ensure robustness, the Pesaran CD test will be repeated using the residuals of the model. If CSD is detected, this study will use Driscoll-Kraay standard errors, since they address CSD, heteroskedasticity, and serial correlation. Otherwise, the analysis proceeds to test heteroskedasticity with the Breusch-Pagan test (Baltagi, 2005), and apply White standard errors if heteroskedasticity is detected. Moreover, a Variance Inflation Factor (VIF) test will be used to assess multicollinearity. If there is multicollinearity, only one of the collinear variables is maintained. Furthermore, the decision of which variable is maintained is based in its role in the model (for instance, if there is a variable collinear with PPP, PPP will always be maintained since it is the core variable for the analysis).

3.2.8. Testing for group differences

In order to assess how country's characteristics can affect the PPP effects, the sample will be split according to country groups. Then, the analysis proceeds to compare the estimators, and will add an interaction between the PPP variable and the country's group dummy, and analyse its magnitude and statistical significance.

4. Descriptive statistics

4.1. Summary statistics

4.1.1. Main sample

Descriptive statistics provide an initial overview of the data before proceeding to regression analysis, allowing the identification of potential patterns and relationships across variables and countries. This section presents descriptive statistics for the main dataset, followed by a descriptive analysis of the euro area dataset. Table 2 presents the summarised statistics for the full sample, and it can be observed that:

	mean	standard deviation	min	max
Δlog(NER)	.0066921	.0506598	-.156618	.39535
NER	133.7228	339.4427	.342132	1412.513
CPI	276.4485	542.3953	96.14185	6746.06
Inflation	.0114487	.019536	-.0199738	.2490978
NIR	6.802199	10.92159	.0133333	119.695
Trade openness	40.90504	15.6072	14.58036	86.77761
M3 growth rate	2.605982	2.312346	-1.378183	26.80152
Observations	980			

Table 2 - Summary statistics for all countries. Source: self-computation

The average CPI is approximately 276.45, suggesting a considerable increase in price levels over the sample period, reflecting long-term inflation trends across the countries analysed. However, the data reveal deflationary periods, as indicated by the minimum negative inflation value and CPI observations below 100.

The average 3-month interbank interest rate is 6.8%, but the data suggest a considerable dispersion across periods and countries. This is reflected by the relatively high standard deviation (10.9) and the amplitude of the data between the minimum (0.01%) and maximum (119.70%).

The trade openness index data suggests that the sum of exports and imports represents an average of 40.9% of GDP. However, considerable heterogeneity between countries and periods is observed as some countries exhibit considerably lower levels of trade openness (minimum of 14.58%) while others experience periods of much higher integration with international trade (up to 85.78% of GDP).

Regarding monetary conditions, the average M3 growth rate suggests M3 increased on average by approximately 2.6% per quarter, although the data reveal periods of contraction in money supply (minimum of -1.37%) as well as periods of rapid expansion (up to 26.8%).

4.1.2. Developed vs Developing countries

As this study will further analyse for potential differences in PPP validation across groups of countries, the analysis of summary statistics per group allows to identify potential differences on their macroeconomic variables. For that reason, Table 3 and Table 4 present the summary statistics of developed and developing countries, respectively, they suggest that:

	mean	standard deviation	min	max
Δlog(NER)	.000717	.0415608	-.1319232	.2847472
NER	250.7655	450.3193	.48885	1412.513
CPI	128.1814	24.71385	96.14185	197.1976
Inflation	.005021	.0062852	-.0190482	.0377402
NIR	2.380842	2.111296	.0133333	7.8
Trade openness	42.66706	15.56719	15.16041	86.77761
M3 growth rate	1.581111	1.226115	-1.378183	7.553306
Observations	490			

Table 3 - Summarised statistics of developed countries. Source: self-computation

	mean	standard deviation	min	max
Δlog(NER)	.0126672	.057786	-.156618	.39535
NER	16.68004	20.90077	.342132	82.26557
CPI	424.7155	737.7805	97.72364	6746.06
Inflation	.0178764	.0253336	-.0199738	.2490978
NIR	11.22356	13.97039	1.153333	119.695
Trade openness	39.14301	15.46312	14.58036	84.67723
M3 growth rate	3.630852	2.663917	-.1760776	26.80152
Observations	490			

Table 4 - Summarised statistics of developing countries. Source: self-computation

Exchange rate variation (Δlog(NER)) is, on average, significantly lower in developed countries of this sample, as well as their standard deviation, which suggests greater exchange rate stability. Also, the lower average inflation, NIR, and M3 growth rate values observed in this group of countries suggest greater macroeconomic stability. However, average 3-month interbank interest rate is significantly higher in developing countries, as well as its standard deviation, which may reflect higher macroeconomic volatility and risk premia in developing economies. Regarding trade openness, although these developed countries exhibited a higher trade openness index on average, this difference is not sufficiently large to be economically meaningful, as reflected in the similar standard deviation, minimum and maximum value. Therefore, these results suggest that developed and developing countries have considerable differences is most of macroeconomic variables analysed.

4.2. Evolution between nominal exchange rate and purchasing power parity

As this study's focus is on PPP validation, the analysis of its behaviour allows to observe preliminary results about it. Therefore, figures 1 to 10 compare the behaviour of the natural logarithm of NER and Relative PPP. To enhance the comparison of their behaviours, both variables were normalised to the first period, where 0 represents the value of the first period in the vertical axis. The analysis of these figures suggests that:

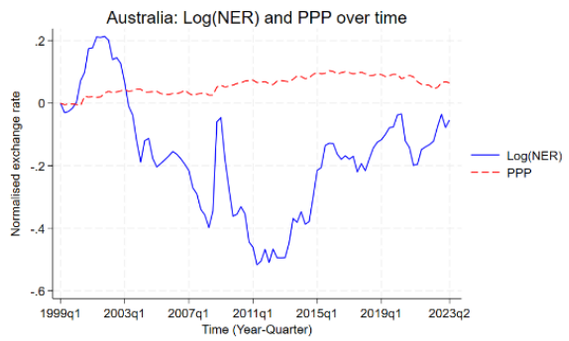


Figure 1 - Evolution of Normalised Log(NER) and Relative PPP in Australia (1999Q1 - 2023Q2). Source: Self-computation

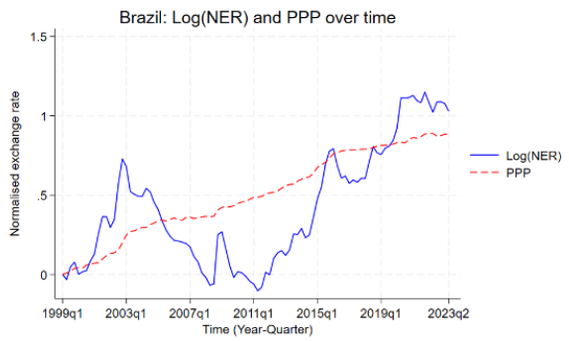


Figure 2 - Evolution of Normalised Log(NER) and Relative PPP in Brazil (1999Q1 - 2023Q2). Source: Self-computation

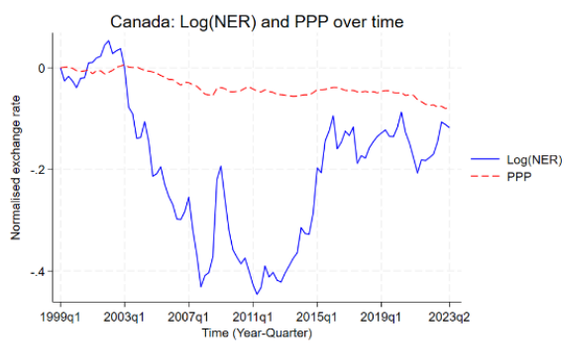


Figure 3 - Evolution of Normalised Log(NER) and Relative PPP in Canada (1999Q1 - 2023Q2). Source: Self-computation

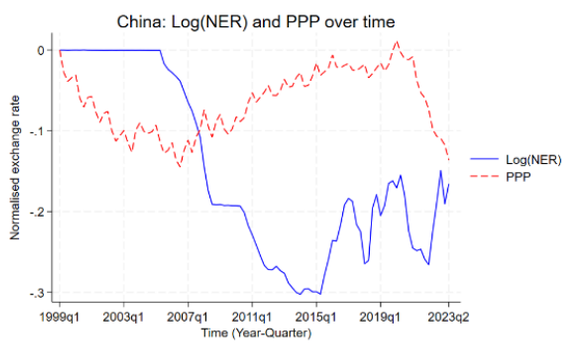


Figure 4 - Evolution of Normalised Log(NER) and Relative PPP in China (1999Q1 - 2023Q2). Source: Self-computation

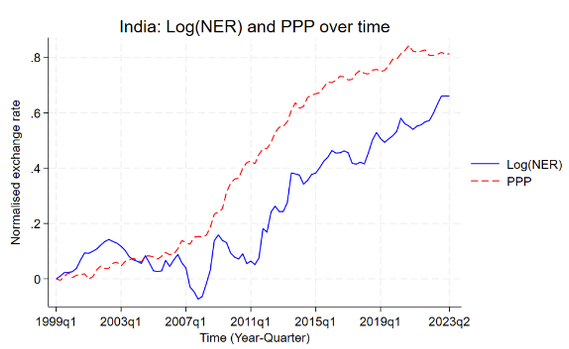


Figure 5 - Evolution of Normalised Log(NER) and Relative PPP in India (1999Q1 - 2023Q2). Source: Self-computation

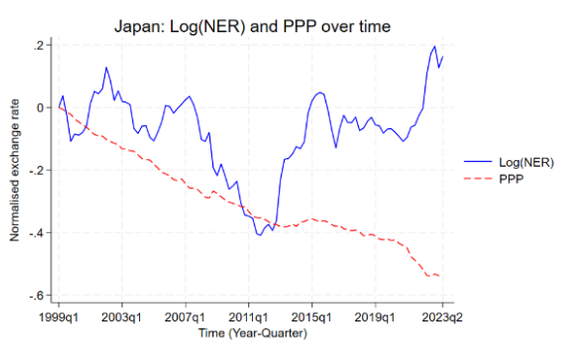


Figure 6 - Evolution of Normalised Log(NER) and Relative PPP in Japan (1999Q1 - 2023Q2). Source: Self-computation

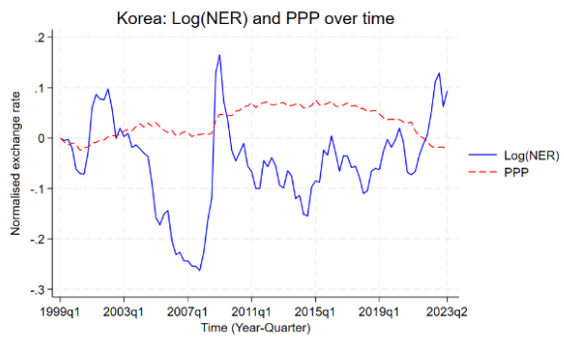


Figure 7 - Evolution of Normalised Log(NER) and Relative PPP in Korea (1999Q1 - 2023Q2). Source: Self-computation

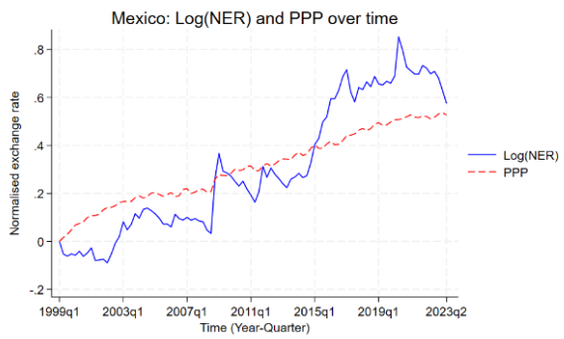


Figure 8 - Evolution of Normalised Log(NER) and Relative PPP in Mexico (1999Q1 - 2023Q2). Source: Self-computation

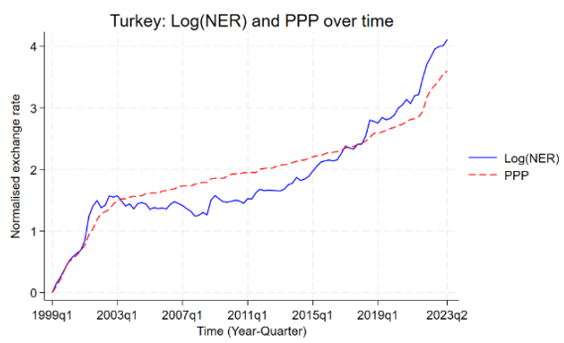


Figure 9 - Evolution of Normalised Log(NER) and Relative PPP in Turkey (1999Q1 - 2023Q2). Source: Self-computation

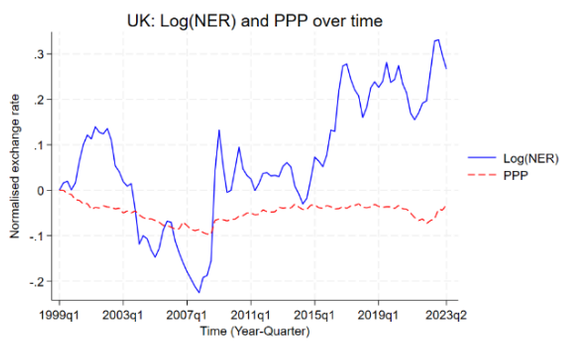


Figure 10 - Evolution of Normalised Log(NER) and Relative PPP in UK (1999Q1 - 2023Q2). Source: Self-computation

With the exception of China, relative PPP suggests smoother exchange rate movements than those observed in the data. However, in most countries, NER appears to converge to the levels proposed by PPP (Japan and UK seemed to converge to PPP-implied value until 2012 and 2015, respectively).

Moreover, only in four countries (Brazil, India, Mexico and Turkey) NER appears to move alongside relative PPP. As these behaviours only appeared in developing countries, not only this analysis may suggest some preliminary support for PPP, but also that there might be differences between groups of countries that could affect the strength of PPP validation in favour of developing countries.

4.3. Pairwise correlations

Pairwise correlations provide preliminary insights about the relationships between variables and help to identify potential multicollinearity issues prior to the regression analysis. It's important to note that these pairwise correlations do not imply causal relationships and may be influenced by omitted variables or common trends. Therefore, Table 5 presents the pairwise correlations between the variables of the model, and suggests that:

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) log(NER)	1.000					
(2) PPP	-0.148***	1.000				
	(0.000)					
(3) UIP	-0.200***	0.398***	1.000			
	(0.000)	(0.000)				
(4) Openness	0.265***	0.088***	-0.110***	1.000		
	(0.000)	(0.006)	(0.001)			
(5) M3 growth rate differential	-0.151***	0.226***	0.568***	-0.023	1.000	
	(0.000)	(0.000)	(0.000)	(0.472)		
(6) Secondary exchange rate arrangement	-0.038	0.002	-0.023	-0.070**	-0.244***	1.000
	(0.235)	(0.956)	(0.479)	(0.029)	(0.000)	

Table 5 - Pairwise correlations matrix. Source: Self-computation

Notes: ***, ** and * denotes significance at 1%, 5% and 10% levels. P-values in parentheses.

The natural logarithm of NER is negatively correlated with all explanatory variables, with the exception of trade openness index, which is positively correlated. However, the sign of these correlations is contrary to what is typically expected in the exchange rate literature. Also, these correlations with the dependent variable are statistically significant at a 1% significance level, except for the secondary exchange rate arrangement that is not statistically significant even at a 10% significance level. Regarding PPP, the data suggest a weak and positive correlation with UIP, trade openness, and M3 growth rate differential, all significant at a 1% significance level, with the largest coefficient (0.398) being with UIP. UIP is also negatively correlated with trade openness and positively correlated with M3 growth rate, where this latter pairwise correlation is moderate and is the strongest in this table (0.568), and they are all statistically significant at a 1% significance level. The existence of this moderate correlation emphasizes the need to further test for multicollinearity between explanatory variables. Regarding trade openness index and M3 growth rate differential, they are both weakly and positively correlated with the secondary exchange rate arrangement, with the first one being significant at a 5% significance level only and the latter one being significant at 1% significance level.

Therefore, most variables are correlated with the dependent variable with the opposite sign compared to what is expected to be their effect. However, these results are insufficient to determine their effects, and therefore cannot replace the regression estimators' results. Also, most explanatory variables are correlated with each other in most cases, with most of them being weak correlation, except for the correlation between M3 growth rate differential and UIP, which would require further analysis by employing a multicollinearity test.

4.4. Evolution of real exchange rate in euro area

Regarding the Euro area dataset, as its purpose for this study is solely to the analysis of RER dynamics and test if the series across countries consistently stationary. Therefore, the annexed figures 11 to 22 present the dynamics of the natural logarithm of RER of each country over time, in comparison to their respective mean.

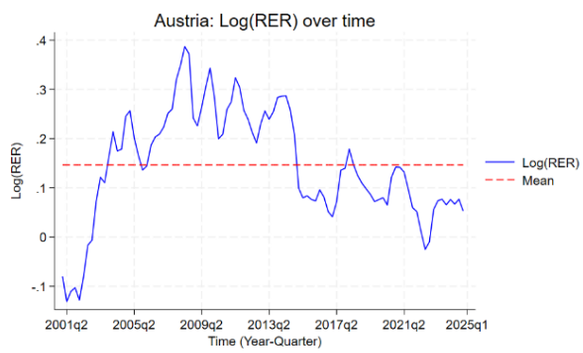


Figure 11 - Evolution of Log(RER) and its mean in Austria (2001Q1-2024Q4). Source: Self-computation

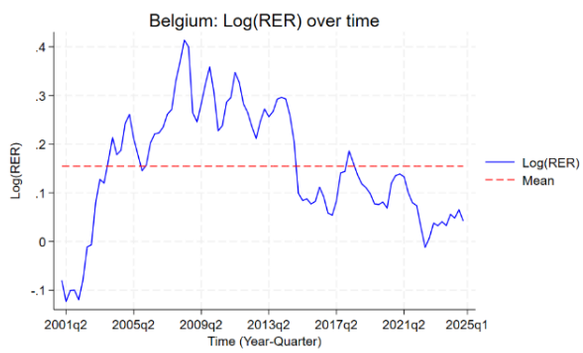


Figure 12 - Evolution of Log(RER) and its mean in Belgium (2001Q1-2024Q4). Source: Self-computation

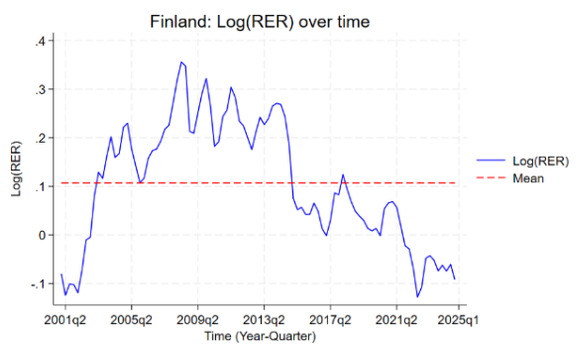


Figure 13 - Evolution of Log(RER) and its mean in Finland (2001Q1-2024Q4). Source: Self-computation

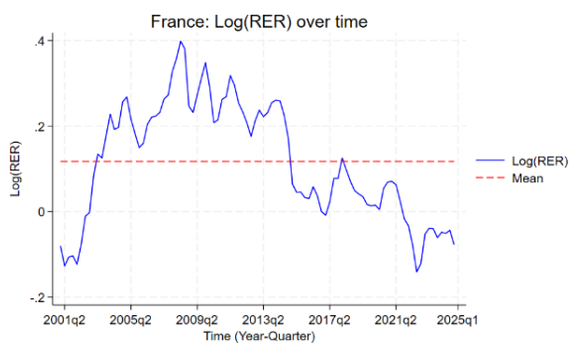


Figure 14 - Evolution of Log(RER) and its mean in France (2001Q1-2024Q4). Source: Self-computation

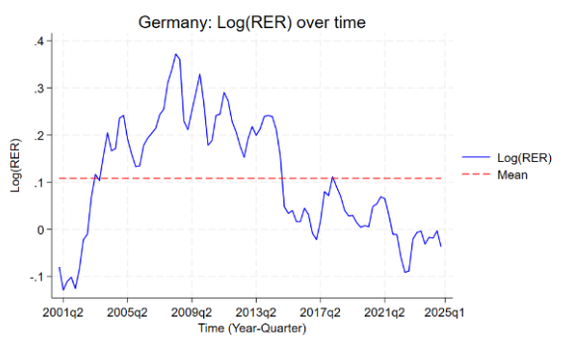


Figure 15 - Evolution of Log(RER) and its mean in Germany (2001Q1-2024Q4). Source: Self-computation

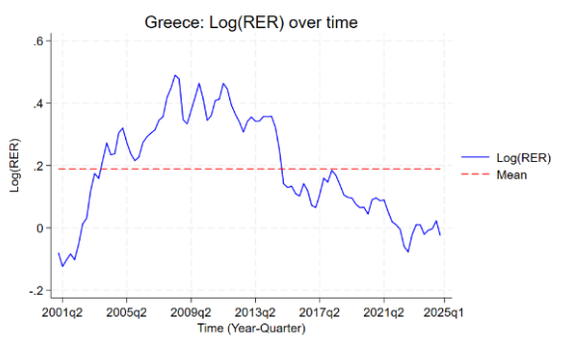


Figure 16 - Evolution of Log(RER) and its mean in Greece (2001Q1-2024Q4). Source: Self-computation

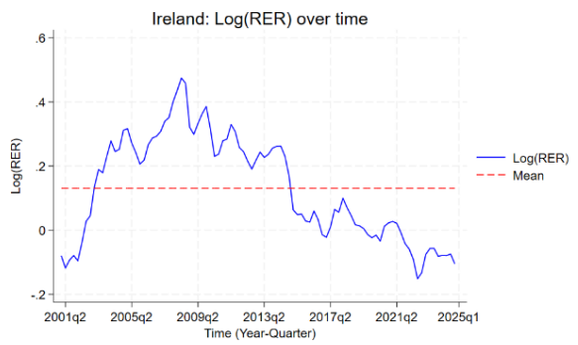


Figure 17 - Evolution of Log(RER) and its mean in Ireland (2001Q1-2024Q4). Source: Self-computation

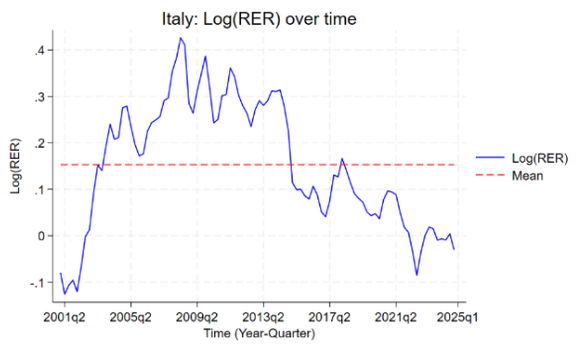


Figure 18 - Evolution of Log(RER) and its mean in Italy (2001Q1-2024Q4). Source: Self-computation

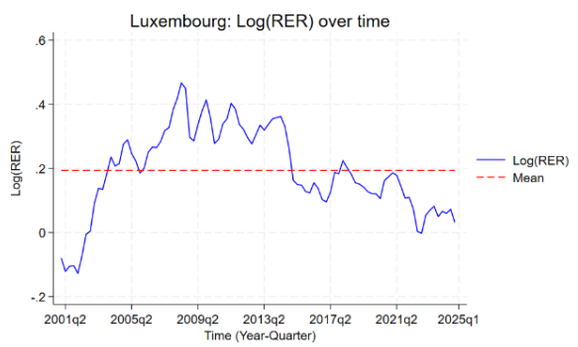


Figure 19 - Evolution of Log(RER) and its mean in Luxembourg (2001Q1-2024Q4). Source: Self-computation

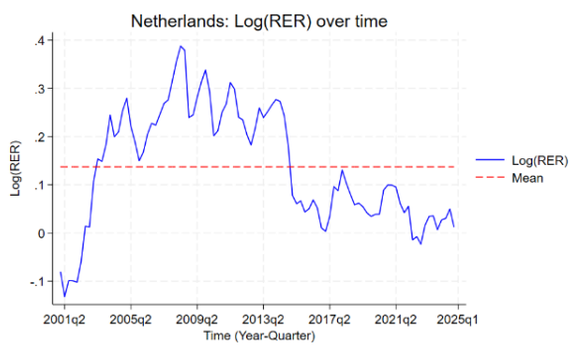


Figure 20 - Evolution of Log(RER) and its mean in Netherlands (2001Q1-2024Q4). Source: Self-computation

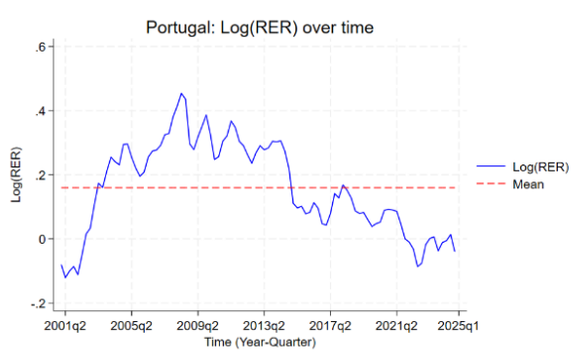


Figure 21 - Evolution of Log(RER) and its mean in Portugal (2001Q1-2024Q4). Source: Self-computation

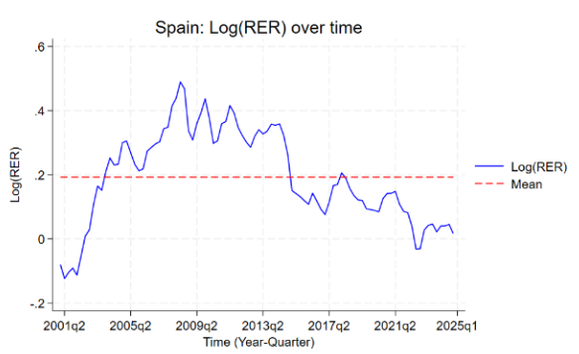


Figure 22 - Evolution of Log(RER) and its mean in Spain (2001Q1-2024Q4). Source: Self-computation

These figures suggest that these countries can be aggregated into three main groups. First, some countries that appear to display more mean-reverting RER dynamics. First, Austria, Belgium, the Netherlands, France, and Germany show relatively frequent fluctuations around their country-specific mean, suggesting stronger mean-reversion compared to other countries. Second, countries such as Greece, Portugal, Spain, and Ireland show more persistent deviations to the mean as well lower speed of adjustments, suggesting some structural shifts. Third, countries such as Finland, Italy and Luxembourg appear to lie between these patterns, showing some mean reversion but at relatively slower adjustments than the first group. However, all countries show

high persistent and slow adjustment towards the mean during the period analysed, which may indicate the presence of a unit root, suggesting no support for PPP in the euro area. Nonetheless, this study will employ a panel unit root test to assess whether the RER is stationary.

Overall, the descriptive evidence highlights substantial heterogeneity across countries and potential differences between developed and developing economies regarding macroeconomic stability and exchange rate variability. These preliminary observations motivate the econometric analysis aimed to formally test PPP and other macroeconomic relationships with exchange rate movements, and test whether the support of PPP is heterogeneous across groups of countries.

5. Results

Since this study will use two datasets, the PPP will be analysed into two parts. Firstly, this study will elaborate the secondary analysis using the Euro area Dataset to test whether the RER is stationarity across the former 12 euro area countries. Afterwards, this study will focus on the main dataset to study the NER Dynamics. In order to properly decide the model specification, this study will primarily test the data properties and long-run relationships of the variables.

5.1. Real exchange rate stationarity in the euro area

The main goal of this secondary dataset is to test the validity PPP by testing the stationarity of RER. As these countries use the same currency, the validation of PPP allows to evaluate the existence of price convergence among the euro former countries.

5.1.1. Cross-sectional dependence test

The results of the CD test strongly suggest that the RER series has CSD. The CD statistic is 77.756, and its respective p-value is 0.0000. Thus, the null hypothesis of cross-sectional independence is rejected at a 1% significance level. This implies that shocks are correlated across countries, likely reflecting common macroeconomic factors. As a result, first-generation panel unit root tests would yield invalid inference.

5.1.2. Panel unit root test

The results from the CIPS test indicates that the RER series is non-stationary in levels but stationary in first differences. This test is appropriate given the presence of CSD. Table 6 reports the results of the CIPS test at levels and first differences for the RER series. This test only includes a constant in its specification, as in the previous evolution graphs suggested that the RER series do not seem to follow a linear trend. The lag structure is selected based on AIC and BIC (see Table A1), indicating one lag as the optimal structure.

Variable	**At Levels**	**First Differences**
Log(RER)	-1.287(1)	-6.190(0) ***

Table 6 - CIPS unit root test at level and first differences (Euro area dataset). Source: Self-computation

Notes: ***, ** and * denotes significance at 1%, 5% and 10% levels. Figures in parenthesis are the lag length.

The results from table 6 indicate that, at levels, the null hypothesis of unit root cannot be rejected at conventional significance levels. In contrast, the null hypothesis was rejected in first differences at 1%

significance level, indicating that the RER is integrated of order one, I(1). This indicates the absence of mean reversion in the RER series, with shocks in the variable having persistent effects on the RER.

In the euro area context, these results suggest that prices across member countries do not converge over time. Since the PPP implies that RER is stationary, these findings provide no support for its validity.

5.2. Main panel analysis: nominal exchange rate framework

This section analyses the NER dynamics and PPP validity through a unit root and cointegration tests. Then, it estimates the model with PPP and other macroeconomic factors and compares it across groups of countries.

5.2.1. Cross-sectional dependence test

There is strong evidence of CSD in the dataset. With a CD statistic of 34.417 and a p-value of 0.0000, the null hypothesis of cross-sectional independence is rejected at a 1% significance level. This implies that shocks are correlated across countries, likely reflecting common macroeconomic factors. As a result, the use of first-generation panel unit root tests would produce unreliable inference, and the use of second generation panel unit roots is appropriate.

5.2.2. Panel unit root test

The results from the CIPS test indicate the presence of both stationary variables, I(0), and integrated of order one (I(1)) variables. Table 7 reports the results of the CIPS test at levels and first differences using only the specification with a constant, as the previous descriptive statistics of the main dataset did not suggest that these variables follow a linear trend. This test uses as null hypothesis the presence of a unit root. Moreover, the lag structure is selected based on AIC and BIC (see Table A2 to A6), indicating one lag as optimal for Log(NER) and four lags for the remaining variables.

Variable	**At Levels**	**First Differences**
Log(NER)	-1.950 (1)	-6.190 (0) ***
PPP	-1.645 (4)	-2.836 (3) ***
UIP	-2.442 (4) **	-4.531 (3) ***
Trade openness	-1.479 (4)	-4.593 (3) ***
M3 growth rate differential	-3.176 (4) ***	-6.190 (3) ***

Table 7 - CIPS unit root test at level and first differences (Main dataset). Source: Self-computation

Notes: ***, ** and * denotes significance at 1%, 5% and 10% levels. Figures in parenthesis are the lag length.

For Log(NER), PPP, and trade openness, the null hypothesis wasn't rejected at conventional significance levels at levels. However, the null hypothesis is rejected at 1% significance level at first differences for these variables, indicating strong evidence that these variables are I(1). The null hypothesis was rejected for M3 growth rate differential at 1% significance level, and for UIP at 5% significance level, thus providing strong evidence that these variables are stationary. Since the dataset contains I(1) variables, including the dependent variable, the requirements to proceed with a cointegration test are met.

5.2.3. Panel cointegration test

The results from Westerlund cointegration test (bootstrap version) provide no evidence of cointegration between the dependent variable and the remaining I(1) variables. The use of the bootstrap version of this test is adequate due to the presence of CSD. Since this study focus is in testing PPP validity in the long-run, this test includes two specifications: one using solely the PPP variable and another that includes trade openness. Therefore, the test can distinguish whether PPP is solely cointegrated with NER, or is only cointegrated with the inclusion of the trade openness variable. Additionally, a lag length of two is used as the baseline specification to balance overfitting and loss of observations. As a robustness check, the test is also estimated using one lag. Table 8 shows the results of the bootstrap version of the Westerlund cointegration test for both panel and group means, to detect whether cointegration exists in the whole panel or only in some countries.

	1 lag		**2 lags**	
Statistics	PPP Only	PPP + Trade Openness	PPP Only	PPP + Trade Openness
Gt	-1.887	-1.885	-1.744	-1.848
	(0.351)	(0.697)	(0.547)	(0.740)
Ga	-7.399	-7.197	-6.939	-7.073
	(0.441)	(0.834)	(0.547)	(0.850)
Pt	-5.192	-4.751	-4.595	-4.915
	(0.268)	(0.741)	(0.493)	(0.687)
Pa	-5.444	-5.218	-4.710	-4.871
	(0.194)	(0.643)	(0.366)	(0.713)

Table 8 - Westerlund cointegration test results (Bootstrap version), Source: Self-computation

Notes: Gt and Ga are the t and error correction statistics of group mean tests. Pt and Pa are the t and error correction statistics of panel tests. ***, ** and * denotes significance at 1%, 5% and 10% levels. P-values in parentheses.

Under the null hypothesis of the absence of cointegration, the results show that the null hypothesis cannot be rejected in either the panel or group-mean statistics, and either if trade openness is included or not. Although in all cases the error correction statistics are lower than -1, due to their high p-values, they are not statistically significant. Moreover, these results are consistent across lag structures.

Therefore, these results provide no evidence of cointegration between the dependent variable and I(1) explanatory variables, indicating that there is no equilibrium long-run relationship in any country analysed. According to the theory, PPP is a long-run mechanism and implies cointegration with log(NER). As no cointegration was found, this implies that the Westerlund test found no support for PPP validity in this sample. The absence of a long-run relationship imply that models such as PMG and MG may not be the appropriate to further analyse. Consequently, the analysis proceeds with a FE model to analyse NER dynamics in the short-run. To avoid a spurious regression, log(NER), PPP and trade openness will be transformed into first differences.

5.2.4. Baseline fixed effects estimation

Once no cointegration was found, the analysis proceeds with a short-run model using FE estimators. Since the dependent variable is expressed in first differences, it is now interpreted as NER depreciation rate. Moreover, since the PPP variable is now transformed into first differences, this variable now represents the inflation rate differentials. Table 9 presents the results of the baseline model, and they indicate that:

VARIABLES	(1) All countries
Δ PPP	0.5933***
	(0.0948)
Δ Trade Openness	0.0040***
	(0.0004)
UIP	-0.0004*
	(0.0002)
M3 growth rate differential	0.0059***
	(0.0008)
Secondary exchange rate arrangement index	-0.0011
	(0.0016)
Observations	970
Number of countries	10
Time fixed effects	Yes
Within R-squared	0.555
Wald statistic	10.59***

Table 9 - Baseline Fixed effects model estimation. Source: Self estimation.

Notes: Standard errors in parentheses. ***, ** and * denotes significance at 1%, 5% and 10% levels.

Under the null hypothesis of all slope coefficients being jointly equal to zero, the Wald statistic of this model is 10.59. As the null hypothesis is rejected at 1% significance level, the Wald test suggests that the model is

statistically significant. Additionally, the within R^2 of 0.555 indicates that approximately 55.5% of the dependent variable's variation is explained by the model.

Regarding PPP, its coefficient suggests that, on average, an increase in the inflation rate differential relative to the US by 1 percentage point is associated with an increase in the rate of NER depreciation of approximately 0.5933%, ceteris paribus. This result is statistically significant at the 1% level. However, its value is considerably lower than predicted by theory (equal to 1), implying partial support of PPP in the short run.

Turning to the remaining exchange rate determinants, results suggest that a 1 percentage point increase in the trade openness ratio is associated with an average increase in the rate of NER depreciation of approximately 0.4%, ceteris paribus. Additionally, this variable is statistically significant at the 1% level. Furthermore, its sign and significance are aligned with empirical expectations. Moreover, the money supply growth differential has a positive impact on the NER depreciation rate. More precisely, an increase in the M3 growth rate differential by 1 percentage point is associated, on average, with an increase in the rate of NER depreciation of approximately 0.59%, ceteris paribus. This effect is statistically significant at the 1% level, and in line with theoretical and empirical expectations.

In contrast, UIP has a negative impact on the dependent variable. The results indicate that a 1 percentage point increase in the interest rate differential is associated with an average decrease in the rate of NER depreciation of approximately 0.04%, ceteris paribus. However, this result is only statistically significant at the 10% level. Despite the variable being statistically significant is partially expected from the literature, the sign is not aligned with theoretical expectations. Regarding the exchange rate regime effect, although its sign is negative, this value is not statistically significant, even at a 10% significance level. Therefore, results indicate that the exchange rate regime has no effect on the dependent variable.

5.2.5. Diagnostic and reliability tests

To ensure the reliability of the estimators, this subsection tests whether the statistical inference is valid. The diagnostic procedure includes test for CSD, heteroskedasticity (if no CSD is detected), and multicollinearity, and correcting the estimation if necessary.

Starting with CSD, which was previously detected, the CD Perasan test is applied again but now including all variables. Against the null hypothesis of cross-sectional independence, the CD test yields a statistic of -6.297 and a p-value of 0.0000. Therefore, the null hypothesis is rejected at the 1% significance level, indicating the presence of CSD. As CSD is detected, the standard statistical inference may be unreliable. To ensure the

robustness of the coefficients, the model is re-estimated using Driscoll-Kraay standard errors. Since they address CSD and heteroskedasticity, a separate test for the latter issue is not required.

Testing for multicollinearity allows the detection of problematic relationships among explanatory variables. If explanatory variables are highly correlated, the exogeneity assumption may be violated and estimators may be biased. Although the highest correlation (0.568) is not at a concerning level, higher values are expected between UIP and M3 growth rate differential. Furthermore, the inclusion of timed fixed effects may inflate correlation levels across variables. Table 10 presents the results of the VIF statistics for all variables of the model, which suggest that:

Variable	VIF
Δ PPP	2.55377841
Δ Trade Openness	1.49639535
UIP	3.14856434
M3 growth rate differential	3.45071054
Secondary exchange rate arrangement	1.18326461
Time fixed effects (average)	2.020383

Table 10 - VIF statistics. Source Self-Computation

The VIF statistics indicate that the highest values (3.45 and 3.14) correspond to UIP and M3 growth rate differential, which is consistent with the previously analysed correlation matrix. Although the timed fixed effects were expected to increase the VIF values, the results show that they remain relatively low with their inclusion. Since they are lower than 10, no concerning multicollinearity is detected.

Given the presence of CSD, table 11 reports the results of the baseline model estimated with Driscoll-Kray standard errors, which indicate that:

VARIABLES	(1) All countries
Δ PPP	0.5933***
	(0.1360)
Δ Trade Openness	0.0040***
	(0.0007)
UIP	-0.0004
	(0.0003)
M3 growth rate differential	0.0059***
	(0.0015)
Secondary exchange rate arrangement	-0.0011
	(0.0019)
Observations	970
Number of groups	10
Time fixed effects	Yes
Within R-squared	0.555
Wald statistic	46.10***

Table 11 - Robust Fixed Effects estimation results. Source: Self-estimated

Notes: Robust (Driscoll-Kraay) standard errors in parentheses. ***, ** and * denotes significance at 1%, 5% and 10% levels.

Compared to the previous specification, which did not account for CSD, the statistical inference changes only marginally, with two main differences. First, UIP is no longer statistically significant, not even at the 10% level, suggesting that this result is not robust across standard errors alternative methods. Second, the Wald statistics increases considerably, strengthening the evidence of the model's explanatory power for NER movements.

5.2.6. Heterogeneity analysis and model fit

One of this study's objectives is to assess whether the effect of PPP on NER dynamics differs across groups of countries. Therefore, the analysis proceeds with the introduction of three new model specifications. These specifications include a model with developing countries only, and a model with developed countries only, and they represent supporting evidence. The third model introduces an interaction term between PPP and the group of country. This specification is used to formally test PPP heterogeneity. Table 12 summarises the results of these models, which indicates that:

VARIABLES	(1) All Countries	(2) Developing Countries	(3) Developed Countries	(4) All Countries + PPP interaction
Δ PPP	0.5933***	0.6645***	-0.2939	0.6167***
	(0.1360)	(0.1422)	(0.3485)	(0.1364)
Δ Trade Openness	0.0040***	0.0028***	0.0059***	0.0041***
	(0.0007)	(0.0007)	(0.0015)	(0.0007)
UIP	-0.0004	-0.0006*	-0.0013	-0.0004
	(0.0003)	(0.0004)	(0.0017)	(0.0003)
M3 growth rate differential	0.0059***	0.0071***	0.0049*	0.0059***
	(0.0015)	(0.0017)	(0.0025)	(0.0015)
Secondary exchange	-0.0011	-0.0019	0.0074	-0.0010
rate arrangement	(0.0019)	(0.0022)	(0.0070)	(0.0019)
ΔPPP X Developed				-0.5637**
				(0.2265)
Observations	970	485	485	970
Number of countries	10	5	5	10
Time fixed effects	Yes	Yes	Yes	Yes
Within R-squared	0.555	0.619	0.635	0.556
Wald statistic	46.10***	62.97***	19.49***	39.29***

Table 12 - Robust Fixed Effects estimation results with all models included. Source: Self-estimated.

Notes: Robust (Driscoll-Kraay) standard errors in parentheses. ***, ** and * denotes significance at 1%, 5% and 10% levels.

When comparing the second and third models, the results suggest differences between them in both magnitude, sign and significance. PPP and UIP are only statistically significant in the developing-country model. They are statistically significant at 1% and 10% significance levels, respectively. Furthermore, although the effect of PPP is not statistically significant in the developed-country model, the sign of its coefficient changes across models. Moreover, the effect of the M3 growth rate differential appears to be stronger in developing countries. In contrast, trade openness has a stronger effect in the developed-country model. Since the effect of PPP, as well as its statistical significance and sign, varies between these models, this suggests that its effect may differ across groups of countries.

To confirm whether the effect of PPP is heterogenous across groups, the analysis' focus shifts towards the model with the interaction term. Regarding the effect of PPP, the estimation suggests that, in developing countries, an increase in the inflation differential relative to the US by 1 percentage point is associated, on average, with an increase in the NER depreciation rate of approximately 0.62%, ceteris paribus. This result is statistically significant at 1% significance level. However, in developed countries an increase in the inflation differential relative to US by 1 percentage point is associated, on average, with an increase of approximately 0.05% in the NER depreciation rate, ceteris paribus. This result is statistically significant at 5% significance

level. This indicates that the PPP effect is weaker in developed countries, thus suggesting that the support for PPP is affected by the country's development level.

Regarding the rest of the macroeconomic factors, their coefficient remained unchanged in comparison to the baseline model. The only exception is the trade openness ratio, which effect increased by a negligible amount.

Regarding the model statistics, the Wald statistic of 39.29 indicates statistically significant to explain exchange rate movements. Although this statistic is smaller than the baseline model's Wald statistic, it's still statistically significant at a 1% significance level. Moreover, the within R^2 indicates that approximately 55.6% of the dependent variable's variation is explained by the model. The increase in the within R^2 is almost negligible and expected with the interaction term inclusion.

Therefore, the results suggest that PPP is not fully supported in the short-run. However, the interaction term's coefficient indicates that the effect of PPP is heterogeneous across groups, with its magnitude being greater in developing countries.

To further analyse this exchange rate model, this study evaluates the goodness of fit of the final model. For that, the NER depreciation rate values predicted by the model are compared to the actual NER depreciation rate values. Table 13 presents the average values of the predicted, and actual NER depreciation rate and the gap (in percentage points) between them for each country. These values are segmented into two subperiods.

Country	First Half			Second Half		
	Predicted ΔNER	Actual ΔNER	Gap (p.p.)	Predicted ΔNER	Actual ΔNER	Gap (p.p.)
Australia	-0.68%	-0.96%	0.28%	0.77%	0.83%	-0.06%
Brazil	0.41%	-0.13%	0.54%	1.37%	2.22%	-0.85%
Canada	-1.23%	-0.89%	-0.34%	0.94%	0.63%	0.31%
China	1.01%	-0.48%	1.49%	1.41%	0.13%	1.28%
India	0.85%	0.13%	0.71%	1.75%	1.22%	0.53%
Japan	-1.80%	-0.72%	-1.08%	0.39%	1.04%	-0.65%
Korea	-0.69%	-0.14%	-0.55%	0.83%	0.33%	0.50%
Mexico	-0.03%	0.40%	-0.43%	1.38%	0.78%	0.60%
Turkey	3.48%	3.18%	0.30%	3.78%	5.27%	-1.49%
UK	-0.86%	0.05%	-0.92%	0.33%	0.49%	-0.16%

Table 13 - Predicted vs Actual variation of NER. Source: Self-computed

The values suggest that, although the average absolute deviation does not exceed 1.5 percentage points, the gaps are relatively high in most countries. Furthermore, there are cases where the predicted ΔNER shows the opposite sign to its actual value. Moreover, the data suggest that in the first half the model mostly overshot the actual value of the NER depreciation rate, while in the second half it mostly undershot the actual value. Therefore, the comparison reveals that the model had difficulties in predicting the NER depreciation rate.

6. Discussion

This study has three main goals: first, to test whether the PPP hypothesis is supported. Second, to compare the effect of PPP with other exchange rate macroeconomic fundamentals. Third, to assess if the PPP support is heterogeneous across country-development groups. Based on the estimated results, this section will discuss the main findings encountered. Thus, it compares the results with the literature and explain why they differ from theoretical expectations as well as their implications.

The discussion of results has the following structure: First, the general support of PPP is analysed. Second, the discussion of why PPP support is heterogeneous across groups of countries is assessed. Third, the evidence of other macroeconomic fundamentals is discussed. Fourth, the implications for the reliability of the results are explained. Then this section finishes with the limitations identified and recommendation for future research.

6.1. Empirical evidence on PPP

The main finding was no support for PPP in the long-run. This result is consistent with the findings from some studies (Berka & Devereux, 2010; Boundi-Chraki & Mateo Tomé, 2022; Wang, 2004; Xu, 2003; Yiheyis & Cleeve, 2016). However, in the short-run, the hypothesis received partial support (Dornbusch & Krugman, 1976; Krugman, 1978).

One of the reasons for this finding can be attributed to the measure used for price levels. As in many studies, the indicator used to define price levels is CPI due to its availability and comparability across countries. However, CPI could be a poor proxy for PPP due to a high proportion of non-tradable goods that is usually included in this index (Boundi-Chraki & Mateo Tomé, 2022; Xu, 2003). Moreover, according to the Balassa-Samuelson effect, faster-growing economies experience higher productivity growth in the tradable-goods sectors, which leads to wages and non-traded goods prices increase (Xu, 2003). Since there is no arbitrage for nominal exchange rate movements to internationally offset the diverging prices of non-tradables, an increase in their prices can result in non-diminishing deviations from PPP (Fischer & Porath, 2010).

Another reason for PPP failing to validate can be related to the assumptions this hypothesis relies on. As previously mentioned, for the law of one price to hold, which underlies the PPP theory, the absence of arbitrage is required. However, this assumption is often violated due to the existence of trade barriers and transaction costs in tradable goods (such as transportation charges, import/export taxes and tariffs) (Boundi-Chraki & Mateo Tomé, 2022). Therefore, as this condition is usually not met in international trade, this may result in the non-stationarity of RER (Nusair, 2013). Additionally, the law of one price might fail since the

bundle of goods used to define the price levels may be heterogeneous across countries, directly affecting PPP movements (Boundi-Chraki & Mateo Tomé, 2022).

Moreover, Nusair (2013) suggested that PPP validity could be negatively affected by institutional intervention. Even though the theory predicts that the hypothesis must hold under flexible exchange regimes, in some countries the data suggest that not all exchange rates float freely. In those cases, it may be common to central banks to intervene to maintain international competitiveness or to control inflation. Therefore, these market interventions can lead to the exchange rate being more volatile than price levels, moving the exchange rate away from the equilibrium condition proposed by PPP (Kyei-Mensah, 2023).

6.2. PPP heterogeneity across country groups

Although PPP was not fully validated, its effect appears to differ across groups of countries. More precisely, the PPP support seemed to be stronger in developing countries. Therefore, the focus is on understanding how the characteristics of each group can affect the validity of the PPP hypothesis.

This result is partially consistent with studies that validated PPP in developing countries (Aslan, 2010; Kasem & Al-Gasaymeh, 2022; Wallace, 2017). Even though Kyei-Mensah (2023) when tested the PPP theory using both emerging and advanced economies, the study did not compare them but validated PPP in developing countries. Thus, this study's results are partially consistent with his study.

According to the literature, PPP tends to hold better in countries with high inflation or even episodes of hyperinflation (Boundi-Chraki & Mateo Tomé, 2022; Kyei-Mensah, 2023; Nusair, 2013). In those cases, exchange rate movements would correspond more closely to the inflation differentials, strengthening the PPP validity.

This seems consistent with the evolution presented in figures 1-10 as, in most cases, price differentials have smoother movements than NER. Furthermore, the reported values from Table 3 and 4 suggested that the average inflation rate is considerably higher in developing countries. Therefore, this difference in inflation rate movements across countries could contribute to stronger PPP evidence in developing countries.

Additionally, Krugman (1978) and Nusair (2013) pointed out that PPP validity might hold better when nominal disturbances are significantly larger than real ones. They explain that developing countries are characterised by rapid expansions of the money supply, with these changes tending to be a dominant contributor to exchange rate movements.

As previously mentioned, an increase in money supply depreciates the exchange rate via inflationary pressures (Beldjebel & Hellal, 2024; Funashima, 2020). In this case, if disturbances are purely monetary, shocks could leave real relative prices unchanged and lead to proportional changes in all prices, including the exchange rate, strengthening PPP support (Dornbusch & Krugman, 1976; Fischer & Porath, 2010; Nusair, 2013). Moreover, money growth rate differences across groups of countries could be a key factor to explain why PPP held better in developing countries as the data reported that the average M3 growth rate is considerably larger in developing countries.

Furthermore, Nusair (2013) suggested that the rapid changes in prices and money supply could lead to unstable and less credible monetary policies in developing countries. This can result in Central banks to actively manage exchanges to control inflation and maintain the country's competitiveness. However, these policies could often lead to larger exchange rate deviations from PPP. Nevertheless, Taylor & Sarno (2001) argued that the speed that the exchange rate converge towards PPP equilibrium is not constant, and it's positively related to the deviation size. Moreover, since these countries can be more susceptible to shocks or structural shifts, market forces and policy interventions could increase the speed of adjustment of the exchange rate towards PPP equilibrium (Nusair, 2013).

Therefore, the high inflation rate and rapid expansion of money supply present in developing countries can be key factors toward monetary policy instability. Along with the active effort to stabilise exchange rate, these studies suggest that these factors could lead to greater PPP deviations. However, they also suggest that greater deviations could lead to a greater speed of adjustment in the exchange rate towards equilibrium. Thus, these circumstances usually present in developing countries could explain why exchange rates might converge faster towards PPP than developed countries, which are characterised by lower inflation rates and money supply growth rates.

6.3. The role of other macroeconomic determinants

Results further suggested that some of the additional macroeconomic variables have explanatory power over exchange-rate movements. For that reason, the effect of those variables is discussed in relation to theoretical and empirical literature as well.

Regarding trade openness, its positive and significant effect aligns with empirical findings (Gantman & Dabós, 2018; Glebocki Keefe & Saha, 2022; Lee & Law, 2013; Li, 2003). This effect suggests that the substitution effect dominates in trade openness. Thus, an increase in trade openness leads to an increase in the tradable/non-tradable goods ratio that offsets the effect of an increase in the aggregate demand, as suggested

by Gantman & Dabós (2018) and Li (2003). Furthermore, the sign of this effect implies that the trade liberalisation reforms applied in the countries analysed are credible and have permanent effects. Therefore, more open economies tend to experience higher rates of exchange rate depreciation.

The effect of money supply was also positive and robustly significant in the short-term, which is consistent with the theoretical and empirical findings (Beldjebel & Hellal, 2024; Funashima, 2020; Levin, 1997; Umoru et al., 2023). Therefore, greater money growth can lead to inflationary pressures and excess liquidity. A related channel is that, increases in money supply lead economic agents to anticipate future currency depreciation, making them sell it, contributing to the currency depreciation pressure (Beldjebel & Hellal, 2024; Umoru et al., 2023). Moreover, this result may indicate the existence of a linkage between PPP and money supply, even though the VIF test did not indicate problematic collinearity.

Regarding UIP, this variable was initially found to have a weak and negative effect on NER depreciation rate. The sign of this variable, although against theoretical expectations, was empirically consistent with some studies. For instance, Hacker et al. (2012) found a negative effect in the short-run as well. They suggest that this sign could be due to the existence of sticky prices and high capital mobility, and that an increase in interest rates leads to capital inflows, since investors seek for higher returns. Consequently, this could result in a positive balance of payments, leading to the appreciation of the domestic currency. This exchange rate movement aims to decrease net exports and maintain external balance.

Moreover, Hnatkovska et al. (2013) concluded that the interest rate effect is negative when the changes are small but positive when they are large. They suggest that when changes are small, increases in the interest rate decreases the opportunity cost of holding domestic-currency assets. As a consequence, the demand for money increases and the exchange rate appreciates. Furthermore, they suggested that at low levels the money demand effect tends to outweigh the negative effect this increase has on output and government budget (due to increase in interest and obligation paid, respectively), leading to an overall appreciation in the exchange rate.

However, after correcting the model with robust errors, this effect is now not statistically significant, so UIP didn't hold in this study. This result is consistent with some studies that did not find support for UIP (mainly Shastri & Shastri (2016) while Liu and Lee (2020) didn't validate in the whole period).

Shastri & Shastri (2016) suggested that the capital flows are insensitive to interest rates in some economies. If the portfolio of capital inflows consists mainly of Foreign Direct Investment and Foreign Institutional Investment, which are usually driven by growth performance and risk perception rather than arbitrage, then the capital inflow composition could weaken the link between exchange rates and interest rates. Furthermore,

as well as PPP, the UIP hypothesis may not held due to the existence of transaction costs and capital controls (the latter one in some countries such as China), breaking the assumptions for this theory to hold (Liu & Lee, 2020).

Another possible channel is the intervention from central banks. If their aim is to stabilise their domestic currency. Consequently, these interventions can lead to the interest rate changes not being reflected into exchange rate movements, potentially decoupling them.

Additionally, the statistics computed suggest that the variable that is most likely to be linked with UIP is the M3 growth rate differential, which is statistically significant. Although no concerning collinearity was found between them, they displayed the highest VIF values. This could suggest that the UIP effect may be absorbed and transmitted by the M3 growth rate differential, which could explain why their effect is statistically equal to zero.

Finally, exchange rate regimes showed no statistically significant effect. One of the reasons could be that, although the index increases with more flexible exchange rate regimes, this variable variability may not be sufficient (or doesn't vary in some countries) to explain exchange rate movements. Moreover, despite the variability of the currency's value is expected to increase with higher degrees of exchange rate regime flexibility, their effects towards both appreciation and depreciation can be symmetrical. Additionally, exchange rate flexibility may influence more the variability of exchange rate movements than the direction of them. Therefore, the exchange rate regimes may explain better exchange rate volatil than directional depreciation dynamics.

6.4. Reliability of the results

The results of diagnostic tests had direct implications in the model specification and estimation. Thus, this part of the discussion focuses on the implication that those tests had in this study.

Starting with the CD test, it indicated that there was CSD in the data. The presence of CSD has two implications. First it reveals that errors terms are correlated across countries, revealing that spillovers across countries or unobserved common shocks may exist. This result was expected since this study was dealing with panel macroeconomic data, which is common to exhibit this condition. Second, the presence of CSD represents an issue for the baseline estimation of this study since, using standard errors, these errors are estimated assuming that individuals are not interconnected. Therefore, this implies that the statistical inference may be unreliable due to biased standard errors.

After correcting the standard errors with applying Driscoll-Kraay standard errors, the results indicated that most coefficients maintained their statistically significance in comparison to the standard significance levels. This indicates that after addressing CSD and heteroskedasticity, the PPP and most variables' coefficient remained positive and significant at 1% significance level, implying that the significance of these variables is robust across inference methods.

However, the results indicated that UIP is now not statistically significant, not even at the 10% level. Since the effect was only statistically significant at 10% level using standard errors, the loss of significance from this correction implies that the evidence of the UIP is not statistically strong to alternative inference methods.

Regarding the reliability of estimators, the VIF test suggested that no concerning multicollinearity was found. Therefore, this test indicates low risk of the variables' variance being inflated due to multicollinearity. As a consequence, the VIF test reassured that the coefficients of this study's estimations are not inflated at concerning levels.

6.5. Limitations and directions for future research

Similar to empirical studies, limitations were also recognised in this study. Therefore, this subsection explores those limitations and gives recommendations for future research.

One of the main limitations of this study concerns the data used. First, although the countries used were based on the G20 group, only a small number of countries were included (N=10). As a consequence, although they represent major players globally, the sample used could not be sufficiently large to be representative of the broader population (in this case, all countries). Furthermore, the small number of cross-sectional units did not allow the use of the Hausman test. For that reason, the test couldn't be employed in this study to formally test which estimator was more appropriate.

Second, although the sample can be considered large (T=98 quarters, 97 for estimations) the time span observed was limited. This limitation was due to the limited availability of data about some countries, resulting in the removal of observations to keep the dataset balanced. Furthermore, maintaining a balanced dataset was a key aspect of the process to avoid sample bias, and to properly compare across groups of countries.

Another limitation in this study may be related to the model specification. Even though the model has explanatory power, it's unlikely that exchange rate movements could have been fully explained by the model. Therefore, one limitation of this model specification could be the absence of explanatory/control variables, such as financial-market or institutional variables.

Although this model was controlled for macroeconomic common shocks using time fixed effects, structural breaks may not be fully accounted for. As a consequence, some exchange rate theories may only hold during certain periods, explaining, for instance, the partial validation of PPP (similarly to Shastri and Shastri (2016) with UIP).

Additionally, the model-fit analysis suggested that although most of the exchange rate variation was explained by the model (within R^2), the model still had difficulties in predicting the exchange rate behaviour. Since this model evaluates short-run fluctuations with some theories used for long-run relationships, one limitation may be that the macroeconomic fundamentals explain better the exchange rate trends than its short-run fluctuations.

Given these limitations, future studies take into account the following aspects: first, broader country samples (beyond G20) to enhance the representativeness of countries globally, and ensure that the test assuming a large number of cross-sectional units can be properly applied. Second, as the exchange rate could be very volatile and PPP is a long-run mechanism, analyse longer periods and try to analyse PPP with monthly data. Furthermore, as Liu & Lee (2020) only validated UIP in some periods, one recommendation for future studies would be to evaluate if PPP hold only in some periods as well with the use of subsamples and structural breaks. Additionally, as some empirical studies highlighted the role of policy credibility in the effect from exchange rate determinants, future research may consider the inclusion of how the quality of the public institutions or monetary policy credibility could impact PPP validation.

7. Conclusion

In summary, this empirical study analysed the exchange rate dynamics. The analysis mainly involved testing the PPP hypothesis, which has been highly debated, by testing panel data properties. Additionally, this study compared the effect of PPP with other exchange rate determinants. Furthermore, this study assessed whether the support of PPP was heterogeneous across groups of countries.

The estimated results found no support for the PPP hypothesis in the long-run in the main panel dataset, and in the euro area. However, in the main dataset, the results indicated a partial support for PPP in the short-run, and that its evidence was stronger in developing countries. This study also found that some of the other macroeconomic determinants have an impact on exchange rate movements too, but they have a smaller impact than PPP. More precisely, trade openness and M3 growth rate differential contribute to the exchange rate depreciation. However, the final results indicated that UIP and the exchange rate regimes had no statistically significant impact on exchange rate movements.

This dissertation contributes to the literature in different ways. First, it positions itself in the PPP debate. Second, it explores PPP further by testing panel data properties (unit root and cointegration tests) to not only validate PPP in the long-run but also to choose the appropriate model specification. Third, it combines PPP with other macroeconomic fundamentals to explain exchange rate movements. Fourth, it compares support for PPP between developed and developing countries.

However, this study has its limitations too. Those consist of using a small sample, along with a limited period of analysis. Additionally, the existence of omitted variables in the model represents a limitation in this study. Although the analysis takes into the account for common shocks, it did not account for structural breaks.

Given these limitations, future research can focus on the use of broader samples to increase the representativeness of the sample, along with longer periods and higher-frequency data. Additionally, future studies could include structural breaks in their research, as well as variables to assess the impact of institutional quality and credibility.

Finally, this study highlights that the PPP hypothesis is not universally supported, and that the effects of price level changes may vary across groups of countries. Even though the results suggested that PPP was the strongest determinant, they indicated that other macroeconomic fundamentals are relevant to explain exchange rate movements. However, even considering the relevant results in this study, they also show the complexity and difficulty in explaining exchange rate movements.

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Appendix

Exchange rate main arrangement	Exchange rate secondary arrangement		Classification
	From 1998 de facto system	From 2008 de facto system	
Hard pegs	Arrangement with no separate legal tender	Exchange rate arrangement with no separate legal tender	1
	Currency board arrangement	Currency board arrangement	2
Soft pegs	Conventional fixed peg	Conventional pegged arrangement	3
		Stabilized arrangement	4
	Pegged exchange rate within horizontal bands	Pegged exchange rate within horizonal bands	5
	Crawling peg	Crawling peg	6
	Crawling band	Craw-like arrangement	7
Residuals	Other managed arrangement	Other managed arrangement	8
Floating	Managed floating with no pre announced/predetermined path for the exchange rate	Floating	9
	Independently floating	Free floating	10

Table A1 - Exchange rate arrangement index classification. Source: Self elaboration using IMF exchange rate arrangement de facto system.

Variable: log(RER)		
number of lags	AIC	BIC
0	-4270	-4260
1	-4370	-4360
2	-4360	-4340
3	-4310	-4290
4	-4280	-4250

Table A2 - AIC and BIC of Autoregressive model of Log(RER) per number of lags. Source: Self computation

Variable: Log(NER)		
number of lags	AIC	BIC
0	-3020	-3010
1	-3100	-3080
2	-3070	-3050
3	-3030	-3010
4	-2990	-2960

Table A3 - AIC and BIC of Autoregressive model of Log(NER) per number of lags. Source: Self computation

Variable: PPP		
number of lags	AIC	BIC
0	-5080	-5070
1	-5430	-5420
2	-5380	-5360
3	-5430	-5410
4	-5520	-5490

Table A4 - AIC and BIC of Autoregressive model of Relative PPP per number of lags. Source: Self computation

Variable: UIP		
number of lags	AIC	BIC
0	4762.019	4771.773
1	4660.978	4675.579
2	4619.609	4639.035
3	4576.17	4600.4
4	4198.824	4227.835

Table A5 - AIC and BIC of Autoregressive model of UIP per number of lags. Source: Self computation

Variable: Trade openness index		
number of lags	AIC	BIC
0	5078.76	5088.514
1	5005.616	5020.217
2	4939.42	4958.846
3	4774.45	4798.68
4	4507.891	4536.903

Table A6 - AIC and BIC of Autoregressive model of Trade openness index per number of lags. Source: Self computation

Variable: M3 growth rate differential		
number of lags	AIC	BIC
0	4058.504	4068.259
1	3947.911	3962.512
2	3890.501	3909.927
3	3834.06	3858.29
4	3786.255	3815.266

Table A7 - AIC and BIC of Autoregressive model of M3 growth rate differential per number of lags. Source: Self computation