Economia Aplicada, v. 26, n. 2, 2022, p. 221-238

THE ROLE OF INTERNATIONAL RESERVES ON REAL EXCHANGE RATE: A PANEL DATA ANALYSIS

Flávio Vilela Viera*
Cleomar Gomes da Silva†

Abstract

This article analyzes whether the accumulation of international reserves affects real exchange rates for a set of 57 economies. Panel ARDL estimations, for annual data from 1994 to 2017, show that higher (lower) levels of international reserves cause appreciation (depreciation) of exchange rate and reduce (increase) its volatility, in the long run. As for the error-correction related to deviations from the long run, short run adjustments in exchange rate volatility occur at a much faster rate than corrections in the exchange rate level. The Balassa-Samuelson effect, inflation and inflation differential also play significant roles, whereas monetary independence is partially important. Public debt is significant in all estimated models for real effective exchange rate, with negative (positive) coefficient when using inflation (inflation differential), with positive coefficient for the exchange rate volatility models, changing coefficient sign when monetary independence is included.
Keywords: international reserves, real exchange rate; panel ARDL.
JEL codes: F31, C23, C58.

Resumo

Este artigo analisa o efeito da acumulação de reservas internacionais nas taxas reais de câmbio de 57 países. Para dados anuais de 1994 a 2017, as estimações via Painel ARDL mostram que níveis mais elevados (baixos) de reservas causam apreciação (depreciação) cambial e reduzem (aumentam) sua volatilidade, no longo prazo. Quanto à correção de erros relacionados aos desvios de longo prazo, ajustes de curto prazo na volatilidade cambial ocorrem de forma mais rápida que correções no nível da taxa de câmbio. Efeito Balassa-Samuelson, inflação e diferencial da inflação também são relevantes. Já a independência monetária tem relevância parcial. Dívida pública é significativa em todos os modelos estimados para a taxa de câmbio real efetiva, com coeficientes negativos (positivos) quando se inclui inflação (diferencial de inflação), com coeficientes positivos para os modelos de volatilidade cambial, com mudança de sinal do coeficiente quando a variável independência monetária é incluída.
Palavras-chave: reservas internacionais; taxa de câmbio real; painel ARDL.
Códigos JEL: F31, C23, C58.

DOI: http://dx.doi.org/10.11606/1980-5330/ea180445

* Federal University of Uberlândia (PPGE- IERI-UFU) & CNPq Associate Researcher, Brazil. E-mail: flaviovieira@ufu.br; orcid.org/0000-0001-9316-7990.
† Federal University of Uberlândia (PPGE-IERI-UFU) & CNPq Associate Researcher, Brazil. E-mail: cleomargomes@ufu.br; orcid.org/0000-0002-1543-9097.
Both authors thank CNPQ and FAPEMIG for financial support.

Recebido em 29 de dezembro de 2020 . Aceito em 22 de junho de 2021.

Introduction

Capital flows, accumulation of international reserves and, consequently, exchange rate movements are key elements in many economies nowadays. They influence, and are influenced, by domestic economic policies such as monetary and fiscal policies. In particular, countries without a comfortable cushion of international reserves are more susceptible to the effects coming from negative external shocks. On the other hand, high levels of foreign reserves, usually coming by capital inflows, can cause considerable impact on the exchange rate. Therefore, there must be an equilibrium between 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 movements. Some of the works have focused on analyzing exchange rate levels. This is the case of Frenkel (1978, 1980), Edwards (1984), Flood et al. (1998), Rodrik (2006), for instance, as we will see in the literature revision.

Nevertheless, not only is the level of real exchange rate important, but also its volatility is crucial, as reported by the results found in Hviding et al. (2004) and Vieira et al. (2013), for example. Volatility is certainly a considerable source of obstruction for investment and trade and, as a result, for 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 restricts all empirical analysis related to the role of international reserves on the level and volatility of 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. Our argument is that those countries accumulate international reserves as a cushion against external shocks, even though reserves affect both level and volatility of exchange rate. For annual data ranging from 1994 to 2017, we apply a Panel ARDL (Pooled Mean Group) Cointegration Approach as econometric methodology to examine the following variables: real exchange rate (level and volatility), real per capita GDP, CPI inflation rate, inflation differential and monetary independence index. We consider a higher exchange rate level an indication of appreciation, whereas a lower level indicates depreciation. As for inflation differential, it is the difference of each country's CPI inflation relative to the US CPI inflation rate.

Our Panel ARDL cointegration estimations show that, in the long run, higher levels of international reserves have significant and positive effects on both level and volatility of real exchange rate. The opposite applies for lower levels of international reserves. The outcomes are also robust for different model specifications. When short run adjustments are considered, there are differences in the results. While the exchange rate level estimations suggest a yearly average correction of 17.2% of a long-run deviation, exchange rate volatility estimations show a much faster correction, an average of 61.9% within a year. There is also evidence that the following control variables (Balassa-Samuelson GDP effect, inflation, and inflation differential) affect both level and volatility of real exchange rate, whereas the influence coming from monetary independence is partial. Public debt is significant in all estimated models for real effective exchange rate, with negative (positive) coefficient when using inflation (inflation differential), with positive coefficient for the exchange rate volatility models, changing coefficient sign when monetary independence is included.

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

Literature Review

The literature on the effects of international reserves on real exchange rate is vast and it has been debated academically for decades. Frenkel (1978) examined 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 was that the optimal degree of exchange rate flexibility depended on the stochastic nature of shocks (real and monetary, domestic and foreign shocks, for instance) faced by the economy. Frenkel (1980) extended his previous analysis until 1979, but found no change in the qualitative findings.

Edwards (1984) analyzed a sample of developing countries and concluded that not only did reserves movements respond to monetary factors, but also to differences between actual and desired reserves. Therefore, monetary considerations were important for estimating and analyzing models with international reserves. On a similar topic, Obstfeld et al. (2010) gathered more than 130 years of data to conclude that economic policies related to exchange-rate regime were still constrained by the monetary policy trilemma (a tradeoff among exchange stability, monetary independence, and capital market openness).

Jeanne & Rancière (2006) derived a formula of an optimal level of foreign reserves for a small open economy susceptible to sudden stops in capital flows. The authors argued that, with proper calibrations, their model could explain the magnitude of international reserves of many emerging market economies. Obstfeld et al. (2010) built an empirical financial-stability model based on financial stability and financial openness and found that international reserve stocks could 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 was also a good predictor of reserve stocks.

Aizenman & Lee (2007) showed that precautionary motives were important to emerging market economies, in their accumulation of international reserves. These reserves were usually increased when a more liberal capital account regime was in place, and they were also important to keep the economy going when sudden stops were about to happen. Aizenman & Hutchison (2012) found 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) focused on 12 Latin American countries, in the 1970s and 1980s, and showed how cycles in reserves and exchange rate premium could be a result of leakages between official and parallel foreign exchange markets. Athukorala & Rajapatirana (2003) showed that, for the period ranging from 1985 to 2000, real exchange rate appreciation was 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 & Marion (2003) used a sample of about 125 developing countries to analyze why Far East countries used to demand high amounts of international reserves, as opposed to some other developing countries. The authors found that, compared to other emerging markets, foreign reserves of Asian countries depended on the size and volatility of global transactions, as well as on exchange rate arrangements and political considerations. However, after the 1997 Asian financial crisis, the authors had to adapt their models to the new scenario. In that case, large precautionary demand for foreign reserves was related to countries showing high sovereign risk and costly tax system to cover fiscal expenditures. On the other hand, politically unstable developing nations tended to hold less reserves.

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

Rodrik (2006) argued that the rapid increase in international reserves in emerging market economies was more related to preventing exchange rate from appreciation and maintaining international trade competitiveness, than to a self-insurance motive. The author's results also showed that the costs of holding these reserves amount to an average of 1 p.p. of annual GDP in those countries. Reinhart & Reinhart (2011) examined the accumulation of international reserves of about 100 countries by making use of an interest-parity relationship to identify possible sources of exchange rate upward pressure, and how international reserve accumulation had been sterilized. The authors were only able to find some connection between capital inflow and low foreign interest rates. They also listed the major economic policies related to preventing exchange rate from appreciating, especially due to capital inflows. The necessity of a stable exchange rate led to more reserve accumulation. As a result, reserve requirements were one of the many tools usually applied to mitigate the consequence of accumulating foreign reserves.

Pina (2015) investigated the effect of international reserves accumulation in developing countries, based on data from 1970 to 2009. From 1987 on, the author found a different trend in the inflows of international reserves/GDP, compared to developed economies. The author examined why these different patterns occurred and argued that adequate levels of international reserves depended on what central banks did in developing countries, which was related to managing inflation and exchange rate and supporting the financial sector during periods of crises. The model's prediction showed distortions associated with how rigorous central bank constraints were, and with the magnitude of crisis and inflation dynamics. These distortions were crucial for the determination of international reserve levels.

Gregorio (2011) argued that reserves played a dissuasive role as they were accumulated as a safety cushion, but rarely used. The author also argued that reserve accumulation and exchange rate impacts could not be treated separately. This implied a challenge for central banks, as floating exchange rate regimes had to be coherent with the maintenance of an adequate level of reserves.

Dominguez et al. (2012) focused 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 showed that those countries which accumulated large amount of international reserves, before the crisis, were those with higher economic growth, after the crisis.

Bayoumi & Saborowski (2014) investigated the effects of international reserve intervention on the current account, particularly on the role played by of capital controls. The authors' results confirmed that capital controls are important for the impact of current account intervention. In particular, they found strong evidence that sterilized intervention is completely (partially) counterbalanced by capital outflows in economies without (with) capital controls. The authors concluded that the effects related to reserve accumulation has declined over time because many economies have decreased restrictions on their current account. Therefore, despite an increase in intervention, the influence on current account (% GDP) has been declining.

Aizenman et al. (2015) analyzed the effects of the 2008 financial crisis on international reserve hoarding. They found that, before the financial crisis (from 1999 to 2006), reserve accumulation was related to savings in developing and emerging markets. However, results from the post crisis period (from 2010 to 2012) showed a pattern change, especially related to the link between direct investment and reserve accumulation. For developed economies, higher savings were related to lower reserve levels, possibly because rich countries were channeling their funds to global financial markets. On the other hand, emerging market economies with low reserve accumulation experienced currency depreciation in 2012, due to the announcement of tapering quantitative easing.

Jeanne (2016) used a welfare-based model of capital flows with international banking frictions to analyze what role foreign reserves played in capital flow management. The author listed some stylized facts: i) "exorbitant privilege": emerging market countries must issue high-yield bonds to finance their low-yield assets, but they also need to accumulate reserves as a cushion against instability in advanced countries, and not because of their own weaknesses; ii) gross capital flows tend to exhibit more volatility than net flows, and that global factors, not domestic fundamentals, are responsible for the flow of capitals.

Regarding volatility, Hviding et al. (2004) focused on a panel of 28 emerging market economies, from 1986 to 2002. Their results showed that holding adequate reserves decreased exchange rate volatility. The importance of real exchange rate volatility on long-run GDP growth was analyzed by Vieira et al. (2013), who used a panel of 82 advanced and emerging economies, from 1970 to 2009, and concluded that more volatility affects economic growth negatively, and vice versa.

Data and Econometric Approach

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

The following variables will be analyzed:

i) *lreer*= Real Effective Exchange Rate (2010 = 100). (Source: BIS).

ii) *volreer* = Real Effective Exchange Rate Volatility.

iii) *reserv* = International Reserves (% of GDP). (Source: IFS-IMF).

iv) *gdp* = Real per Capita GDP relative to US. (Source: PENN World Table).

v) *cpi* = CPI Inflation Rate (%). (Source: IFS-IMF).

vi) *cpidif* = Inflation Differential relative to US. (%). (Source: IFS-IMF).

vii) *monet* = Monetary Independence Index. (Source: Aizenman et al., 2018).

viii) *debt* = Public Debt/GDP. (Source: IMF Historical Public Debt Database).

Real effective exchange rate is in logs. A higher (lower) value indicates an appreciation (depreciation). Real effective exchange rate volatility is estimated via ARCH-GARCH models, as it is explained in section Empirical Results (see Table 1). Monetary independence index comes from Aizenman et al. (2018). Higher (lower) values of the index mean more (less) monetary policy independence. The idea of including inflation differential as an explanatory variable is to analyze whether or not changes in real exchange rate are due to movements in domestic and foreign relative prices. If the answer is no, then nominal exchange rate is the variable responsible for relative price changes. Variable "real per capita GDP" is a proxy for productivity and captures the Balassa-Samuelson effect on real exchange rate (see Balassa (1964) and Samuelson (1964)). It means that countries with higher (lower) relative per capita income tend to face real exchange rate appreciation (depreciation) over time.

The explanatory variables (Reserves, GDP, Inflation, Inflation Differential, Monetary Independence and Public Debt) and their impact on Exchange Rate (level and volatility) can be described as follows. GDP captures the Balassa-Samuelson effect based on the argument the higher (lower) relative productivity is associated to more appreciated (depreciated) exchange rate. Inflation and Inflation Differential are included in the model to capture the role played by prices, since it is important that economies in general should be able to avoid significant and extended real exchange rate misalignments, and for most emerging and developing countries, to avoid real exchange rate appreciation with undesirable effects on the current account. Regarding the use of Monetary Independence in our model, it plays a similar role to interest rates, or interest rates differential, since economies with a higher degree of monetary independence tend to have more autonomy to use interest rates to impose price (inflation) restrictions, which help keeping the real exchange rate at a more stable path. As for Debt, it captures a country risk, and higher (lower) levels of public debt are generally associated to exchange rate depreciation (appreciation) and more (less) exchange rate volatility. Finally, our variable of interest (International Reserves), was introduced in our model to address the argument that higher (lower) levels reserves are usually associated with more exchange rate appreciation (depreciation). The idea is that a cushion of foreign reserves can be used to reduced exchange rate volatility and also to avoid significant exchange rate misalignments, either excessive appreciation or depreciation.

The empirical analysis developed in this work is based on Autoregressive Distributed Lag (ARDL) models applied to cointegration, as proposed in Pesaran & Shin (1999) (1999) and Pesaran et al. (2001). They were chosen due to their advantage over cointegration tests in non-stationary variables, such the ones developed by Engle & Granger (1987), Phillips & Hansen (1990) and Johansen (1991), as well as over traditional VAR methodology. ARDL models applied to cointegration also tend to be more effective in capturing a long-run relationship in small samples. They also perform well, irrespective of whether variables are stationary I(0), non-stationary I(1), or even mutually cointegrated (Pesaran & Shin (1999) 1999).

Pesaran et al. (1999) (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. Another important feature of the ARDL framework, particularly the PMG approach, is that the inclusion of lags of all variables delivers consistent estimation and, therefore, is able to deal with endogeneity problems (Pesaran et al. (1999) 1999).

A basic ARDL model can be specified as follows:

$$y_{it} = \sum_{j=1}^{p} \lambda_{ij}^{*} y_{i,t-j} + \sum_{j=0}^{q} \delta_{ij}^{*'} x_{i,t-j} + \mu_i + \varepsilon_{it} \tag{1}$$

where: $t = 1, 2, \ldots, T$ identifies the period, and $i = 1, 2, \ldots, N$ 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 can find the ECM equation:

$$\Delta y_{it} = \phi_i y_{i,t-1} + \beta_i' x_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}^{*'} \Delta x_{i,t-j} + \mu_i + \epsilon_{it} \tag{2}$$

where: $\phi_i = -(1 - \sum_{j=1}^{p} \lambda_{ij})$ = the error correction term for the ith group;

$\beta_i = \sum_{j=0}^{q} \delta_{ij}$ = long-run parameter for the ith group; $\lambda_{ij}^* = -\sum_{m=j+1}^{p} \lambda_{im}, j = 1,\ 2, \ldots,\ p-1$; and $\delta_{ij}^* = -\sum_{m=j+1}^{q} \delta_{im}, j = 1,\ 2, \ldots, q-1$.

In our specific case, Panel ARDL (PMG) models are applied in the analysis of the role of international reserves for two different dependent variables: log of real effective exchange rate and exchange rate volatility. The estimated equations for our baseline panel ARDL models are:

Dependent Variable - log of Real Effective Exchange Rate (lreer)

$$\begin{aligned}\Delta(lreer)_{it} &= \mu + \alpha_1 t + \beta_1 (lreer)_{it-1} + \beta_2 (cpi)_{it-1} + \beta_3 (gdp)_{it-1} \\ &+ \beta_4 (reserv)_{it-1} + \sum_{j=1}^{p} \beta_5 \Delta(lreer)_{it-j} + \sum_{j=0}^{q} \beta_6 \Delta(cpi)_{it-j} \\ &+ \sum_{j=0}^{r} \beta_7 \Delta(gdp)_{it-j} + \sum_{j=0}^{s} \beta_8 \Delta(reserv)_{it-j} + \varepsilon_{it} \qquad (3)\end{aligned}$$

Dependent Variable - Real Effective Exchange Rate Volatility (volreer)

$$\begin{aligned}\Delta(volreer)_{it} &= \mu + \alpha_1 t + \beta_1 (volreer)_{it-1} + \beta_2 (cpi)_{it-1} + \beta_3 (gdp)_{it-1} \\ &+ \beta_4 (reserv)_{it-1} + \sum_{j=1}^{p} \beta_5 \Delta(volreer)_{it-j} + \sum_{j=0}^{q} \beta_6 \Delta(cpi)_{it-j} \\ &+ \sum_{j=0}^{r} \beta_7 \Delta(gdp)_{it-j} + \sum_{j=0}^{s} \beta_8 \Delta(reserv)_{it-j} + v_{it} \qquad (4)\end{aligned}$$

We also estimate a second specification for Equations 3 and 4 using inflation differential relative to the US, instead of inflation rate. Another extension to the previous estimated models is to include an additional control variable, monetary independence, to the baseline model with inflation and to the alternative model using inflation differential.

Empirical Results

Estimating Real Exchange Rate Volatility, via ARCH-GARCH Models

Real effective exchange rate volatility measures are calculated by the following expression:

$$r_{it} = ln(reer)_{it} - ln(reer)_{it-1} \qquad (5)$$

where r_{it} is the return of the real exchange rate in logs, based on average structures ARMA, and ARCH/GARCH for conditional variance. Conditional variance is the measure used for exchange rate volatility, which is calculated by making use of monthly data for each of the 57 countries, from February 1994 to December 2017. After the calculation, each monthly series are then transformed into annual data, by means of the 12-month monthly average for each country.

Table 1 summarizes the models for the 57 return time series. There is some dominance of models with a GARCH (1,1) structure. For the average structure, there is predominance of AR(1) and AR(2) structures.

Table 1: Real Effective Exchange Rate Volatility - ARCH/GARCH Models

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

Notes: i) n is the autoregressive order for *Dlreer*; ii) (n, r) stand for autoregressive and moving average terms, respectively; iii) (p,q) refers to the presence of p lagged squared residuals and the q lagged conditional variance; iv) Model Selection: AR(n) or ARMA (n,r) GARCH (p,q).

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, which is depicted by the following equation:

$$y_{it} = \alpha_i + \beta_{1i}x_{1i,t} + \beta_{2i}x_{2i,t} + \ldots + \beta_{Mi}x_{Mi,t} + \varepsilon_{i,t} \quad (6)$$
$$\text{for: } t = 1,\ 2, \ldots,\ T;\ i = 1,\ 2, \ldots,\ N;\ M = 1,\ 2, \ldots,\ m.$$

where: i) y and x are I(1) variables, by assumption; ii) T is the number of observations over time; iii) N is the number of individuals in the panel; iv) M is the number of variables; v) α_i refers to individual effects, which may be set to zero; vi) parameters $\beta_{1i}, \beta_{2i}, \ldots, \beta_{Mi}$ 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 calculating the following auxiliary regression for each cross-section:

$$\varepsilon_{it} = \rho_i \varepsilon_{i,t-1} + \sum_{k=1}^{K_i} \rho_{i,k} \Delta\varepsilon_{i,t-k} + \mu_{i,t} \quad (7)$$

Pedroni (1999) describes several methods to construct appropriate statistics to test the null hypothesis of non-cointegration ρ_i from the residuals' equation. Table 2 reports both within and between dimension panel cointegration tests statistics related to the models estimated. Cointegration is found in at least one of the statistics for all models, regardless of using the level or volatility of real exchange rate, but cointegration seems to be much stronger when the dependent variable is exchange rate volatility. Therefore, the evidence suggests a long run equilibrium relationship among real effective exchange rate and volatility with the other variables of our models.

Table 2: Pedroni Cointegration Tests

	With Inflation				With Inflation Differential			
	Within-Dimension							
	Dep. Var. *lreer*		**Dep. Var. *volreer***		**Dep. Var. *lreer***		**Dep. Var. *volreer***	
Panel Stat.	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Panel v	1.15 [0.12]	-3.30 [0.99]	-2.04 [0.97]	-6.28 [1.00]	-3.42 [0.99]	-3.44 [0.99]	-4.46 [1.00]	-4.56 [1.00]
Panel rho	4.55 [1.00]	5.43 [1.00]	**-3.07** [0.00]	2.35 [0.99]	4.35 [1.00]	5.55 [1.00]	-0.45 [0.32]	2.09 [0.98]
Panel PPS	1.24 [0.89]	0.05 [0.52]	**-13.45** [0.00]	**-15.69** [0.00]	-0.14 [0.44]	0.07 [0.52]	**-15.28** [0.00]	**-14.81** [0.00]
Panel ADF	**-1.57** [0.05]	**-2.55** [0.01]	**-13.82** [0.00]	**-14.89** [0.00]	**-3.33** [0.00]	**-1.70** [0.04]	**-16.54** [0.00]	**-15.29** [0.00]
	Between-Dimension							
Group Stat.	**Dep. Var. *lreer***		**Dep. Var. *volreer***		**Dep. Var. *lreer***		**Dep. Var. *volreer***	
Group rho	7.00 [1.00]	8.12 [1.00]	-0.38 [0.34]	4.69 [1.00]	7.12 [1.00]	8.30 [1.00]	2.41 [0.99]	4.53 [1.00]
Group PP	2.55 [0.99]	-0.17 [0.43]	**-16.96** [0.00]	**-20.26** [0.00]	-0.05 [0.47]	-0.84 [0.19]	**-15.70** [0.00]	**-17.60** [0.00]
Group ADF	**-2.09** [0.02]	**-2.44** [0.01]	**-17.53** [0.00]	**-14.67** [0.00]	**-3.65** [0.00]	**-2.20** [0.01]	**-15.49** [0.00]	**-13.70** [0.00]

Notes: i) weighted statistic used in within-dimension. p-values in brackets.
ii) Null Hypothesis: No cointegration.

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 (Balassa-Samuelson effect), international reserves/GDP and inflation. In the second model monetary independence is added to the baseline estimation.

Table 3 reports the PMG long-run coefficients having the log of real effective exchange rate as dependent variable. Concerning our main variable of interest, which is international reserves, the estimated coefficients are positive and statistically significant in all four models, which is line with the idea that higher (lower) levels of international reserves tend to appreciate (depreciate) exchange rate. This is an indication that the country has enough international reserves to face any external shock and it is also a suggestion that the country has no external adjustment problems.

Regarding coefficients related to CPI inflation rate, they are all statistically significant with positive estimated coefficients, indicating that higher (lower) inflation tends to appreciate (depreciate) the exchange rate. In this case, a negative coefficient is usually expected, indicating that higher (lower) levels of inflation are associated with more depreciated (appreciated) exchange rates. However, a positive sign can also be possible, due to issues such as more rigid (pegged) exchange rate regimes and even to what the literature calls *fear of floating* (Calvo & Reinhart (2002)).

Table 3: Long Run and Short Run (ECM) Coefficients
Dependent Variable: Real Effective Exchange Rate

	With Inflation		**With Inf. Differential**	
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Real per Capita GDP	**2.16E-06** [0.000]	**9.91E-06** [0.000]	**2.33E-06** [0.003]	**2.13E-05** [0.000]
International Reserves	**0.0011** [0.000]	**0.0010** [0.0254]	**0.0014** [0.000]	**0.0013** [0.000]
CPI Inflation Rate	**0.0165** [0.000]	**0.0446** [0.000]		
Inflation Differential			**0.0198** [0.000]	**0.0229** [0.000]
Monetary Independence Index		0.0276 [0.5664]		**-0.1255** [0.000]
ARDL Lags	(3, 3, 3, 3)	(1, 1, 1, 1, 1)	(2, 2, 2, 2)	(1, 2, 2, 2, 2)
Max. Dep. Lags	3	2	2	1
ECM(-1)	-0.270 [0.000]	-0.101 [0.000]	-0.192 [0.000]	-0.164 [0.000]

Note: p-values in brackets. ECM(-1) Average = -0.181.

Coefficients related to inflation differentials are all positive and statistically significant for the two estimated models. As in the CPI inflation rate case, this suggests some difficulty of countries to keep up with higher inflation rates and not changing the exchange rate at the same pace, which will result in more appreciated real exchange rates. 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 estimated coefficients for real per capita GDP, based on the Balassa-Samuelson hypothesis, the expected positive sign holds for all four estimated models. In fact, positive long run coefficients are 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) the exchange rate over time.

When monetary independence is used as control variable, it is statistically significant in Model 4 with inflation differential, but not in Model 2 with CPI inflation rate. The negative estimated coefficient in Model 4 suggests that a higher degree of monetary independence is associated with a more depreciated 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 index. A more (less) monetary independence will indicate more (less) ability and autonomy of monetary authorities to adopt instruments to keep the exchange rate at an adequate macroeconomic level, and so to avoid undesirable impacts on the economy. Such measures can be either appreciation or depreciation of the exchange rate, depending on each country.

Table 4 reports the PMG long-run coefficients when real effective exchange rate volatility is used as dependent variable. The results related to international reserves, our main variable of interest, indicate that the estimated coefficients are statistically significant in all estimations. In other words, higher (lower) levels of international reserves reduce (increase) exchange rate volatility. The expected negative coefficient is an indication that higher (lower) levels of international reserves are associated with lower (higher) uncertainty levels on the exchange rate market. This makes sense if foreign reserve hoarding 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 measures to reduce changes in the exchange rate, and so to reduce its volatility.

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

All CPI inflation rate estimated coefficients are statistically significant with negative estimated coefficients, implying that higher (lower) inflation tends to reduce (increase) exchange rate volatility. Inflation differential coefficients are negative and statistically significant in all estimated models. Monetary independence has positive estimated coefficients, but it is statistically significant only in Model 4 with inflation differential.

Once the long-run effects have been examined, we go one step further and analyze the 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.

The short-run adjustments related to the exchange rate level, reported in Table 3, and exchange rate volatility, reported in Table 4, show that all ECM coefficients are also statistically significant with a negative sign, confirming a stable long-run relationship between the variables. When the exchange rate level is used as dependent variable (Table 3), the Error Correction Mechanism (ECM) ranges from -0.101 to -0.27, with an average of -0.181. It means that, on average, 18.1% of a short-run perturbation is corrected within a year. When the dependent variable is exchange rate volatility, Table 4 shows that the ECM coefficients range from -0.599 to -0.632 (average = -0.615). It means that between 59.9% and 63.2% of a long-run deviation is corrected within a year. Comparing the short-run adjustment results related to the level and volatility of real exchange rate it seems that exchange rate volatility is corrected much faster than the exchange rate level itself.

We have extended our model specification (Tables 3 and 4) in order to in-

Table 4: Long Run and Short Run (ECM) Coefficients
Dependent Variable: Real Effective Exchange Rate Volatility

	With Inflation		**With Inf. Differential**	
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Real per Capita GDP	**-4.44E-11** [0.000]	**-5.30E-12** [0.000]	**-5.00E-11** [0.000]	**-4.64E-12** [0.000]
International Reserves	**-7.94E-09** [0.000]	**-2.18E-10** [0.0291]	**-4.70E-09** [0.000]	**-5.83E-10** [0.000]
CPI Inflation Rate	**-5.73E-09** [0.0053]	**-1.63E-09** [0.0019]		
Inflation Differential			-1.47E-09 [0.4016]	**4.02E-09** [0.000]
Monetary Indep. Index		9.83E-09 [0.1741]		**1.03E-08** [0.0576]
ARDL Lags	(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
ECM(-1)	-0.611 [0.000]	-0.632 [0.000]	-0.599 [0.000]	-0.619 [0.000]

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

clude a fiscal variable (Public Debt/GDP). Tables A.1 and A.2, in the appendix, shows that Debt/PIB is statistically significant in all estimated models in Table A.1, with real effective exchange rate as dependent variable. In this case, the Debt/PIB coefficient is negative, when inflation is used in the estimation, and positive, in the presence of inflation differential. As for international reserves, our main variable of interest, its coefficient is positive and significant in all estimations performed, which is in line with the coefficients for the same variable reported in Table 3. When the dependent variable is exchange rate volatility (Table A.2), the Debt/PIB coefficient is positive and statistically significant for models without monetary independence, and it changes the sign when including monetary independence. As for the coefficients related to international reserves, they are all statistically significant and with a negative sign, as in Table 4. The only exception is the positive sign found in Model 2.

Conclusion

This article aimed at empirically investigate the role of accumulation of international reserve policies on the level and volatility of the real exchange rate, 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 variables were used as control variables: CPI inflation rate, inflation differential relative to US, a monetary independence index, 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, and found similarities and differences in role played by foreign reserves on the level and volatility of real exchange rate. Regarding long run effects, higher reserve levels usually tend to appreciate the exchange rate and reduce its volatility, whereas lower reserve accumulation has the opposite effect on both level and volatility. These results are in line with several articles, such as Rodrik (2006) and Reinhart & Reinhart (2011), for the exchange rate level, and Hviding et al. (2004), for volatility issues.

Short run effects were also estimated and are worth mentioning. Our results showed that exchange rate volatility is corrected at a much faster rate than the exchange rate level itself. In other words, the 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, together with the accumulation of foreign reserves, other control variables are important to the determination of the level and volatility of exchange rate. This was the case of GDP, as a proxy for the Balassa-Samuelson effect, CPI inflation rate and inflation differential, and public debt. However, partial evidence was found when monetary independence as applied as a control variable.

Acknowledgements

Financial support provided by CNPq, CAPES and FAPEMIG.

Referencias

Bibliography

Aizenman, J., Cheung, Y. & Ito, H. (2015). International Reserves Before and After the Global Crisis: Is There no End to Hoarding? *Journal of International Money and Finance*, Amsterdam, v. 52, p. 102–126.

Aizenman, J., Cheung, Y. & Ito, H. (2018). *Assessing the Emerging Global Financial Architecture: Measuring the Trilemma's Configurations Over Time* NBER Working Paper 14533. Update Database. Available at: http://web.pdx.edu/ ito/trilemma_indexes.htm.

Aizenman, J. & Hutchison, M. M. (2012). Exchange Market Pressure and Absorption by International Reserves: Emerging Markets and Fear of Reserve Loss During the 2008-2009 Crisis? *Journal of International Money and Finance*, Amsterdam, v. 31, p. 1076–1091.

Aizenman, J. & Lee, J. (2007). International Reserves: Precautionary versus Mercantilist Views, Theory and Evidence. *Open Economies Review*, Heidelberg, v. 18, p. 191–221.

Aizenman, J. & Marion, N. (2003). The High Demand for International Reserves in the Far East: What is Going on?. *Journal of the Japanese and International Economies*, Cambridge, v. 17, p. 370–400.

Aizenman, J. & Riera-Crichton, D. (2008). Real Exchange Rate and International Reserves in the Era of Growing Financial and Trade Integration. *Review of Economics and Statistics*, Cambridge, v. 90, n. 4, p. 812–815.

Athukorala, P. & Rajapatirana, S. (2003). Capital Inflows and the Real Exchange Rate: A Comparative Study of Asia and Latin America. *World Economy*, Hoboken, v. 26, p. 613–637.

Balassa, B. (1964). The Purchasing Power Parity Doctrine: A Reappraisal. *Journal of Political Economy*, Chicago, v. 72, p. 584–596.

Bayoumi, T. & Saborowski, C. (2014). Accounting for Reserves. *Journal of International Money and Finance*, Amsterdam, v. 41, p. 1–19.

Calvo, G. A. & Reinhart, C. M. (2002). Fear of floating. *Quarterly Journal of Economics*, Cambridge, v. 117, p. 379–408.

Dominguez, K., Hashimoto, Y. & Ito, T. (2012). International reserves and the global financial crisis. *Journal of International Economics*, Amsterdam, v. 88, p. 388–406.

Edwards, S. (1984). The demand for international reserves and monetary equilibrium: some evidence from developing countries. *Review of Economics and Statistics*, Cambridge, v. 66, p. 495–500.

Engle, R. & Granger, C. (1987). Co-integration and error correction: representation, estimation, and testing. *Econometrica*, New Haven, v. 55, n.2, p. 251–276.

Flood, R., Perraudin, W. & Vitale, P. (1998). Reserve and exchange rate cycles. *Journal of International Economics*, Amsterdam, v. 46, p. 31–59.

Frenkel, J. A. (1978). *International reserves under alternative exchange rate regimes and aspects of the economics of managed float*. Cambridge, MA: NBER. (NBER Working Paper No. 287).

Frenkel, J. A. (1980). International reserves under pegged exchange rates and managed float: corrections and extensions. *Journal of Monetary Economics*, Amsterdam, v. 6, p. 295–302.

Gosh, A. R., Ostry, J. D. & Tsangarides, C. G. (2014). Accounting for emerging market countries international reserves: are pacific rim countries different?. *Journal of International Money and Finance*, Amsterdam, v. 49, p. 52–82.

Gregorio, J. (2011). Acumulación de reservas internacionales en economías emergentes. *Cuadernos de Economía*, v. 30, p. 77–90.

Hviding, K., Nowak, M. & Ricci, L. A. (2004). *Can higher reserves help reduce exchange rate volatility?*. Washington, DC: IMF. (IMF Working Paper WP/04/189).

Jeanne, O. (2016). International Reserves: Precautionary versus Mercantilist Views, Theory and Evidence. *American Economic Review*, Nashville, v. 106, p. 570–573.

Jeanne, O. & Rancière, R. (2006). *The optimal level of international reserves for emerging market countries: formulas and applications*. Washington, DC: IMF. (IMF Working Paper WP/06/229).

Johansen, S. (1991). Estimation and hypothesis testing of cointegration vectors in gaussian Vector Autoregressive models. *Econometrica*, New Haven, v. 59, p. 1551–1580.

Obstfeld, M., Shambaugh, J. C. & Taylor, A. M. (2010). Financial stability, the trilemma, and international reserves. *American Economic Journal: Macroeconomics*, Nashville, v. 2, p. 57–94.

Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics*, Oxford, v. 61, p. 653–670.

Pesaran, M. H. & Shin, Y. (1999). An autoregressive distributed-lag modelling approach to cointegration analysis. *In*: Strøm, S. (Ed). *Econometrics and Economic Theory in the 20th century*, p. 371–413.

Pesaran, M. H., Shin, Y. & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, Kingston, v. 16, p. 289–326.

Pesaran, M. H., Shin, Y. & Smith, R. P. (1999). Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association*, London, v. 94, p. 621–634.

Phillips, P. C. B. & Hansen, B. E. (1990). Statistical inference in instrumental variables regression with I(1) processes. *Review of Economic Studies*, Bingley, v. 57, p. 99–125.

Pina, G. (2015). The recent growth of international reserves in developing economies: a monetary perspective. *Journal of International Money and Finance*, Amsterdam, v. 58, p. 172–190.

Reinhart, C. & Reinhart, V. (2011). Entrada de capitales y acumulación de reservas: evidencia reciente. *Revista Estudios Económicos*, Lima, v. 20, p. 15–25.

Rodrik, D. (2006). The social cost of foreign exchange reserves. *International Economic Journal*, London, v. 20, p. 253–266.

Samuelson, P. A. (1964). Theoretical notes on trade problems. *Review of Economics and Statistics*, Chicago, v. 46, p. 145–154.

Vieira, F. V., Holland, M., Gomes Silva, C. & Bottecchia, L. C. (2013). Growth and exchange rate volatility: a panel data analysis. *Applied Economics*, Abingdon, v. 45, p. 3733–3741.

Appendix

Tabela A.1: Additional Estimation with Inclusion of Debt/GDP Long Run and Short Run (ECM) Coefficients Dependent Variable: Real Effective Exchange Rate

	With Inflation		**With Inf. Differential**	
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Real per Capita GDP	2.31E-06 [0.267]	1.23E-05 [0.615]	-8.34E-05 [0.008]	-8.85E-05 [0.000]
International Reserves	**0.002** [0.000]	**0.0002** [0.0254]	**0.0236** [0.004]	**0.031** [0.000]
CPI Inflation Rate	0.032 [0.000]	0.024 [0.000]		
Inflation Differential			0.013 [0.064]	-0.035 [0.000]
Monetary Indep. Index		0.017 [0.620]		-0.210 [0.289]
Debt	**-0.001** [0.000]	**-0.001** [0.000]	**0.034** [0.000]	**0.030** [0.000]
ARDL Lags	(2,2,2,2,2)	(1, 1, 1, 1, 1)	(1,2, 2, 2, 2)	(1, 1, 1, 1, 1)
Max. Dep. Lags	2	1	2	1
ECM(-1)	-0.238 [0.000]	-0.157 [0.000]	-0.003 [0.000]	0.001 [0.806]

Note: p-values in brackets. ECM(-1) Average = -0.132 (only models 1, 2 and 3).

Tabela A.2: Additional Estimation with Inclusion of Debt/GDP Long Run and Short Run (ECM) Coefficients Dependent Variable: Real Effective Exchange Rate Volatility

	With Inflation		**With Inf. Differential**	
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Real per Capita GDP	-2.13E-09 [0.000]	-6.31E-13 [0.002]	-1.19E-11 [0.000]	-2.66E-12 [0.000]
International Reserves	-1.31E-06 [0.000]	6.97E-10 [0.000]	-8.41E-09 [0.000]	-5.32E-10 [0.000]
CPI Inflation Rate	1.66E-05 [0.000]	1.19E-10 [0.031]		
Inflation Differential			-5.34E-10 [0.122]	3.98E-12 [0.875]
Monetary Indep. Index		1.62E-08 [0.000]		-1.96E-10 [0.945]
Public Debt	**6.71E-07** [0.000]	**-1.94E-10** [0.000]	**9.79E-10** [0.000]	**1.24E-11** [0.653]
ARDL Lags	(1,2,2,2,2)	(1, 1, 1, 1, 1)	(1,1,1,1,1)	(1, 1, 1, 1, 1)
Max. Dep. Lags	2	1	1	1
ECM(-1)	-0.461 [0.000]	-0.675 [0.000]	-0.609 [0.000]	-0.628 [0.000]

Note: p-values in brackets. ECM(-1) Average = -0.593.