The Role of International Reserves on Real Exchange Rate: A Panel ARDL Model Approach *

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Abstract

This article aims at investigating whether the accumulation of international reserves affects real exchange rates (level and volatility) for a set of 57 advanced and emerging economies. We apply Panel ARDL (Pooled Mean Group) estimations, for annual data from 1994 to 2017. Long run results indicate that higher levels of international reserves tend to appreciate exchange rate and reduce its volatility. The opposite occurs with lower levels of reserves. Short run adjustments for the exchange rate level indicate that an average of 17.2% of a long-run deviation is corrected within a month. But volatility is corrected at a much faster rate (61,9%). There is also evidence of a significant role from other control variables (Balassa-Samuelson GDP Effect, Inflation, Inflation Differential and Financial Development), and partial evidence from Monetary Independence. Finally, the accumulation of international reserves seems to Granger-cause both level and volatility of real exchange rate.

Keywords: International Reserves; Real Exchange Rate; Volatility; Panel ARDL
JEL Codes: F31; C23; C58

Resumo

Este artigo investiga se o acúmulo de reservas internacionais afeta o nível e a volatilidade da taxa de câmbio real, para um grupo de 57 economias avançadas e emergentes. Com estimações de Modelos de Painel ARDL (Pooled Mean Group), para dados anuais de 1994 a 2017, os resultados de longo prazo indicam que níveis mais altos de reservas tendem a causar valorização cambial, com redução de volatilidade. O oposto ocorre com níveis mais baixos. Quanto aos ajustes de curto prazo, nível e volatilidade da taxa de câmbio mostram correções médias dos desvios de longo prazo de 17,2% e 61,9%, respectivamente. Isso significa que os ajustes ocorrem muito mais rapidamente para a volatilidade cambial. Há também evidências de um papel significativo de outras variáveis de controle (PIB – Efeito Balassa-Samuelson, inflação, diferencial de inflação e desenvolvimento financeiro), mas evidência parcial da variável independência monetária. Por fim, o acúmulo de reservas internacionais Granger-causa o nível e a volatilidade da taxa de câmbio real.

Palavras-Chave: Reservas Internacionais; Taxa de Câmbio Real; Volatilidade; Painel ARDL
Classificação JEL: F31; C23; C58

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1 Introduction

Capital flows, accumulation of international reserves and, consequently, exchange rate movements are key elements in the majority of economies nowadays. They influence, and are influenced, by domestic economic policies such as monetary and fiscal policies. Foreign reserves, in particular, are essential to prevent any economy from being severely hit by external shocks. There is no doubt that any country without a proper amount of reserves can face serious economic problems. On the hand, high levels of foreign reserves, usually coming from capital inflows, can cause considerable impact on exchange rates. Therefore, there has to be an equilibrium among these important variables, and a policymaker must be aware that one affects another, and vice-versa.

In fact, there has been a growing discussion related to analyzing how international reserves affect real exchange rate (RER) movements. Some of the works have focused on examining exchange rate levels. For instance, this is the case of Frenkel (1978, 1980), Edwards (1984), Flood et al. (1998), Rodrik (2006), among others, as we will see in the literature revision.

Nevertheless, not only is RER level important, but also its volatility is crucial, as reported by the results found in Hviding et al. (2004) and Vieira et al. (2013), for instance. Volatility is certainly a considerable source of obstruction for investment and trade and, consequently, economic growth. However, the majority of articles measures exchange rate volatility by means of a non-conditional standard deviation. This brings considerable limitations to any empirical analysis and, as a result, restricts all empirical analysis related to the role of international reserves on the level and volatility of the exchange rate.

This article aims to analyze the effect of international reserves on real exchange rate (level and volatility) for a group of 57 advanced and emerging economies. We first make use of ARCH-type models to calculate an accurate exchange rate volatility of each country. Then, together with variables such as: real per capita GDP, CPI inflation rate, inflation differential, monetary independence index, financial development, a Panel ARDL Model Approach (Pooled Mean Group) is applied as our econometric methodology. Our argument is that emerging and developed economies accumulate international reserves as a cushion against external shocks, even though those reserves cause considerable impact on exchange rate, either on level or volatility. For the period ranging from 1994 to 2017, our Panel ARDL cointegration estimations show that a higher level of international reserves has significant positive effect on both level and volatility of RER. The opposite applies for lower levels of international reserves. Our results are also robust for different model specifications. When we consider short run adjustments, there are some differences. While exchange rate level estimations indicate a monthly correction of 17.2%, on average, of a long-run deviation, exchange rate volatility estimations show a much faster correction, an average of 61.9% within a month. Finally, we also find evidence that the following control variables (Balassa-Samuelson GDP Effect, Inflation, Inflation Differential and Financial Development) affect both level and volatility of exchange rate, whereas the influence coming from Monetary Independence is partial. Last but not least, our results show that the accumulation of international reserves seems to Granger-cause the level and volatility of real exchange rates.

Besides this introduction, this article has four more sections. Section 2 brings the literature related to the relationship between international reserves and real exchange rate level and volatility. Section 3 describes the data and econometric approach. Section 4 reports all empirical results, and the final section concludes.

2 Literature Review

The literature on the effects of international reserves on real exchange rate is vast and it has been debated academically for decades. For instance, Frenkel (1978) examines what role international reserves played under different exchange rate regimes (pegged and managed floating). For the period 1963-1975, his analysis showed a difference in the demand for reserves between developed and less-developed countries. The conclusion is that the optimal degree of exchange rate flexibility depends on the stochastic nature of shocks (real and monetary, domestic and foreign shocks, for instance) faced by the economy. Frenkel (1980) extends his previous analysis until 1979, but finds no change in the qualitative findings.

Edwards (1984) analyzes a sample of developing countries and concludes that not only do reserves movements respond to monetary factors, but also to differences between actual and desired reserves. Therefore, monetary considerations are important for estimating and analyzing models with international reserves. On a similar topic, Obstfeld et al. (2005) gather more than 130 years of data to conclude that economic policies related to exchange-rate regime is still constrained by the monetary policy trilemma (a tradeoff among exchange stability, monetary independence, and capital market openness).

Jeanne and Rancière (2006) derive a formula an optimal level of foreign reserves for a small open economy susceptible to sudden stops in capital flows. The authors argue that, with proper calibrations, their model is able to explain the magnitude of international reserves of many emerging market economies. Obstfeld et al. (2010) build an empirical financial-stability model based on financial stability and financial openness and find that international reserve stocks can be well predicted by exchange rate policy, financial openness and access to foreign currency through debt markets. The size of domestic financial liabilities that could potentially be converted into foreign currency is also a good predictor of reserve stocks.

Aizenman and Lee (2007) show that precautionary motives are important to emerging market economies, in their accumulation of international reserves. Foreign reserves are usually increased when a more liberal capital account regime is in place, and they are also important to keep the economy going when sudden stops are about to happen. Aizenman and Hutchison (2012) find that, in spite of having accumulated high amounts of foreign reserves, prior to the crisis, emerging market countries chose not to lose them during the crisis, relying on more currency depreciation to absorb the shock.

Flood et al. (1998) focus on 12 Latin American countries, in the 1970s and 1980s, and show how cycles in reserves and exchange rate premia may result from leakages between official and parallel foreign exchange markets. Athukorala and Rajapatirana (2003) show that, for the period ranging from 1985 to 2000, real exchange rate appreciation is much higher in Latin America than in Asia, despite foreign capital inflows to Asian countries being greater, compared to the size of their economies. For the period ranging from 1980 to 1996, Aizenman and Marion (2003) find that, compared to other emerging markets, international reserves of Asian countries depend on the size and volatility of international transactions, as well as on exchange-rate arrangement and on political considerations. But results are inconclusive for the period after the Asian financial crisis, in 1997.

Aizenman and Riera-Crichton (2008) examine how real exchange rate is affected by international reserves, terms-of-trade shocks, and capital flows. The authors find that terms-of-trade shocks on RER are cushioned by international reserves. This is important in developing countries, particularly Asian economies and natural resource exporters. Gosh et al. (2014) focus particularly on Asian Pacific Rim economies, comparing them with other emerging market economies. Their results show that such accumulation changed from a cushion against current account shocks, in the 1980s, to a cushion against capital account shocks, in the 1990s. RIM economies are also more prone to accumulating reserves against current account exposures, as opposed to capital account vulnerabilities. But they accumulate more reserves in general.

Rodrik (2006) argues that the rapid increase in international reserves in emerging market economies is more related to preventing exchange rate from appreciation and maintaining international trade competitiveness, than a self-insurance motive. Results also show that the costs of holding these reserves amount to an average of 1 p.p. of annual GDP in those countries. Reinhart and Reinhart (2011) examine the accumulation of international reserves of over 100 economies and find that emerging market economies tend to limit exchange rate fluctuations, but there are a few controlled experiments. The authors are only able to find some connection among capital inflow and low foreign interest rates, and tax increases on those inflows.

Pina (2015) investigates the effect of international reserves accumulation in developing countries based on data from 1970 to 2009. There is a different trend for developed (developing) countries since 1987, revealing lower (higher) levels of international reserves / GDP. The idea is to investigate why these different patterns happen. The author argues that adequate levels of international reserves depend on what central banks do in developing countries: manage inflation and exchange rate and support the financial sector during periods of crises. The model predicts that distortions associated to the magnitude of crisis, to inflation and to constraints related to central banks are crucial to the determination of the level of international reserves.

De Gregorio (2011) argues that reserves play a dissuasive role as countries tend to accumulate them as a safety cushion, but rarely use them. The author also argues that reserve accumulation and exchange rate impacts cannot be treated separately. This implies a challenge for central banks, as floating exchange rate regimes must be coherent with the maintenance of an adequate level of reserves. Dominguez et al. (2012) focus on a large panel of countries to investigate if differences in cross-country economic performance, after the 2008 financial crisis, could be related to pre-crisis foreign reserve accumulation, as well as decisions taken during the crisis regarding exchange rate and reserves. Their results show that those countries which accumulated large amount of international reserves, before the crisis, were those with higher economic growth, after the crisis.

Bayoumi and Saborowski (2014) find that in countries with no capital control, sterilized intervention is fully counterbalanced by private money outflow. On the other hand, capital controls are able to block such outflows. Aizenman et al. (2015) find that previous to the financial crisis (from 1999 to 2006), reserve accumulation was related to gross savings in developing and emerging markets. Results from the post crisis period (from 2010 to 2012) show a higher gross saving associated with lower foreign reserve holding, whereas emerging market economies with low reserve accumulation experienced currency depreciation in 2012, due to the announcement of tapering quantitative easing.

Regarding volatility, specifically, Hviding et al. (2004) focus on a panel of 28 emerging market economies, over the period ranging from 1986 to 2002. Their results are in line with the assumption that that holding adequate reserves decreases exchange rate volatility. The importance of real exchange rate volatility on long-run GDP growth is analyzed by Vieira et al. (2013). The authors make use of a panel of 82 advanced and emerging economies, for the period 1970-2009, and conclude that more volatility affects economic growth negatively, and vice versa.

3 Data and Econometric Approach

As mentioned previously, our main aim is to analyze how international reserves influence the level and volatility of real exchange rates, by means of a Panel ARDL Model Approach. We make use of a monthly database which encompasses a group of 57 countries (listed in Table 1), for the period ranging from 1994 to 2017.

The following variables will be analyzed:

- *lreer*: ln of Real Effective Exchange Rate (2010 = 100). A higher (lower) value indicates an appreciation (depreciation). Source: BIS.
- *volreer*: Real Effective Exchange Rate Volatility Estimations via ARCH-GARCH models (See Table 1).
- *reserv*: International Reserves (% of GDP). Source: IFS-IMF.
- *gdp*: Real per Capita GDP relative to the US. Source: PENN World Table.
- *cpi*: CPI Inflation Rate (%). Source: IFS-IMF.
- *monet*: Monetary Independence Index. (Higher/lower values of the index mean more/less monetary policy independence). Source: Aizenman, Chinn and Ito (2018).
- *findev*: Financial Development. (Higher/lower values for three measures of financial development indicate a more/less integrated and developed financial system. Source: Svirydzenka (2016).

It is worth noting that the idea of having inflation differential (*cpidif*) as an explanatory variable is to examine whether or not changes in the real exchange rate are due to movements in relative prices (domestic and foreign). If the answer is negative, this suggests that the nominal exchange rate is the variable responsible for those changes. As for *gdp*, it is going to capture the Balassa-Samuelson (BS) effect on real exchange rate, as in Balassa (1964) and Samuelson (1964). It means that countries with higher (lower) relative per capita income (proxy for productivity) tend to face real exchange rate appreciation (depreciation) over time.

The empirical analysis developed in this work is based on Autoregressive Distributed Lag (ARDL) models applied to cointegration, as proposed in Pesaran and Shin (1999) and Pesaran et al. (2001). They were chosen due to their advantage over the cointegration tests in non-stationary variables, such the ones developed by Engle and Granger (1987), Phillips and Hansen (1990) and Johansen (1991), as well as over traditional VAR models. ARDL models applied to cointegration also tend to be more efficient to capture the long-run relationship data in small samples, and they perform well, irrespective of whether variables are stationary I(0), non-stationary I(1), or even mutually cointegrated (Pesaran and Shin, 1999). Table 7, in the appendix, reports the results of some panel unit root estimations. There is certainly a mix of I(0) and I(1) variables, which makes Panel ARDL approach more than appropriate to our analysis.

Pesaran, Shin and Smith (1999) developed a Pooled Mean Group (PMG) model, which is based on a cointegrated ARDL framework adapted for a panel data set environment. In fact, PMG likelihood estimators are used to estimate long-run coefficients, capturing the pooling behavior of homogeneity restrictions, and short-run coefficients, by the average across groups used to obtain means of the estimated error-correction coefficients and other short-run parameters (Pesaran, Shin and Smith, 1999).

A basic ARDL model can be specified as follows:

$$y_{it} = \Sigma_{j=1}^{p}\lambda_{ij}^{*}y_{i,t-j} + \Sigma_{j=0}^{q}\delta_{ij}^{*}x_{i,t-j} + \mu_i + \varepsilon_{it} \tag{1}$$

where: $t = 1, 2..., T$ identifies the period and $i = 1, 2, ..., N$ identifies the groups; x_{it} = vector $k \times 1$ of explanatory variables for group i; μ_i = fixed effects term; λ_{ij} = scalar of coefficients related to all lagged dependent variables; and δ_{ij} = coefficient vectors $k \times 1$.

This econometric methodology is capable of maintaining important information related to short and long-run properties of a model. Besides, any short-run disequilibrium is seen as an adjustment process towards the long-run equilibrium. Such adjustments are made through the Error Correction Form (ECM). By making a re-parametrization of Equation (1), we are able to find the ECM equation:

$$\Delta(y)_{it} = \phi_i(y)_{i,t-1} + \beta_i^{'}x_{it} + \Sigma_{j=1}^{p-1}\lambda_{ij}^{*}\Delta(y)_{i,t-j} + \Sigma_{j=0}^{q}\delta_{j=0}^{*'}\Delta(x)_{i,t-j} + \mu_i + \varepsilon_{it} \tag{2}$$

where: $\phi_i = -(1 - \Sigma_{j=1}^{p}\lambda_{ij})$ is the error correction term for the i^{th} group; $\beta_i = \Sigma_{j=0}^{q}\delta_{ij}$ is the long-run parameter for for the i^{th} group; $\lambda_{ij}^{*} = -\Sigma_{m=j+1}^{p}\lambda_{im}$, $j = 1, 2, ..., p-1$ and $\delta_{ij}^{*} = -\Sigma_{m=j+1}^{q}\lambda_{im}$, $j = 1, 2, ..., q-1$

In our specific case, Panel ARDL (PMG) models are applied in the analysis of the role of international reserves (% of GDP) for two different dependent variables: log of real effective exchange rate ($lreer$) and exchange rate volatility ($volreer$). If we let μ denote a constant and T denote a time trend, the estimated equations for our baseline panel ARDL models are:

Dependent Variable: log of Real Effective Exchange Rate ($lreer$)

$$\begin{aligned}\Delta(lreer)_{it} = \mu + \alpha_1 T + \beta_1(lreer)_{it-1} + \beta_2(cpi)_{it-1} + \beta_3(gdp)_{it-1} + \beta_4(reserv)_{it-1} \\ +\Sigma_{j=0}^{p}\beta_5\Delta(lreer)_{it-j} + \Sigma_{j=0}^{q}\beta_6\Delta(cpi)_{it-j} + \Sigma_{j=0}^{r}\beta_7\Delta(gdp)_{it-j} + \Sigma_{i=0}^{s}\beta_8\Delta(reserv)_{it-j} + \nu_t\end{aligned} \tag{3}$$

Dependent Variable: Exchange Rate Volatility ($volreer$)

$$\begin{aligned}\Delta(volreer)_{it} = \mu + \alpha_1 T + \beta_1(volreer)_{it-1} + \beta_2(cpi)_{it-1} + \beta_3(gdp)_{it-1} + \beta_4(reserv)_{it-1} \\ +\Sigma_{j=0}^{p}\beta_5\Delta(volreer)_{it-j} + \Sigma_{j=0}^{q}\beta_6\Delta(cpi)_{it-j} + \Sigma_{j=0}^{r}\beta_7\Delta(gdp)_{it-j} + \Sigma_{i=0}^{s}\beta_8\Delta(reserv)_{it-j} + \nu_t\end{aligned} \tag{4}$$

We will also estimate a second specification for Equations 3 and 4 using inflation differential relative to the US ($cpidif$), instead of inflation rate (cpi). Another extension is to include two other control variables, one at a time, to the baseline model with inflation and to the alternative model using inflation differential ($cpidif$): monetary independence ($monet$) and financial development ($findev$).

4 Empirical Results

4.1 Measuring Exchange Rate Volatility

Volatility measures are calculated by the following expression:

$$r_{it} = ln(lreer)_{it} - ln(lreer)_{it-1} \quad (5)$$

which is return r_{it} of real exchange rate in logs, based on average structures ARMA, and ARCH GARCH for conditional variance. Once the monthly conditional variance is estimated for the period Feb/1994-Dec/2017, we average the results to obtain annual data, as our final measure of volatility.

Table 1 summarizes the models for each of the 57 countries. GARCH (1, 1) structures seem to prevail over other ARCH-Type models. For the average structure, there is predominance of an AR(1) structure, with occasional cases for ARMA (1, 1) and AR(2).

Table 1: **Real Effective Exchange Rate Volatility - ARCH-type Models**

Countries	**Model Selection**	**Countries**	**Model Selection**
Algeria	AR(1) GARCH (1,1)	Korea	AR(1) GARCH(1,1)
Argentina	AR(2) ARCH(1)	Latvia	AR(1) GARCH(1,1)
Australia	AR(2) GARCH(1,1)	Lithuania	AR(1) GARCH(1,1)
Austria	AR(2) GARCH(0,1)	Luxembourg	AR(1) GARCH(0,1)
Belgium	AR(2) GARCH(0,1)	Malaysia	AR(1) GARCH(1,1)
Brazil	AR(1) ARCH(1)	Malta	AR(1) GARCH(1,1)
Bulgaria	AR(1) GARCH(1,1)	Mexico	AR(1) ARCH(1)
Canada	AR(1) GARCH(1,1)	Netherlands	AR(2) GARCH(0,1)
Chile	AR(1) GARCH(1,1)	New Zealand	AR(1) GARCH(1,1)
China	AR(1) GARCH(0,1)	Norway	AR(1) GARCH(1,1)
Colombia	AR(2) GARCH(1,1)	Peru	AR(2) GARCH(1,1)
Croatia	AR(1) GARCH(0,1)	Philippines	AR(1) GARCH(1,1)
Cyprus	AR(2) ARCH (1)	Poland	AR(2) GARCH(1,1)
Czech Republic	AR(1) GARCH(1,1)	Portugal	AR(2) GARCH(1,1)
Denmark	AR(2) GARCH(1,1)	Romania	AR(1) GARCH(1,1)
Estonia	AR(2) GARCH(1,1)	Russia	AR(2) GARCH(1,1)
Finland	AR(2) GARCH(1,1)	Saudi Arabia	AR(2) ARCH(1)
France	AR(1) GARCH(0,1)	Singapore	ARMA (1,1) ARCH (1)
Germany	AR(1) GARCH(1,1)	Slovakia	AR(1) GARCH(1,1)
Greece	AR(2) GARCH(0,1)	Slovenia	AR(1) GARCH(0,1)
Hong Kong	AR(1) ARCH(1)	South Africa	AR(1) GARCH(1,1)
Hungary	AR(1) GARCH (1,1)	Spain	AR(2) ARCH(1)
Iceland	AR(2) GARCH(1,1)	Sweden	AR(1) GARCH(1,1)
India	AR(2) GARCH(1,1)	Switzerland	AR(1) GARCH(1,1)
Indonesia	AR(1) GARCH(1,1)	Thailand	AR(1) GARCH(1,1)
Ireland	AR(1) GARCH(1,1)	Turkey	AR(2) GARCH(1,1)
Israel	AR(2) GARCH(1,1)	United Kingdom	AR(1) GARCH(1,1)
Italy	AR(2) GARCH (0,1)	Venezuela	AR(2) GARCH(1,1)
Japan	AR(1) ARCH(1)		

Note: Model Selection: AR(n); ARMA (n,r) GARCH (p,q)

4.2 Cointegration Tests

The first step is to check whether there is a cointegration (long-run) relationship among the variables specified. In order to do that, we apply Pedroni's Panel Cointegration Tests (Pedroni, 1999), which can be depicted by the following equation:

$$y_{it} = \alpha_{it} + \beta_{1i}x_{1i,t} + \beta_{2i}x_{2i,t} + ... + \beta_{Mi}x_{Mi,t} + \varepsilon_{i,t} \quad (6)$$

where: i) y, x are I(1) variables, by assumption; ii) T is the number of observations over time ($t = 1, 2, ..., T$); iii) N is the number of individuals member in the panel ($i = 1, 2, ..., N$); iv) M is the number of variables ($m = 1, 2, ..., M$); v) α_i refers to individual effects, which may be set to zero; vi) parameters $\beta_{1i}, \beta_{2i}, ..., \beta_{Mi}$ can vary across individual members of the panel, allowing for heterogeneous intercepts and trend coefficients across cross-sections .

Once Equation (6) is estimated, the residuals obtained are tested for non-stationarity I(1), by estimating the following auxiliary regression for each cross-section:

$$\varepsilon_{i,t} = \rho_{it}\varepsilon_{i,t-1} + \Sigma_{k=1}^{k_i}\rho_{i,k}\Delta(\varepsilon)_{i,t-k} + \mu_{i,t} \quad (7)$$

Pedroni (1999) describes several methods to construct appropriate statistics to test the null hypothesis of non-cointegration ρ_i from the residuals' equation. Tables 2 and 3 report both within and between dimension test statistics. Cointegration is found in at least one of the statistics for all three estimated models, regardless of using either inflation (cpi) or inflation differential ($cpidif$). Cointegration seems to be much stronger when the dependent variable is exchange rate volatility ($volreer$). Therefore, the evidence suggests a long run equilibrium relationship among real effective exchange rate (level and volatility) and all other control variables.

Table 2: **Pedroni Cointegration Tests - Dep. Var.** $d(lreer)$

	With Inflation			**With Inflation Differential**		
Within-Dimension						
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Panel v-Statistic	1.157 [0.123]	-3.303 [0.999]	-4.392 [1.000]	-3.426 [0.999]	-3.444 [0.999]	-3.009 [0.998]
Panel rho-Statistic	4.552 [1.000]	5.430 [1.000]	5.193 [1.000]	4.353 [1.000]	5.552 [1.000]	5.594 [1.000]
Panel PP-Statistic	1.241 [0.892]	0.059 [0.523]	-1.853 [0.031]	-0.143 [0.442]	0.075 [0.529]	-1.011 [0.155]
Panel ADF-Statistic	-1.572 [0.057]	-2.550 [0.005]	-4.103 [0.000]	-3.334 [0.0004]	-1.700 [0.044]	-4.313 [0.000]
Between-Dimension						
Group rho-Statistic	7.008 [1.000]	8.120 [1.000]	8.260 [1.000]	7.124 [1.000]	8.301 [1.000]	7.977 [1.000]
Group PP-Statistic	2.559 [0.994]	-0.175 [0.430]	-1.851 [0.032]	-0.050 [0.479]	-0.843 [0.199]	-2.930 [0.001]
Group ADF-Statistic	-2.093 [0.018]	-2.446 [0.007]	-2.388 [0.008]	-3.656 [0.0001]	-2.209 [0.013]	-4.323 [0.000]

Note: p-values in brackets. Within-dimension with weighted statistic. Null: No cointegration.

Table 3: **Pedroni Cointegration Tests - Dep. Var.** $d(volreer)$

	With Inflation			With Inflation Differential		
Within-Dimension						
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Panel v-Statistic	-2.041 [0.979]	-6.282 [1.000]	-5.537 [1.000]	-4.467 [1.000]	-4.562 [1.000]	-4.585 [1.000]
Panel rho-Statistic	-3.079 [0.001]	2.358 [0.990]	1.936 [0.973]	-0.458 [0.323]	2.091 [0.981]	1.671 [0.952]
Panel PP-Statistic	-13.453 [0.000]	-15.69 [0.000]	-15.966 [0.000]	-15.288 [0.000]	-14.816 [0.000]	-15.598 [0.000]
Panel ADF-Statistic	-13.826 [0.000]	-14.895 [0.000]	-15.547 [0.000]	-16.544 [0.000]	-15.299 [0.000]	-16.126 [0.000]
Between-Dimension						
Group rho-Statistic	-0.388 [0.348]	4.696 [1.000]	4.672 [1.000]	2.410 [0.992]	4.535 [1.000]	4.269 [1.000]
Group PP-Statistic	-16.962 [0.000]	-20.263 [0.000]	-15.867 [0.000]	-15.707 [0.000]	-17.606 [0.000]	-15.324 [0.000]
Group ADF-Statistic	-17.533 [0.000]	-14.671 [0.000]	-14.698 [0.000]	-15.490 [0.000]	-13.704 [0.000]	-15.061 [0.000]

Note: p-values in brackets. Within-dimension with weighted statistic. Null: No cointegration.

4.3 PMG Results

Given the long run relationship found, we move forward and analyze the long and short run coefficients estimated. Firstly, we estimate a baseline Model 1, controlling for the role of GDP (gdp) (Balassa-Samuelson effect), international reserves/GDP ($reserv$) and inflation (cpi). In Model 2 monetary independence ($monet$) is added to the baseline model, while degree of financial development ($findev$) is added to Model 3.

Table 4 reports the PMG long-run coefficients having $lreer$ as dependent variable. Concerning our main variable of interest, which is international reserves ($reserv$), the estimated coefficients are statistically significant in all six models. Positive coefficients are found in Models 1, 2, 4 and 5, which is line with the idea that higher (lower) levels of international reserves tend to appreciate (depreciate) exchange rate. This is an indication that a country has enough international reserves to face any external shock and it is also a common sign that the country has no external adjustment problems. On the other hand, negative coefficients are found in Models 3 and 6. This is also a possible result in a situation where countries have the ability to keep the exchange rate at a more depreciated level, as a key issue for stimulating the exports sector (export-oriented growth strategies). For instance, China has done this and, as a result, it has built up a huge amount of international reserves. Besides that, Models 3 and 6 are the ones which include financial development ($findev$) as a control variable. As $findev$ is related to integration and financial system development level, one possible explanation for the $reserv$ variable showing a negative coefficient might be associated to other issues, such as countries with growth strategies based on keeping exchange rates at a more depreciated level, with positive impact on trade balance and on the levels of international reserves.

Regarding the coefficients related to inflation (cpi), they are all statistically significant with positive estimated coefficients, indicating that a higher (lower) inflation tends to appreciate (depreciate) exchange rate. Although a negative coefficient would be usually expected, meaning that higher (lower) levels of inflation are associated with more depreciated (appreciated) exchange rates, the positive signs found are also possible. This is due to issues such as more rigid (pegged) exchange

Table 4: **Long Run and Short Run (ECM) Coefficients - Dep. Var.** $d(lreer)$

	With Inflation			With Inflation Differential		
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
gdp	2.16E-06 [0.000]	9.91E-06 [0.000]	-4.15E-05 [0.000]	2.33E-06 [0.003]	2.13E-05 [0.000]	-6.59E-06 [0.000]
reserv	0.001162 [0.000]	0.001061 [0.0254]	-0.00884 [0.000]	0.001419 [0.000]	0.001371 [0.000]	-0.000821 [0.000]
cpi	0.016538 [0.000]	0.044661 [0.000]	0.009653 [0.000]			
cpidif				0.019836 [0.000]	0.022978 [0.000]	0.000471 [0.381]
monet		0.02765 [0.5664]			-0.125548 [0.000]	
findev			0.769158 [0.000]			0.323196 [0.000]
ARDL Lags	(3,3,3,3)	(1,1,1,1,1)	(2,2,2,2,2)	(2,2,2,2)	(1,2,2,2,2)	(2,2,2,2,2)
Max. Dep. Lags	3	2	2	2	1	2
ECM (-1)	-0.270 [0.000]	-0.101 [0.000]	-0.093 [0.000]	-0.192 [0.000]	-0.164 [0.000]	-0.212 [0.000]

Note: p-values in brackets. ECM(-1) Average = -0.172

rate regimes and even to cases related to *fear of floating* (Calvo and Reinhart, 2002).

Coefficients related to inflation differential (*cpidif*) are all positive as well, but statistically significant in only two out of three estimated models. As in the inflation (*cpi*) case, this suggests the difficulty of countries to keep up with higher levels of inflation and not changing exchange rate at the same pace, which usually leads to appreciated real exchange rates. And again, this can also be explained by possible *fear of floating/fear of inflation*, when countries try to avoid significant changes in the exchange rate or at least to procrastinate them.

As for the relative per capita income (*gdp*) estimated coefficients, based on the Balassa-Samuelson hypothesis, the expected positive sign holds in four of the six estimated models (Models 1, 2, 4, and 5). In fact, positive long run coefficients is according to expectations and it means that, if the Balassa-Samuelson effect is in place, higher (lower) levels of per capita GDP, relative to the US, tend to appreciate (depreciate) exchange rate over time.

When monetary independence (*monet*) is used as control variable, it is statistically significant in Model 5 with inflation differential (*cpidif*), but not in Model 2 with inflation (*cpi*). This negative estimated coefficient suggests that a higher degree of monetary independence is associated to a more depreciated (appreciated) exchange rate, while a lower degree leads to more appreciation. In fact, there is no expected sign for the estimated coefficients of the monetary independence (*monet*) index. A more (less) monetary independence indicates more (less) ability and autonomy of monetary authorities to adopt instruments to keep exchange rate at an adequate level, and so to avoid undesirable economic impacts. This might lead to either a more appreciated or depreciated exchange rate, depending on each country.

As for the financial development variable (*findev*), it has a positive and statistically significant sign in both estimated models (3 and 6). This was as expected and it is a clear indication that higher (lower) levels of financial development are usually associated to more (less) advanced economies, and the exchange rate tends to be more appreciated (depreciated) due to differences in relative productivity for advanced vis-à-vis the emerging/developing economies.

Table 5 reports the PMG long-run coefficients when real effective exchange rate volatility (*volreer*) is used as dependent variable. The results related to international reserves (*reserv*), our main variable of interest, indicate that the estimated coefficients are statistically significant in all estimations. According to expectations, negative coefficients are found in Models 1, 2, 4 and 5, suggesting that higher (lower) levels of international reserves reduces (increases) exchange rate volatility. The expected negative coefficient is an indication that higher (lower) levels of international reserves are associated with lower (higher) levels of uncertainty on the exchange rate market. This makes sense if accumulation of international reserves is thought and used as a cushion to avoid excessive exchange rate volatility, which is commonly a desirable feature targeted by policymakers. This is also true when looking at international reserves levels and the ability of monetary authorities to implement policies/measures to reduce exchange rate oscillations, and so to reduce volatility. On the other hand, positive coefficients are found in Models 3 and 4, when financial development ($findev$) is used as control variable.

As for the Balassa-Samuelson (gdp) variable, coefficients are negative in all estimated models, and statistically significant in four out of six models. This indicates that higher (lower) levels of per capita income, relative to the US, are associated to lower (higher) levels of exchange rate volatility. In other words, emerging market economies, with lower levels of income, tend to be more affected by exchange rate volatility, when compared to advanced countries.

All inflation (cpi) estimated coefficients are statistically significant, with negative signs. This implies that a higher (lower) inflation tends to reduce (increase) exchange rate volatility. Inflation differential ($cpidif$) coefficients are negative in Models 4 and 6, and positive in Model 5, whilst statistical significance is found in Models 5 and 6. Monetary independence ($monet$) has positive estimated coefficients, but it is statistically significant only in Model 5 with inflation differential ($cpidif$). As for financial development ($findev$), it is significant and positive for both estimated models (3 and 6), indicating that higher (lower) levels of financial development are associated with higher (lower) levels of exchange rate volatility.

Table 5: **Long Run and Short Run (ECM) Coefficients - Dep. Var.** $d(volreer)$

	With Inflation			**With Inflation Differential**		
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
gdp	-4.44E-11 [0.000]	-5.30E-12 [0.000]	-2.22E-13 [0.187]	-5.00E-11 [0.000]	-4.64E-12 [0.000]	-2.02E-13 [0.129]
$reserv$	-7.94E-09 [0.000]	-2.18E-10 [0.0291]	5.26E-11 [0.0258]	-4.70E-09 [0.000]	-5.83E-10 [0.000]	4.01E-11 [0.024]
cpi	-5.73E-09 [0.0053]	-1.63E-09 [0.0019]	-8.45E-10 [0.000]			
$cpidif$				-1.47E-09 [0.4016]	4.02E-09 [0.000]	-5.88E-10 [0.000]
$monet$		9.83E-09 [0.1741]			1.03E-08 [0.0576]	
$findev$			1.53E-08 [0.000]			1.17E-08 [0.000]
ARDL Lags	(1,1,1,1)	(1,1,1,1,1)	(1,1,1,1,1)	(1,1,1,1)	(1,1,1,1,1)	(1,1,1,1,1)
Max. Dep. Lags	1	1	1	1	1	1
ECM (-1)	-0.611 [0.000]	-0.632 [0.000]	-0.638 [0.000]	-0.599 [0.000]	-0.619 [0.000]	-0.615 [0.000]

Note: p-values in brackets. ECM(-1) Average = -0.619

Once the long-run effects have been examined, we go one step further and analyze all short-run effects, via Error Correction Mechanism (ECM). This is important because, as mentioned previously, cointegration ARDL models can keep both short and long run properties of a model, and any short-run disequilibrium is seen as an adjustment process towards the long-run equilibrium.

Short-run adjustments related to exchange rate level ($lreer$), reported in Table 4, and exchange rate volatility ($volreer$), reported in Table 5, show that all ECM coefficients are statistically significant with a negative sign, confirming a stable long-run relationship between the variables. When ($lreer$) is used as dependent variable (Table 4), the Error Correction Mechanism (ECM) ranges from -0.093 to -0.27, with an average of -0.172. It means that, on average, 17.2% of a short-run perturbation is corrected within a month. When the dependent variable is ($volreer$), Table 5 shows that the ECM coefficients range from -0.59 to -0.63 (average = -0.619). It means that between 59.9% and 63.8% of a long-run deviation is corrected within a month. Comparing the short-run adjustment results, it seems that exchange rate volatility is corrected much faster than the exchange rate level itself.

4.4 Causality Tests

Finally, we estimate Causality Tests, which can be specified as bivariate regressions in a panel data framework. Let t denote the time period dimension and i denote the cross-sectional dimension in a panel data set. Therefore, the bivariate regressions are:

$$\begin{aligned} y_{it} &= \rho_{0,i} + \rho_{l,i} y_{i,t-1} + ... + \rho_{k,i} y_{i,t-k} + \delta_{1,i} x_{i,t-1} + ... + \delta_{k,i} x_{i,t-k} + \mu_{i,t} \\ x_{it} &= \rho_{0,i} + \rho_{l,i} x_{i,t-1} + ... + \rho_{k,i} x_{i,t-k} + \delta_{1,i} y_{i,t-1} + ... + \delta_{k,i} y_{i,t-k} + \mu_{i,t} \end{aligned} \tag{8}$$

We will apply two approaches. The first one is a standard Granger Causality test, which assumes that all coefficients are similar across all cross-sections. In this case, the null hypothesis is: y does not Granger cause x, and vice versa. The second one, developed by Dumitrescu and Hurlin (2012), assumes that all coefficients are different across cross-sections. Therefore, it estimates individual Granger Causality tests for each cross-section, and calculates the average of individual tests, considering a statistical significance ($\bar{W} - statistic$) and a standardized $\bar{W} - statistic$, called $\bar{Z} - statistic$. In this case, the null hypothesis is: y does not homogeneously cause x, and vice versa.

Table 6 reports the causality test results related only to our variables of interests: i) $lreer$ (real effective exchange rate); ii) $volreer$ (real effective exchange rate volatility); iii) $reserv$ (international reserves, as % of GDP). Conventional Granger causality tests indicate that there is no Granger causality for each pair of variables. As for Dumitrescu-Hurlin causality tests, the null hypothesis is rejected for all pair of tests. Regarding our main focus of analysis ($reserv$), international reserves Granger-cause real effective exchange rate ($lreer$) and its volatility ($volreer$).

Table 6: **Causality Tests**

Hypothesis	**Granger Causality** ($H_0: y$ **does not Granger cause** x)		**Dumitrescu-Hurlin Causality** ($H_0: y$ **does not homogeneously cause** x)		
	F-Statistic	**Prob.**	**W-Stat.**	**Z-Stat.**	**Prob.**
$reserv \rightarrow lreer$	2.015	0.155	1.985	3.769	0.0002
$lreer \rightarrow reserv$	0.003	0.955	1.799	2.963	0.003
$reserv \rightarrow volreer$	1.442	0.230	2.166	4.557	5.0E-06
$volreer \rightarrow reserv$	6.8E-05	0.993	1.719	2.613	0.009

Conclusions

This article aimed at investigating the role of accumulation of international reserves on the level and volatility of real exchange rates, for a panel 57 advanced and emerging economies. Before estimating the empirical models, we made use of an ARCH-type methodology to accurately calculate the exchange rate volatility of each country in the sample. Besides that, the following control variables were used: inflation, inflation differential relative to US, a monetary independence index, a financial development measure, real per capita GDP relative to the US. (Balasssa-Samuelson Effect).

For the period ranging from 1994 to 2017, we used a Panel ARDL Approach to Cointegration (Pooled Mean Group), as our econometric methodology. There are similarities and differences related to how foreign reserve accumulation affects the level and volatility of real exchange rate. Regarding long run effects, higher levels of reserves usually tend to appreciate exchange rate and reduce its volatility, whereas lower levels have the opposite effect. These results are in line with several articles, such as Rodrik (2006) and Reinhart and Reinhart (2011), for exchange rate level, and Hviding et al. (2004), for volatility issues.

But short run effects were also estimated and are worth mentioning. Our results show that exchange rate volatility is corrected at a much faster rate than the exchange rate level itself. In other words, real exchange rate tends to firstly correct its distribution around a mean value and, then, it moves towards a desired level.

We also found evidence that the accumulation of international reserves seems to Granger-cause both level and volatility of real exchange rate, and that other control variables are also important is our discussion. This was the case of GDP, as a proxy for the Balassa-Samuelson effect, inflation, inflation differential and financial development. However, partial evidence was found when monetary independence as applied as a control variable.

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Appendix: Panel Unit Root Tests

Table 7: **Panel Unit Root Tests**

	Levin-Lin-Chu	**Im-Pesaran-Shin**	**ADF-Fisher**	**PP-Fisher**	**Breitung**	**Decision**
$lreer$	-10.619 [0.000]	0.387 [0.650]	136.026 [0.078]	101.753 [0.787]	1.711 [0.956]	Non Stationary
$reserv$	0.223 [0.588]	1.483 [0.931]	101.598 [0.790]	91.184 [0.943]	1.359 [0.913]	Non Stationary
cpi	-489.047 [0.000]	-112.563 [0.000]	885.121 [0.000]	1219.93 [0.000]	-2.336 [0.009]	Stationary
$cpidif$	-466.57 [0.000]	-101.725 [0.000]	835.432 [0.000]	1201.55 [0.000]	-2.218 [0.013]	Stationary
gdp	-6.218 [0.000]	-3.417 [0.0003]	157.970 [0.004]	48.349 [1.000]	-1.068 [0.142]	Stationary
$volreer$	-10.449 [0.000]	-14.861 [0.000]	402.735 [0.000]	693.329 [0.000]	-7.352 [0.000]	Stationary
$monet$	-6.218 [0.000]	-3.417 [0.0003]	157.970 [0.004]	48.349 [1.000]	-1.068 [0.142]	Stationary
$findev$	-3.654 [0.0001]	-1.590 [0.055]	152.768 [0.009]	123.783 [0.250]	0.865 [0.806]	Non Stationary

Notes: Levin-Lin-Chu; Breitung (Null: unit root - common process).
Im-Pesaran-Shin; ADF-Fisher; PP-Fisher (Null: unit root - individual process).