# International Reserves and Global Interest Rates

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**Abstract**

In this paper we study the relationship between foreign currency international reserve holdings and global interest rates. To guide empirical work we solve a simple small open economy model with money where a central bank manages international reserves to smooth inflation over time. This model shows that changes in interest rates are positively related to the target level of reserves. As a consequence, increases in interest rates increase reserve transfers, where reserve transfers are defined as the change in international reserves minus interest earned on reserves. Using quarterly data for 75 countries between 2000 and 2014, we document a positive relationship between interest rate changes and reserve transfers as a share of GDP, which is consistent with the model.

## 1 Introduction

The massive accumulation of international reserves by central banks in Asia and Latin America is one of the crucial policy issues in Pacific Rim economies (See, for example, Aizenman and Marion (2003), Jeanne (2007), Aizenman and Lee (2007) and Aizenman and Lee

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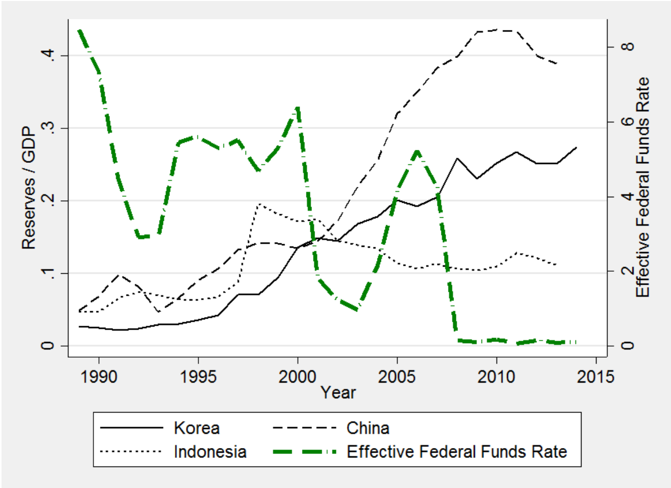


Figure 1: Reserves / GDP for selected countries (left axis) and the US Effective Federal Funds Rate (right axis).

(2008).). This accumulation of highly liquid assets with relatively low returns has important implications for domestic economies and for the world economy. Not only it represents foregone consumption and investment in fast growing economies, it also contributes to global imbalances in the form of upstream capital flows.[1] In this paper, we study how the holdings of international reserves depend on interest rate shocks to the interest-bearing assets that constitute international reserves.

Figure 1 plots the effective federal funds rate in the last 15 years together with Reserves as a share of GDP for three East Asian economies. We can see from the graph that holdings of international reserves slowed down substantially in the recent period of the zero-lower bound in US interest rates. Is this the new normal for reserve accumulation? How would reserve accumulation change if interest rates in developed economies increase? The prospective increase in interest rates in developed economies is one of the most significant near-future challenges for developing economies. Therefore, understanding how reserves relate to global interest-rates is of paramount importance. This paper approaches this question from a monetary perspective and studies theoretically and empirically how international reserve accumulation changes with interest rate fluctuations.

[1] See Fukuda and Kon (2012) for an analysis of reserve accumulation on consumption and investment, and Gourinchas and Jeanne (2013) and references therein for their role in upstream capital flows.

To guide empirical work we solve a simple monetary model of international reserve management. The model is a traditional cash-in-advance small-open economy, which has been used by Calvo (1987) and Burnside et al. (2001) to study balance of payments problems, by Rigobon (2002) to study inflation under fiscal reforms, and by Pina (2015) to study the growth in international reserves. In the model presented in this paper, we focus on the target long-run level of international reserves and how interest rate shocks may change this target. We also show how studying international reserve transfers, defined as international reserve changes minus interest earned on these reserves, allows us to identify empirically the impact of interest rate shocks on the unobservable target level of international reserves.

We set up the problem of a central bank that has to finance exogenous and stochastic foreign currency spending shocks with inflation-related revenues, such as seigniorage or deflating nominal debts. Inflation is distortionary and the central bank wishes to spread distortions over time. To do so, it accumulates reserves in order to smooth inflation against these shocks. Besides managing this stock of international reserves with respect to domestic shocks, the central bank also faces external shocks to the interest rate of its interest-bearing assets. We compare periods of low and high world interest rates and show that an increase in interest rates increases the target level for reserves and leads to an increase in reserve transfers. We also show that reserve transfers are decreasing when interest rates are constant. These results highlight a relationship between changes in interest rates and international reserve transfers that we can test empirically.

In the data section of the paper, we interpret our empirical results under the light of this model of international reserve management. To test whether interest rates are associated with reserve transfers, we take advantage of quarterly data on international reserves and global interest rates for a large panel of economies. Data on the composition of international reserves is available monthly starting January 2000 by the IMF Special Data Dissemination Standard (SDDS) Reserve Template as described in Dominguez et al. (2012). Quarterly data on the currency denomination of international reserves is available through COFER for developed and developing economies, while Wong (2007) reports country-specific data for 2005. We use this data to construct international reserve transfers, defined as changes in international reserves net of interest income, as well as country-specific interest rates earned on reserves. To identify the elasticity of international reserves to interest rate shocks, we explore that interest rate changes in developed economies are plausably exogenous for small developing economies. Furthermore, we benefit from within and cross-country variation in the types of assets used to accumulate reserves as well as the currencies under which they are denominated.

Using quarterly data between 2000 and 2014, we find evidence of a positive relationship between interest rate shocks and international reserve transfers that is consistent with the model. Under the lens of our theoretical results, this implies that positive interest rate shocks increase the target levels of international reserves for developing economies. In our baseline regression, we find that a 1 percentage point increase in the effective interest rate earned on reserves is associated with an increase in reserve transfers as a share of GDP of at most 0.19 percentage points. We perform a number of robustness exercises and document that this effect is stronger outside of the global financial crisis and robust to using an alternative measure of interest rate shocks.

Research on international reserves and interest rates has focused on the quasi-fiscal costs of holding reserves, in particular, on the opportunity cost of holding reserves as measured by the difference between interest earned on reserves and the social return of applying these resources elsewhere. Numerous papers, including Heller (1966), Edwards (1985) and Hauner (2006), have used alternative measures for this social return.[2] Our results are complementary to this research in the sense that we focus our attention on measuring the relevant interest rate changes for developing economies, and do not take a stance on the correct measure of the social return on capital. We also use recent quarterly from the period between 2000 and 2014. Our approach is closely related to the work by Dominguez et al. (2012) and Dominguez (2012), who use the same data on the composition of reserves to study how net purchases of foreign currency international reserves impact economic performance. Instead of studying the effects of actively managing foreign currency international reserves, we focus on the impact of external shocks on interest rates on the target level of international reserves.

The next section solves a simple model of international reserves and interest rates. Section

[2]See Hauner (2006) for an overview of this literature.

3 presents the data set and tests the predictions of the model. Section 4 discusses our findings and suggests areas for future research.

# 2 Model

In this model we study international reserve accumulation using the inflation smoothing approach developed by Calvo (1987), Rigobon (2002) and Pina (2015). There are two optimizing agents, a central bank and a representative consumer. The problem of the representative consumer is a standard cash-in-advance model of consumption where consumption fluctuates with inflation. Our focus is on the problem of the central bank. The central bank has access to a non-contingent asset to smooth inflation while facing stochastic financial responsibilities during crises. They are denominated in foreign currency and can take the form of banking sector support or transfers to the government. To finance these expenses, the central bank can either raise inflation-related revenues or use previously accumulated international reserves. Inflation is costly, and the central bank wishes to spread the burden of inflation across time. As a result, it accumulates reserves in normal periods and uses a mix of inflation and reserves during crises.

## 2.1 Setup

Consider a small open endowment economy with one traded good where time is continuous. There are two agents: an infinitely lived representative consumer and a central bank. At any moment in time, the economy is in one of two states. A normal state ($L$) and a crisis state ($H$). The difference between crisis states and normal states is the amount of foreign funds demanded from the central bank, which are low in normal times and high during crises.

### 2.1.1 Consumer Problem

The representative consumer maximizes the expected lifetime utility from the consumption plan $\{c_t\}_0^\infty$. The objective function of the consumer is given by:

$$E_0 \int_0^{\infty} log\left(c_t\right) e^{-\rho t} dt, \tag{1}$$

where $\rho > 0$ is the subjective discount factor. We assume that the consumer receives an endowment of $y$ every period and has access to two assets: a foreign bond $f$ that earns the foreign real interest rate $\rho$ and domestic money holdings $M_t$. Money is valuable in this economy because it is useful for consumption purposes. The opportunity cost of holding money is given by the nominal interest rate, which corresponds to the loss of value associated with inflation plus the return lost from not being able to apply these resources in the foreign bond.

Let $P_t$ represent the domestic price level at $t$, and $\pi_t = \frac{\dot{P_t}}{P_t}$ the domestic inflation rate (and let the international inflation rate be zero). Assume that purchasing power parity holds, such that the exchange rate is completely determined by inflation. Assume also that all debt is indexed to domestic inflation.[3] Then, the nominal domestic interest rate is given by: $i_t = \rho + \pi_t$. The flow budget constraint of the consumer can be written as:

$$\dot{f_t} + \frac{\dot{M_t}}{P_t} = \rho f_t + y - c_t. \tag{2}$$

In addition, the consumer faces a cash-in-advance constraint. To consume $c_t$, the consumer must have real money holdings $\frac{M_t}{P_t}$ at least larger than $c_t$. The cash-in-advance constraint is given by:

$$c_t \leq \frac{M_t}{P_t}. \tag{3}$$

Define $a_t = f_t + \frac{M_t}{P_t}$ as the wealth of the consumer in real terms. Because consumers only care about real balances, define real money balances as $m_t = \frac{M_t}{P_t}$. As a store of value, money is always dominated by foreign assets if $i_t = \pi_t + \rho \geq 0$, which we assume throughout. Thus, the cash-in-advance constraint (3) will always hold with equality and money demand is given by $m_t = c_t$. We can then rewrite the flow budget constraint as:

[3]This implies that domestic and foreign debt are perfect substitutes for the consumer and limits inflation-related revenues to seigniorage.

$$\dot{a}_t = \rho a_t + y - c_t (1 + i_t). \tag{4}$$

Finally, the consumer's solvency condition is given by:

$$\lim_{t \to \infty} a_t e^{-\rho t} \geq 0. \tag{5}$$

The problem of the consumer is then to choose a sequence of $\{c_t\}_0^\infty$, so as to maximize (1), subject to the flow budget constraint (4) and the solvency condition (5), given $\{i_t\}_0^\infty$, $f_0$ and $m_0$. The solution to this problem is greatly simplified by the fact that the consumer has log-utility and by the assumption that the consumer is as impatient as the market. We assume further that the consumer has perfect foresight. Appendix A shows that the optimal solution is given by:

$$c_t = \frac{\rho a_0 + y}{1 + i_t}, \tag{6}$$

$$m_t = c_t. \tag{7}$$

Equation (6) shows that consumption depends positively on wealth and income but negatively on inflation. We focus now on the problem of the central bank and on the behavior of international reserves.

### 2.1.2 Central Bank Problem

We assume the central bank is benevolent. It solves a constrained optimization problem: subject to the demands of the government, the representative agent's choices and it's own budgetary constraints, the central bank maximizes the representative agent's utility. The solution is represented by a plan for the interest rate $\{i_t\}_0^\infty$ that maximizes (1). Because the agent demands real money balances, the central bank can tax domestic agents through inflation. With the resources obtained from seigniorage $\frac{\dot{M}_t}{P_t}$, the central bank can pay for spending $g_t$ or accumulate international reserves $r_t$ that earn interest $\phi_t$. Absent any borrowing constraint, the central bank can also borrow from the international bond market at rate $\phi_t$. However, since this asset is not contingent on shocks to $g_t$, the central bank does not have access to perfect insurance.

Note that we assume that the central bank has access to different foreign assets than the domestic consumer. In particular, we assume that the central bank can only save in an asset that earns an interest rate that is lower than the interest rate faced by the consumer: $\phi_t < \rho$. One justification for this assumption is to consider that central banks are only interested in highly liquid assets such as treasuries or cash, whiles consumers can save abroad in higher return equities. When borrowing, central banks can also have access to lower interest rates, while private agents pay a high cost for borrowing abroad. Because the central bank has access to a lower interest rate but maximizes the utility of the agent, the central bank acts as an impatient agent.[4]

The objective of the central bank is to choose the interest rate $i_t$ to maximize:

$$E_0 \int_0^\infty \ln(c)\, e^{-\rho t} dt, \tag{8}$$

taking into account the optimal decisions of the representative consumer and the stochastic process for $g$. To simplify the analysis, we study the case where this expenditure takes one of two values $\{g^L, g^H\}$, where $g^H >> g^L$ and $g_t$ evolves according to the following Poisson process:

$$g_{t+dt} = \begin{cases} g^H & w.p. \quad q_1 dt \quad \text{if } g_t = g^L, \\ g^L & w.p. \quad 1 - q_1 dt \quad \text{if } g_t = g^L, \\ g^L & w.p. \quad q_2 dt \quad \text{if } g_t = g^H, \\ g^H & w.p. \quad 1 - q_2 dt \quad \text{if } g_t = g^H. \end{cases} \tag{9}$$

At any point in time, this economy will be in one of two states of nature: in state-L, expenditure

[4] Although this is not necessary to study international reserves using this model, as Pina (2015) shows, this allows for a well defined target level of reserves. It also realistically captures the interest rate differentials that private and public agents face in developing countries.

is low; in state-H, expenditure is high. We think of L-periods as normal economic times, and H-periods as crisis periods. A crisis occurs with probability $q_1$, and once it occurs, it is over with probability $q_2$. In this paper, we do not distinguish between debt, banking or currency crisis. Empirically, these crises come associated with costs for the central bank and the government as Burnside et al. (2001), Burnside et al. (2006) and Laeven and Valencia (2013) show.

Because the consumer demands real money balances, the central bank can tax the consumer through inflation. The revenues from money creation $\frac{\dot{M}_t}{P_t}$ can be used to pay for $g_t$ or to accumulate reserves $r_t$. The external budget constraint of the central bank is given by:

$$\dot{r}_t = \phi r_t + \frac{\dot{M}_t}{P_t} - g_t. \tag{10}$$

In exchange for financing $g_t$ the central bank gets domestic debt ($b_t$), either issued by the government or by financial institutions.[5] The balance sheet of the central bank is then given as:

$$b_t + r_t = m_t, \tag{11}$$

where we assume that the net worth of the central bank is zero. Replacing the balance sheet given by equation (11) into the external constraint of the central bank given by equation (10), we can obtain:

$$\dot{b}_t = \phi b_t + g_t - (\pi_t + \phi_t)\, m_t. \tag{12}$$

We focus on the problem of a central bank that is constrained to have positive reserves. In other words, we assume that $r \geq \underline{r} = 0$.

The problem of the central bank is to choose the inflation rate $\pi_t$ to maximize the consumer's utility given that this interest rate influences consumption decisions of the representative consumer. The central bank can affect the domestic nominal interest rate through inflation $\pi_t$. This problem can be summarized as follows:

[5]This variable can also be interpreted as domestic credit. I assume that these assets are indexed to inflation to avoid any incentive of the central bank to reduce their real value with inflation.

$$
\begin{aligned}
& max_{\{i_t\}} \int_0^\infty log\left(\frac{\rho a_0 + y}{1+i_t}\right) e^{-\rho t} dt, \\
& \text{s.t. } \dot{b_t} = \phi b_t + g_t - \frac{i_t + \phi_t - \rho}{1+i_t}\left(\rho a_0 + y\right), \\
& \quad i_t \geq 0, r_t \geq 0, g_t \text{ given by } (9), \\
& \quad lim_{T\to\infty} b_T e^{-\rho T} = 0.
\end{aligned}
$$

## 2.2 Solution

Appendix B shows that the solution to this problem is given by a system of two differential equations, where we omit time subscripts for simplicity:

$$
\frac{\partial i^L}{\partial b} = \frac{(\rho - \phi)\left(1 + i^L\right) + q_1\left(i^L - i^H\right)}{\phi b + g^L - \frac{i^L + \phi - \rho}{1+i^L}\left(\rho a_0 + y\right)}, \tag{13}
$$

$$
\frac{\partial i^H}{\partial b} = \frac{(\rho - \phi)\left(1 + i^H\right) + q_2\left(i^H - i^L\right)}{\phi b + g^H - \frac{i^H + \phi - \rho}{1+i^H}\left(\rho a_0 + y\right)}. \tag{14}
$$

Together with the boundary conditions:

$$
lim_{b\to -\infty} i^j(B) = -1, j = L, H \tag{15}
$$

$$
\phi\bar{b} + g = \frac{i^{\bar{H}} + \phi - \rho}{1 + i^{\bar{H}}}\left(\rho a_0 + y\right) \tag{16}
$$

$$
\bar{b} = \frac{\rho a_0 + y}{1 + i^{\bar{H}}} \tag{17}
$$

The boundary conditions in the high state given by equations (16)-(17) play an important role in our analysis. They put limits on $i^H$ and $b$ when approaching from below $\bar{b}$, as a consequence of the constraint on reserves that $r \geq 0$. The central bank can only manage inflation and the nominal interest rate up to this constraint. When the central bank runs out of reserves at $\bar{b_t}$, it is forced to rely completely on inflation to obtain the necessary funds, and the interest rate is given by $i_t^{\bar{H}}$. We can further simplify these two conditions:

$$i^{\bar{H}} = \frac{\rho\left(\rho a_0 + y\right) + g}{\rho a_0 + y - g}, \tag{18}$$

$$\bar{b} = \frac{\rho a_0 + y - g}{1 + \rho}. \tag{19}$$

Furthermore, note that holdings of international reserves are represented as:

$$r_t = m_t - b_t, \tag{20}$$

where $m_t = \frac{\rho a_0 + y}{1 + i_t}$. We define accumulation of international reserves net of interest earned as reserve transfers $RT_t$:

$$RT_t = \dot{r_t} - \phi_t r_t. \tag{21}$$

We are now ready to present the main results from the model. Before deriving analytical results we use a numerical example to develop intuition. Figure 2 plots the solution of the model described by equations (13)-(17) for an example parametrization. The top panel plots the inflation rate during normal times ($i^L$, solid blue line) and crises ($i^H$, dashed red line) against the level of reserves as a share of GDP. We also refer to these as the managed inflation rates.

Also plotted are the inflation rates for which $\dot{b_t} = 0$ in both states, which we refer to as the flexible inflation rates. The bottom panel plots reserve transfers during normal times ($RT^L$, solid blue line) and crises ($RT^H$, dashed red line) against the level of reserves as a share of GDP. Also plotted is a line where $RT = 0$.[6]

Focus first on normal periods, represented by the solid blue lines in both panels. We can see that, during normal times, managed inflation is larger than the flexible inflation rate as long as reserves are below their target level. This higher inflation translates into an accumulation of international reserves and is decreasing with the level of reserves. Below this target level of re-

[6] Details for the numerical solution are available in Appendix B.

serves, reserve transfers are positive and also decreasing. In normal times, inflation and reserve transfers are positively correlated. When a crisis hits, for any level of international reserves, the inflation rate goes up and the central banks spends previously accumulated international reserves. Reserve transfers are now negative as inflation is higher. On impact, inflation and reserve transfers are negatively correlated. As the central bank spends international reserves, inflation is increasing while reserve transfers are approach zero.

We turn now to the analytical results. In particular, we first show that there exists a target level of reserves in normal times as implied by $\dot{b}_t^L = \dot{r}_t^L = \dot{m}_t^L = 0$.

**Proposition 1** *There exists a domestic debt level $b_s$ such that*

- *In state-L if $b_t > b_s$, the central bank increases the level of international reserves and $\dot{b}_t^L < 0$, but if $b_t < b_s$, the central bank decreases reserves and $\dot{b}_t^L > 0$.*
- *If $b_t = b_s$, $\dot{b}_t^L = \dot{r}_t^L = \dot{m}_t^L = 0$.*
- *In state-H the central bank always reduces the level of international reserves as long as $b_t < \bar{b}$.*

**Proof.** The proof is presented in Appendix B. ■

This result establishes the existence of a target level of international reserves in state-L that balances the central bank's impatience with the need to finance costly financial crises. Note that we have solved the model assuming there is a borrowing constraint on how many reserves a central bank can have access to in a crisis. One important difference between developing and developed economies is that central banks in developed economies had access to short-term financing in foreign currency from other central banks, in the form of swap arrangements (See Obstfeld et al. (2009) and Aizenman et al. (2011)).[7]

We can now study how this results affects reserve transfers. Reserve transfers are given by $RT_t = \dot{r}_t - \phi r_t$. Replacing $\dot{r}_t$ we obtain:

$$RT_t = \dot{m}_t + \frac{\pi_t (\rho a_0 + y)}{1 + \pi_t + \rho} - g_t. \tag{22}$$

[7]Pina (2015) discusses how this important difference between developed and developing economies affects the growth of international reserves.

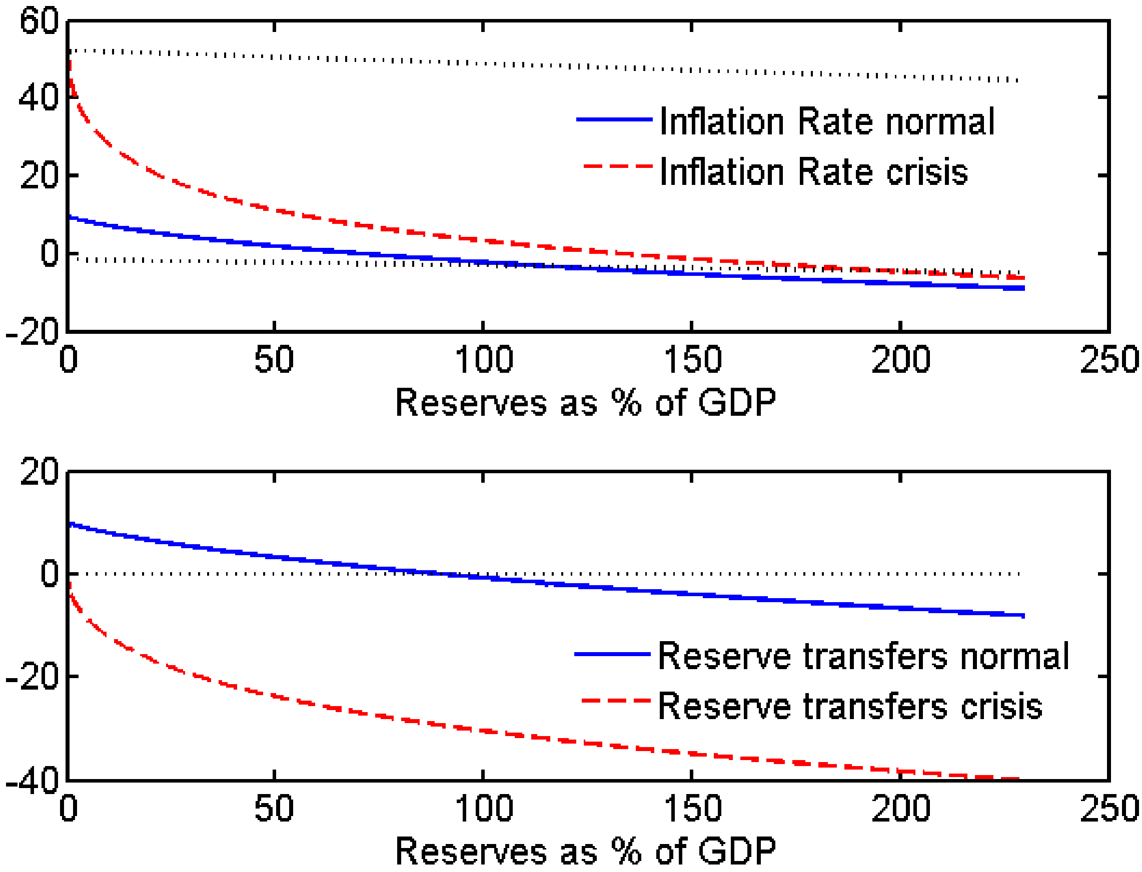


Figure 2: The top panel plots the inflation rate during normal times ($i^L$, solid blue line) and crises ($i^H$, dashed red line) against the level of reserves as a share of GDP. Also plotted are the flexible inflation rates for which $\dot{b}_t = 0$ in both states. The bottom panel plots reserve transfers during normal times ($RT^L$, solid blue line) and crises ($RT^H$, dashed red line) against the level of reserves as a share of GDP. Parameters used: $\phi = 0.015$, $q_1 = 10\%$, $q_2 = 50\%$, $y = 1$, $g^H = 0.35y$, $g^L = 0$, $\rho = 0.02$.

In normal times, $g_t$ and $\dot{m}_t$ are small, and the correlation between $RT$ and $\pi_t$ is positive. In crises however, $g_t$ is large. Furthermore, the central bank increases the inflation rate which depresses consumption and the demand for real money balances, making $\dot{m}_t$ negative. Then, the correlation between $\pi_t$ and $RT_t$ turns negative.[8]

For a given interest rate $\phi$, $g$ and $y$ the model implies that reserve transfers are decreasing if below the target level of reserves. One interesting aspect of studying reserve transfers is that they do not depend qualitatively on the levels of desired reserves by each country. In the next section, we study how shocks to the interest rate affect reserves in the long-run.

## 2.3 Shocks to returns to interest earning assets

In this section we focus the analysis on shocks to $\phi$. Given that our interest is in the long-run, we focus our analysis on the target level of reserves. Consider two levels for $\phi$, $\phi^L < \phi^H < \rho$. Suppose the economy is initially in a low interest rate environment. The previous section showed that conditional on interest rates being constant, in normal times reserves transfers are decreasing when reserves are below the target level. They are increasing when reserves are above the target level. In crisis times, reserve transfers are always increasing. Figure 3 shows that, in normal times, an interest rate increase will lead to an increase in reserve transfers. In crisis times, an increase in the interest rate will also lead to an increase in reserve transfers, but this effect is smaller the closer the central bank approaches the lower bound on reserves. In other words, the model predicts a relationship between changes in interest rates and reserve transfers, in particular, that exogenous changes in interest rates should cause an increase in reserve transfers. The intuition behind this result is that higher interest rates make it easier to sustain a larger long-run level of international reserves, as everything else equal, they make international reserves less costly. In the next section, we test this relationship using a panel data set of emerging countries.

[8] For small $g_t$ and $\dot{m}_t$, $\frac{\partial RT}{\partial \pi} = \frac{X_t(1+\rho)}{(1+\pi+\rho)^2} > 0$, and higher inflation translates into higher $RT$. For high $g_t$ and negative $\dot{m}_t$, $RT$ is negative even though $\pi_t$ is positive.

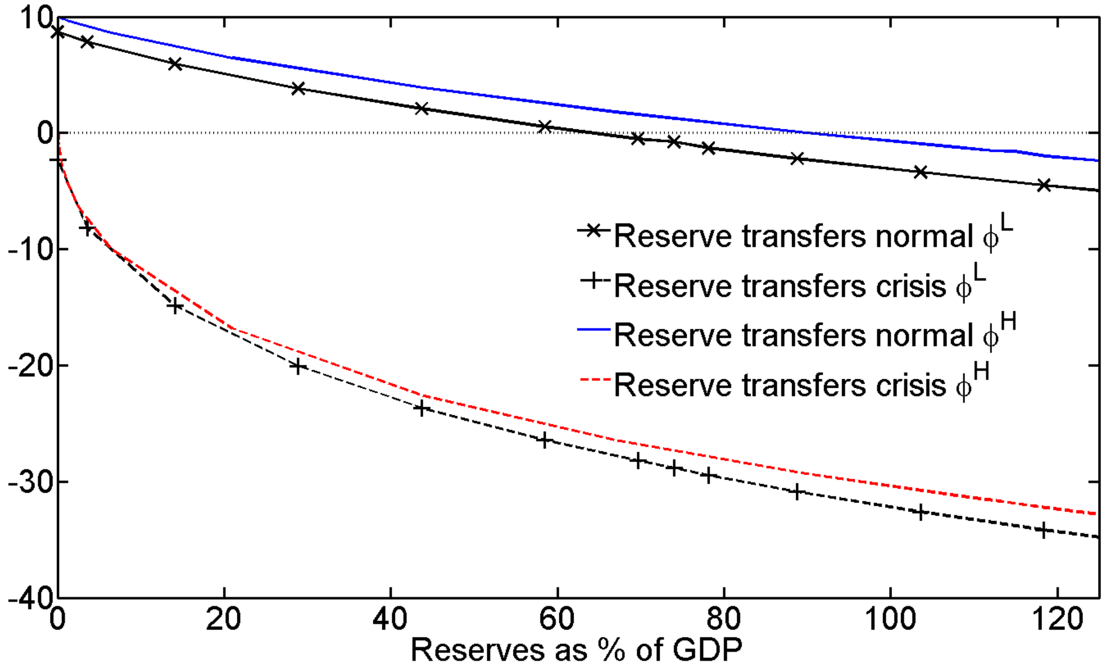


Figure 3: This graph plots reserve transfers during normal times for low and high interest rates against the level of reserves as a share of GDP. Also plotted are reserve transfers during crises for low and high interest rates. Parameters used: $\phi^L = 0.0125$, $\phi^H = 0.015$, $q_1 = 10\%$, $q_2 = 50\%$, $y = 1$, $g^H = 0.35y$, $g^L = 0$, $\rho = 0.02$.

# 3 Empirics

In this section we evaluate empirically how shocks to the interest rate of foreign currency reserve assets affect international reserve accumulation. Given that these returns have a direct impact on international reserves accumulation, we focus on international reserve transfers. International reserve transfers are defined as the change in international reserves minus interest income and are therefore not mechanically affected by interest rate shocks. We take the perspective that fluctuations in interest rates of foreign currency international reserve assets are exogenous for developing economies and that central banks are actively managing their reserve stocks. Building on this perspective, we can then identify the impact of interest rate shocks on reserve transfers by exploring cross-country and within-country variation in exposure to interest rate shocks. To do so, we use data on the composition of foreign currency international reserves into different types of assets and denominations. We combine this data with relevant interest rates for different type of asset and denominations, and use it to investigate empirically if the mechanism identified in the model is a feature of the data.

## 3.1 Measuring reserve transfers

We follow Dominguez et al. (2012) and use the naming conventions from the IMF's Special Data Dissemination Standard (SDDS) Reserve template. Let the stock of international reserves be given by:

$$IR_t = ForexR_t + Gold_t + SDR_t + IMF_t + Other_t, \tag{23}$$

where $ForexR = SEC_t + DEPO_t$ are international foreign currency reserves that can be held as securities or deposits, $Gold_t$ represents gold holdings, $SDR_t$ represents country holdings of Special Drawing Rights, $IMF$ captures the country's position with the IMF, while $Other$ captures other reserve assets. Total reserves can grow from purchases of foreign currency assets, interest earned on existing assets, capital gains on existing assets and increases in non-currency asset holdings. Then, the change in reserves is given by:

$$\Delta IR_t = \Delta ForexR + \Delta NonCR, \tag{24}$$

where $\Delta NonCR = \Delta Gold + \Delta SDR + \Delta IMF + \Delta Other$ represent non-currency reserves. We focus our empirical analysis on foreign currency reserves $ForexR$ as they capture the type of liquid assets that central banks are more likely to use in the event of a crisis, as motivated by our model. An additional reason to focus on foreign currency reserves is that Dominguez (2012) shows that Non-currency reserves do not change frequently. We can then decompose data on international foreign currency reserve changes as:

$$\Delta ForexR = \phi^s SEC + \phi^d DEPO + \Delta\widehat{SEC} + \Delta\widehat{DEPO}, \tag{25}$$

where, $\Delta\widehat{SEC} + \Delta\widehat{DEPO}$ represent non-interest related changes to holdings of international reserves.[9]

We can see from equation (25) that there is a direct impact of interest rates for securities and deposits/currency on $\Delta ForexR$. In order to study if interest rate shocks affect the long-run level of international foreign currency reserves and their accumulation, we focus on reserve transfers, that is, international reserves net of interest earned on reserves:

$$\begin{aligned} ForexRT &= \Delta ForexR - \Big(\phi^s SEC + \phi^d DEPO\Big) \\ &= \Delta\widehat{SEC} + \Delta\widehat{DEPO}. \end{aligned}$$

According to the model presented in the previous section, increases in $\phi^s$ or $\phi^d$ should lead to an increase in $ForexRT$. Data on $\Delta ForexR$ can be readily obtained from the Special Data Dissemination Standard (SDDS) Reserve template, which also provides aggregate quarterly data on $SEC$ and $DEPO$ for each country. The biggest challenge is to measure the relevant

[9] Dominguez et al. (2012) further decomposes $\Delta\widehat{SEC} + \Delta\widehat{DEPO}$ into two components, one representing active management from net purchases of securities and deposits, and the other from valuation changes in existing securities and deposits: $\Delta\widehat{SEC} + \Delta\widehat{DEPO} = \Delta^{PS}SEC + \Delta^{PS}DEPO + \Delta^{VAL}SEC + \Delta^{VAL}DEPO$. In this paper, we are not focusing on the impact of intervention on output or exchange rates and therefore we do not distinguish between passive and active reserve management.

interest rates as they depend on the choice of currencies and assets by central banks, for which we have only approximate information. We turn to the measurement of interest earned and interest rate shocks in the next section.

## 3.2 Measurement of interest and interest rate shocks

In this section we measure interest earned on reserve assets and the relevant interest rate shocks for the countries in our sample. We take the perspective that country-specific factors determine the choice of currencies and maturities in which central banks accumulate international reserves.[10] Although data on the decomposition between securities and deposits/currency is available from the SDDS, unfortunately we do not have country specific information for the currency composition of these assets for the full sample, nor for the exact assets held by each country. Therefore, we construct two different measures of country specific interest rate shocks as proxies.

To proxy for returns to securities and returns to deposits we follow Dominguez et al. (2012) and collect 10-year government bond yields and 3-month inter-bank yields for the United States, Japan, Great Britain and the Euro-area.[11] The first measure follows Dominguez et al. (2012). We use the Currency Composition of Official Foreign Exchange Reserves (COFER) database to obtain currency weights for two groups of countries: "advanced"' and "'emerging and developing economies"'. We combine this data, data on asset composition from SDDS and returns for securities and deposits for four main reserve currencies to compute the country-specific interest rate as follows:

[10] Lim (2007) shows that exchange rate fluctuations lead to portfolio re-balancing, such that reserve currency shares are relatively stable. Beck and Rahbari (2011) study optimal central bank currency portfolios in a minimum variance framework with sudden stops. They find that the US dollar is a better hedge against sudden stops in Asia and Latin American, while the Euro is superior in Emerging Europe. Wooldridge (2006) documents that the composition of international reserve assets has changed within countries, both in terms of composition and currency denomination.

[11] We obtain this data from the respective central banks: Long-Term Government Bond Yields: 10-year: Main (Including Benchmark) for the United States, Long-Term Government Bond Yields: 10-year: Main (Including Benchmark) for the Euro Area, Long-Term Government Bond Yields: 10-year: Main (Including Benchmark) for the United Kingdom, Long-Term Government Bond Yields: 10-year: Main (Including Benchmark) for Japan, 3-Month London Interbank Offered Rate (LIBOR) based on U.S. Dollar, EURIBOR 3 Months (Daily), 3-Month London Interbank Offered Rate (LIBOR) based on British Pound and Call Rates, Uncollateralized 3 Months/End of Month for Japan.

$$interest_{i,t} = 100 \frac{\sum_c \left( w_{t,c}\phi^s_{t,c} SEC_{i,t} + w_{t,c}\phi^d_{t,c} DEPO_{i,t} \right)}{ForexR_{i,t}}, \tag{26}$$

where $i$ represents country, $c = USD, EUR, GBP, YEN$, $w_{t,c}$ captures each currency weight at time $t$ and $\phi^j_{t,c}$ captures the interest rate on asset $j = s, d$, at time $t$ for currency $c$.

Variation in this interest rate captures different holding patterns between securities and deposits/currency across countries and within countries, but note that variation in currency denomination is exclusively between "advanced"' and "'emerging and developing economies"'. Figure 4 plots yields for one unit of foreign currency international reserves held as securities (10-year) and deposits/currency (3-month) weighted by currency share for developed and emerging and developing economies. This figure shows that variation in currency composition between the two types of countries is small. In the empirical specifications, we will focus on within variation in reserve transfers and explore how interest rate shocks affect reserve transfers after controlling for country fixed effects. We cluster standard errors at the country level in all regressions. Using this approach we can compute interest earned on reserve assets $\left(\widehat{\phi^s} SEC + \widehat{\phi^d} DEPO\right)$ and obtain foreign currency international reserve transfers $ForexRT = \Delta ForexR - \left(\widehat{\phi^s} SEC + \widehat{\phi^d} DEPO\right)$. We can also obtain the relevant interest rates for each country. Combining this data, we obtain quarterly data between 2000 and 2014 for 75 countries which we classify as advanced or developing according to the World Economic Outlook (WEO).[12]

Our alternative specification uses data from Wong (2007) for 23 countries for which we can obtain the currency breakdown in international reserve holdings for 2005. We assume that these weights are constant throughout our sample and compute:[13]

[12]Developing countries: Argentina, Armenia Republic, Belarus, Brazil, Bulgaria, Chile, China, P.R.: Hong Kong, Colombia, Costa Rica, Croatia, Cyprus, Czech Republic, Dominican Republic, Egypt, El Salvador, Estonia, Georgia, Guatemala, Honduras, Hungary, India, Indonesia, Jordan, Kazakhstan, Korea Republic, Kyrgyz Republic, Latvia, Lithuania, Macedonia, FYR, Malaysia, Mauritius, Mexico, Moldova, Morocco, Nicaragua, Peru, Philippines, Poland, Romania, Russian Federation, Seychelles, Singapore, Slovak Republic, Slovenia, South Africa, Thailand, Tunisia, Turkey, Ukraine and Uruguay. Advanced: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States

[13]The countries we can use this data for are Australia, Bulgaria, Canada, China, P.R.: Hong Kong, Colombia, Croatia, Finland, Germany, Iceland, Latvia, Lithuania, New Zealand, Norway, Philippines, Romania, Slovak Republic, Slovenia, Sweden, Switzerland, United Kingdom, United States, Uruguay. As described in Wong (2007) some data is missing and for some countries. We use data for the closest year when data for 2005 is not available. For

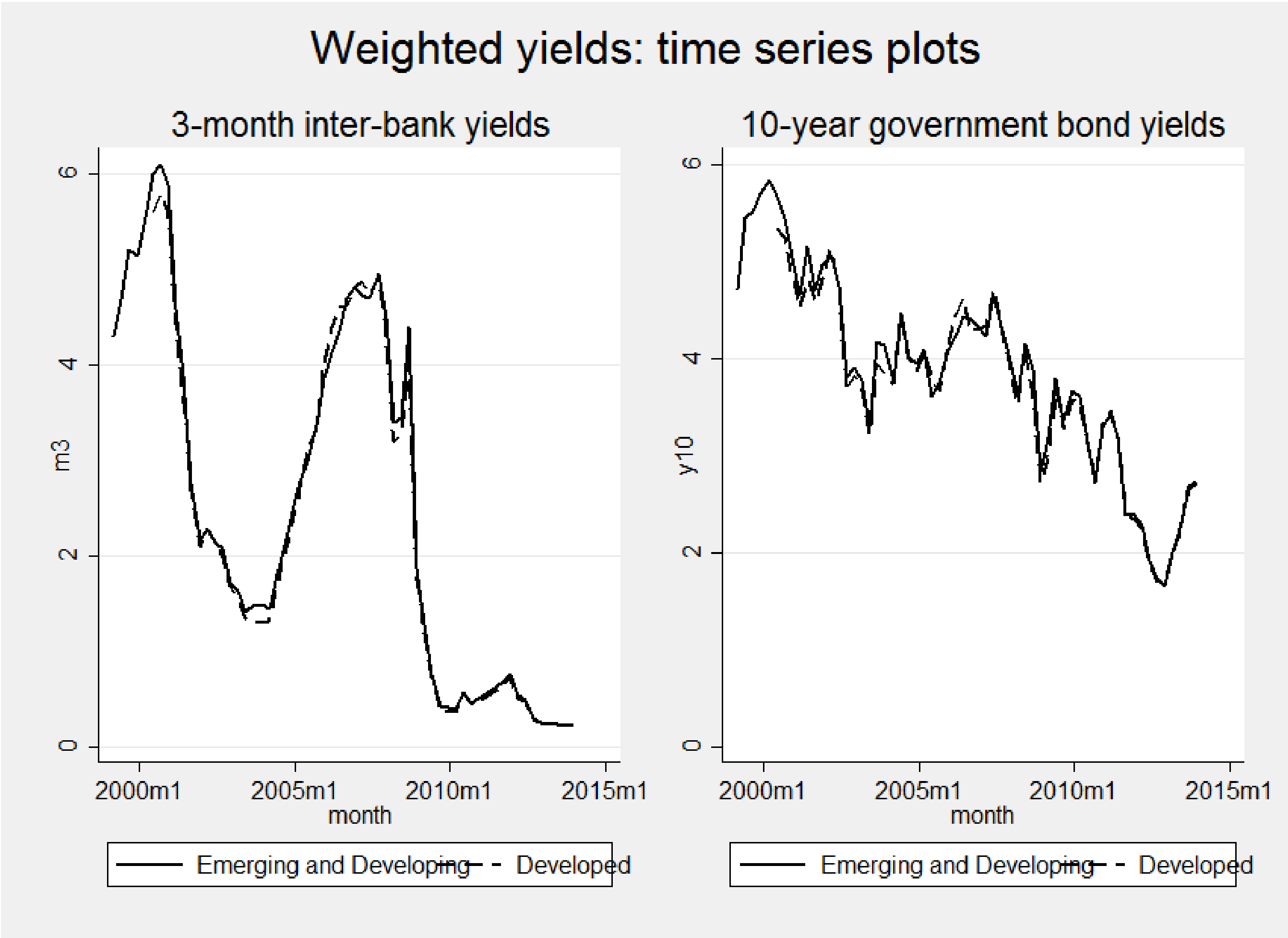


Figure 4: This figure plots yields for one unit of foreign currency international reserves held as securities (10-year) and deposits/currency (3-month) weighted by currency share for developed and emerging and developing economies.

$$interest_{i,t}^{Alt} = 100 \frac{\sum_c \left( \widetilde{w}_{i,2005,c} \phi_{t,c}^{s} SEC_{i,t} + \widetilde{w}_{i,2005,c} \phi_{t,c}^{d} DEPO_{i,t} \right)}{ForexR_{i,t}}, \tag{27}$$

where $c = USD, EUR, GBP, YEN$ and $\widetilde{w}_{i,2005,c}$ captures a country-specific currency weight in 2005. This alternative measure of interest rates includes cross-country variation in currency denomination. We present pooled regressions with standard errors clustered at the country level, but results with country fixed effects are similar.

Peru, we do not have data on euro, yen and other currency shares.

### 3.3 Data

Table 1 summarizes the data. Figures 5 - 7 plot the time series of the variables of interest for countries in our sample. The shaded area represents the global financial crisis for each country, measured as the peak-to-through seasonally adjusted real GDP for the period after 2007 as in Dominguez et al. (2012). Figure 5 plots transfers and interest rates for two developed economies. Looking at Australia, it is possible to see that, with the exception of late 2007, reserve transfers are relatively stable and close to zero, even though interest rates fluctuate substantially. Turning to Japan, a similar pattern holds. With the exception of early 2004, reserve transfers are small and stable. Turning to the developing world, Figure 6 shows that for Peru and Latvia reserve transfers fluctuate much more. These countries also demonstrate the importance of controlling for the effects of the global financial crisis, as reserve transfers turn negative during this period. Turning to the relationship between reserve transfers and interest rates, it is possible to note that reserve transfers are larger when interest rates are increasing. Note that this holds even before the global financial crisis. In Peru, the increase in interest rate increase following 2005 is associated with a higher level of transfers. In both countries, the period after the crisis is associated with lower reserve transfers. Finally, Figure 7 shows that these patterns are similar for the Philippines, but for Korea interest rates are less important in driving the behavior of reserve transfers. In the next sections we test for the relationship between interest rates and international reserve transfers using a quarterly panel of countries.

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Year-Quarter | 3136 | | | 2000Q2 | 2013Q4 |
| Reserve transfers % GDP | 3136 | -0.08% | 1.65% | -20.4% | 17.4% |
| Interest rate | 3136 | 3.10% | 1.12% | 0.23% | 5.91% |
| Interest rate alternative | 1101 | 3.12% | 1.02% | 0.23% | 6.13% |

Table 1: Summary Statistics for quarterly data

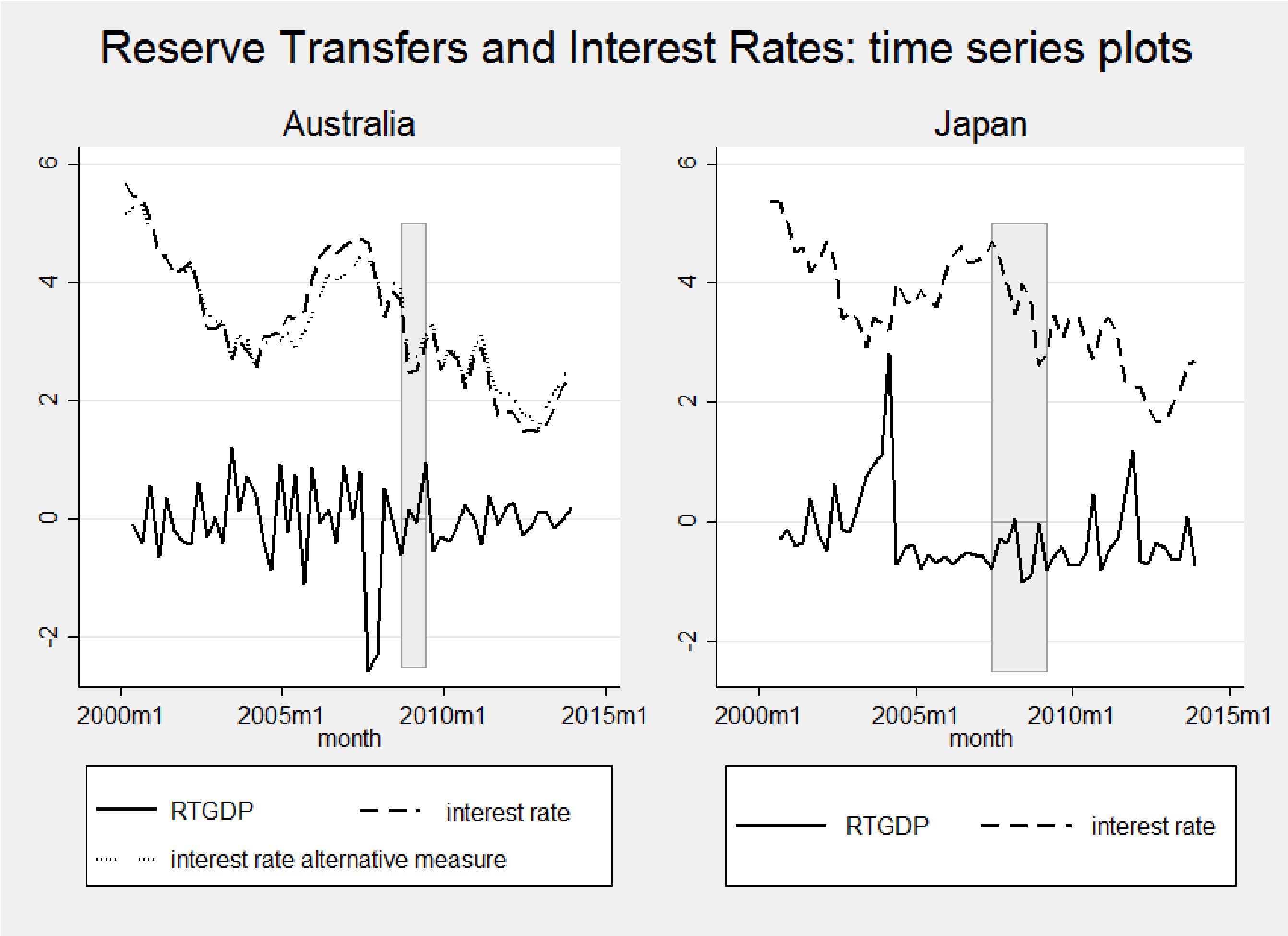


Figure 5: This figure plots foreign currency international reserves transfers as a share of GDP (RTGDP) and two measures of effective interest rates on foreign currency international reserves. The shaded area represents the global financial crisis for each country, measured as the peak-to-through seasonally adjusted real GDP for the period after 2007.

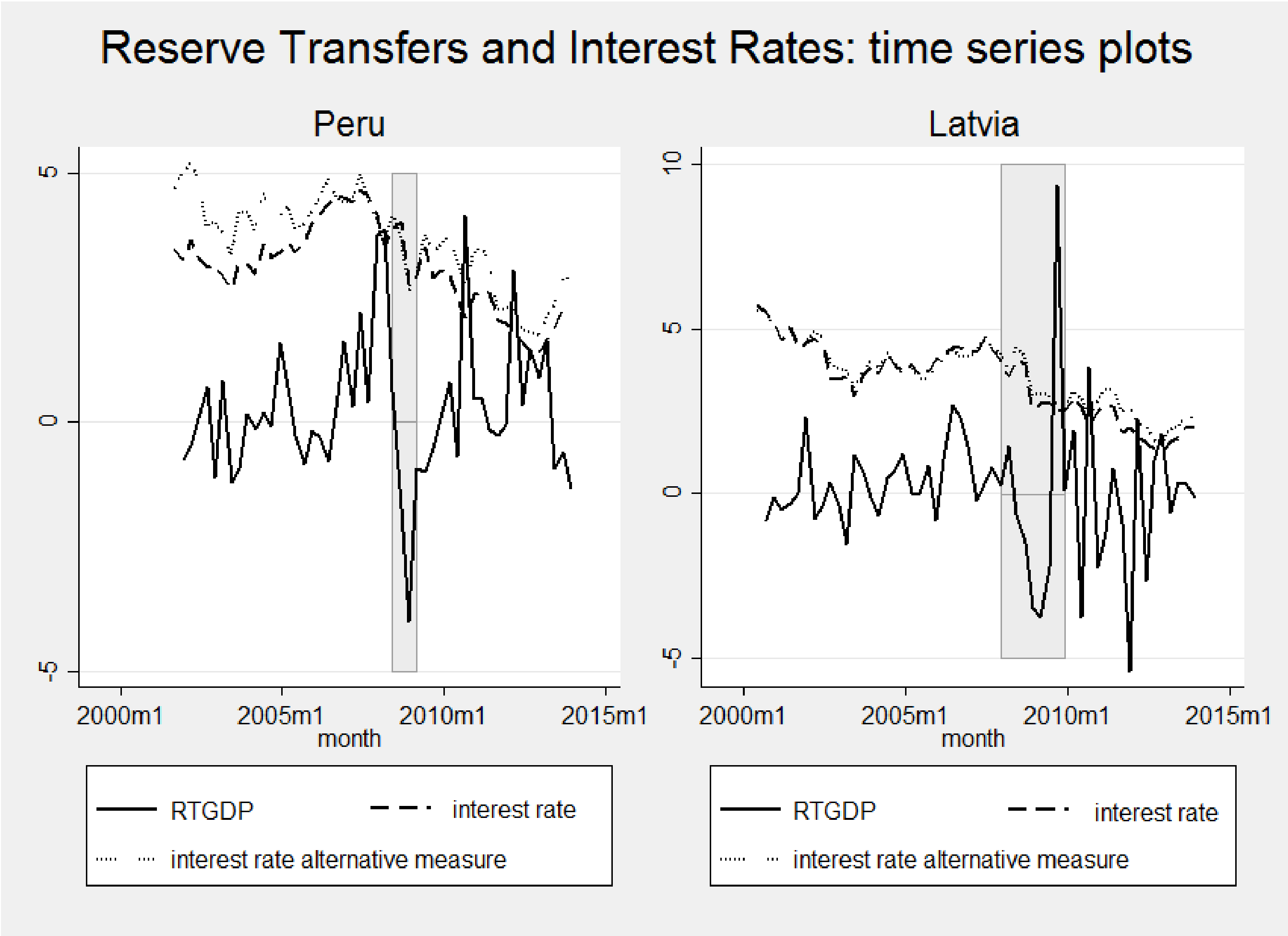


Figure 6: This figure plots foreign currency international reserves transfers as a share of GDP (RTGDP) and two measures of effective interest rates on foreign currency international reserves. The shaded area represents the global financial crisis for each country, measured as the peak-to-through seasonally adjusted real GDP for the period after 2007.

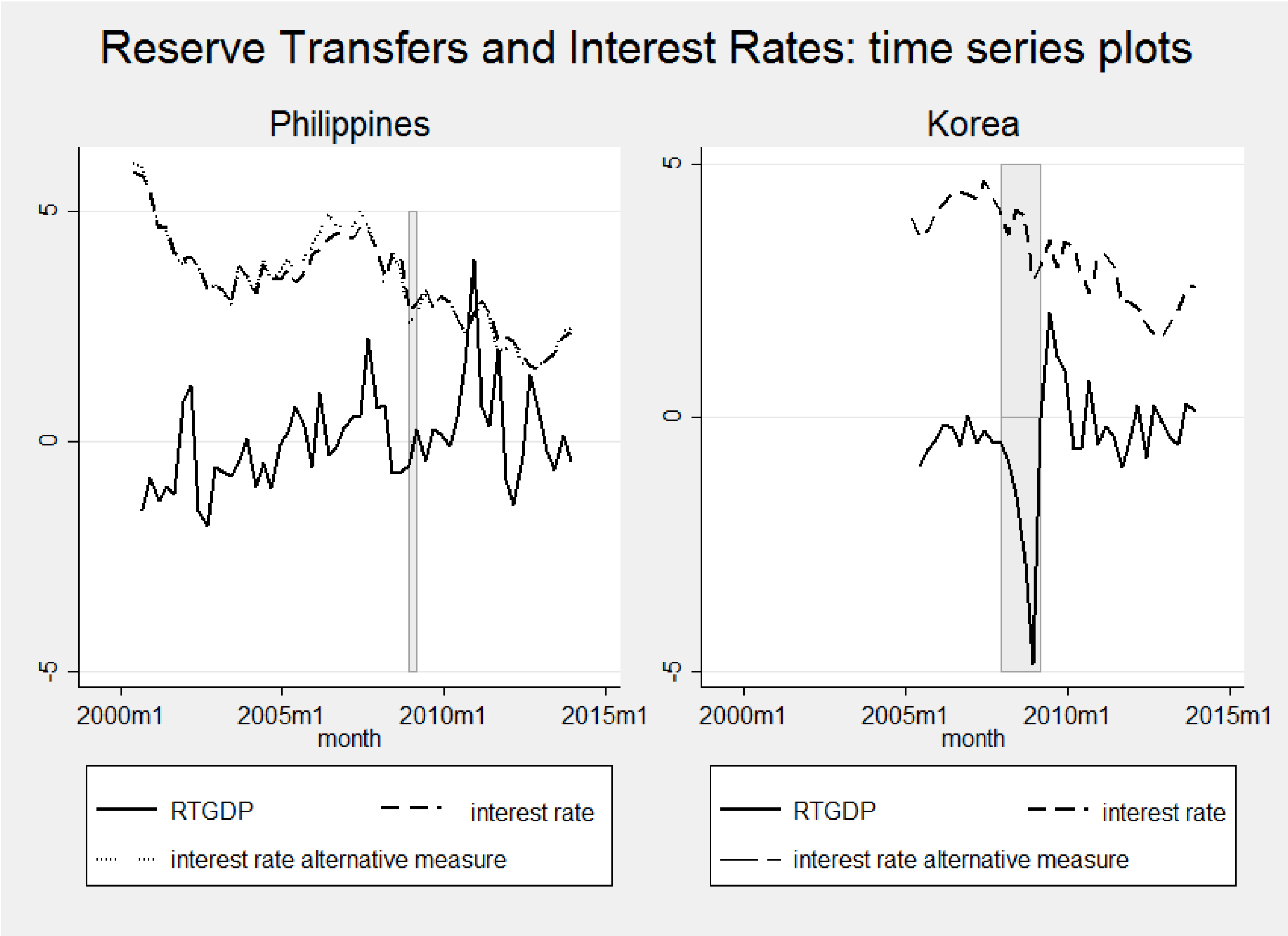


Figure 7: This figure plots foreign currency international reserves transfers as a share of GDP (RTGDP) and two measures of effective interest rates on foreign currency international reserves. The shaded area represents the global financial crisis for each country, measured as the peak-to-through seasonally adjusted real GDP for the period after 2007.

## 3.4 Empirical strategy

To study the relationship between foreign currency international reserve transfers and interest rates, we employ variations of the following regression:

$$\frac{ForexRT_{i,t}}{GDP_{i,t}} = \alpha_i + \psi_t + \beta \Delta interest_{i,t-1} + \gamma Crisis_{i,t} + \epsilon_{i,t} \tag{28}$$

where $\frac{ForexRT}{GDP}_{i,t}$ represents foreign currency international reserve transfers as a share of $GDP$ for country $i$ in quarter $t$, $\alpha_i$ captures time-invariant country fixed effects, $\psi_t$ captures time fixed effects, $\Delta interest_{i,t-1}$ captures interest rate changes as described in the previous section, and $Crisis_{i,t}$ is a country-specific dummy variable that takes on a value 1 if country $i$ is in a crisis period in quarter $t$. This crisis dummy is constructed based on peak-to-through seasonally-adjusted real GDP for the period after 2007 as in Dominguez et al. (2012), and is motivated by the dramatic decreases in reserves during country specific crisis as shown in Figures 5 - 7. We will also consider the role of a global dummy that captures the US financial crisis in this period. The coefficient $\beta$ measures the impact of changes in interest rate between $t$ and $t-1$ on reserve transfers at $t$. Note that reserve transfers captures reserve accumulation not coming from interest earned, but from net purchases or valuation effects of foreign currency international reserves.[14]

This regression is potentially subject to endogeneity concerns and therefore the results should be interpreted with caution. One of these concerns is that reserve accumulation in developing economies causes low interest rates in developed economies. Another of these concerns is that interest rate changes may be associated with the valuation channel of international reserve accumulation. This could be a problem if the central bank is passively managing international foreign currency reserves, as increases in interest rates would mechanically affect reserve transfers through the valuation channel. Note that this would not be a concern if the central bank is actively managing international foreign currency reserves, as net purchases

[14]We also perform an alternative regression where we include country specific time trends $\psi_c$.

$$\frac{ForexRT_{i,t}}{GDP_{i,t}} = \alpha_i + \beta \Delta interest_{i,t-1} + \psi_c t + \gamma Crisis_{i,t} + \epsilon_{i,t} \tag{29}$$

would adjust to keep reserve transfers at the desired level following valuation shocks. To reduce concerns about reserve causation, we look at lagged changes in interest rates, such that $\beta$ measures the impact of changes in interest rates between $t-1$ and $t-2$ on reserve transfers at $t$. If asset price valuations of foreign currency international reserves are determined by interest rate shocks, these effects should be contemporaneous and not captured by lags.[15]

### 3.5 Results

Columns (1) - (4) in Table 2 collect the results for the regression specification given by equation (28), with country fixed effects, while column (5) collects the results for the regression specification given by equation (29), with country-specific time-trends and country fixed effects. We can see in Column (1) from Table 2 that interest rate changes are positively associated with reserve transfers, and this effect is statistically different from zero at the 5% level. In Column (2) - (5) we interact our variable of interest with a dummy variable that takes on the value of 1 if the country is an advanced economy. The coefficient $\beta$ for developing countries, reported in line (1) increases in magnitude but is less finely estimated. In Column (3) we control for country specific crises as defined in the previous section. Column (4) adds year fixed effects, while Column (5) reports results with country-specific time-trends. The coefficient of interest for developing economies is positive, although not very precisely estimated for some of our specifications. Looking at column (2), the interpretation of the coefficient is that a 1 percentage point increase in the interest rate of foreign currency international reserves is associated with a 0.19 percentage points increase in foreign currency international reserve transfers as a share of GDP.

Our sample covers the global financial crisis. We account for country specific drains in international reserve transfers associated with decreases in domestic real GDP, but the global financial crisis can also change the relationship between interest rates and international reserves. The period of extreme instability between the third quarter of 2007 and the first

[15]Note that if interest rate increases actually decrease asset valuations, this effect would go against the effect we are studying in this paper. Results with contemporaneous interest changes are qualitatively similar but slightly smaller and less precisely estimated. Results with an additional lag, that is, where we study the relationship between interest changes between $t-2$ and $t-3$ and reserve transfers at $t$ are of similar magnitude to the ones we present, but less precisely estimated.

quarter of 2009 poses a challenge as it represents a very large shock to all countries. Table 3 collects results of a regression where the coefficient of interest $\beta$ is interacted with a dummy variable that captures the period between the third quarter of 2007 and the first quarter of 2009. Once again, we can track our coefficient of interest in the first line. We see that the effect of interest rate changes is larger outside of this period of instability, and significantly different from zero at least the 10% level for all but the specification with country-specific time-trends. The coefficient on domestic global crisis is relatively unchanged.

In Table 4 we use our alternative measure of interest rates in a setting without country fixed effects, but keeping standard errors clustered at the country level. We omit from these regressions the United States, Germany and United Kingdom, as these are reserve currency countries, and are left with 20 countries for which we have larger variation on the currency denomination of international reserve assets. Note that the coefficient of interest in very similar to the full sample, suggesting that interest rate changes impact reserve transfers.

## 3.6 What will happen to reserve transfers when interest rates increase?

The prospective increase in interest rates in developed economies is one of the most significant near-future challenges for developing economies. Understanding how reserves relate to interest-rates is then of paramount importance. In this section we exploit our empirical strategy to understand what will happen to reserve transfers when interest rates increase. Answering this question is difficult by the exceptional time period that our sample covers, including a long global financial crisis and a post-crisis period with extremely low interest rates and different waves of unconventional monetary policy. To answer this question we look at another time period covered by our sample, where the world economy was doing well and when there were no crises, keeping country fixed effects. Note that Figure 4 shows that this period experienced significant fluctuations in relevant interest rates, potentially allowing us to capture interest rate fluctuations in normal times. We define the start of the global financial crisis as the third quarter of 2007. We also perform finer income and geographical break-downs of our

| Reserve Transfers$_{i,t}$ | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| $\Delta interest_{i,t-1}$ | 0.163** | 0.186* | 0.103 | 0.0901 | 0.0731 |
| | (0.0732) | (0.110) | (0.109) | (0.118) | (0.111) |
| Advanced | | -0.542* | -0.519* | -0.611** | -0.699** |
| | | (0.272) | (0.279) | (0.294) | (0.343) |
| Advanced # $\Delta interest_{i,t-1}$ | | -0.0625 | -0.0585 | -0.0846 | -0.0386 |
| | | (0.164) | (0.161) | (0.170) | (0.164) |
| Crisis$_{i,t-1}$ | | | -0.658*** | -0.895*** | -0.691*** |
| | | | (0.201) | (0.245) | (0.208) |
| Year Fixed Effects | | | | X | |
| Country-specific time-trends | | | | | X |
| Constant | -0.0672*** | 0.159 | 0.195 | -0.0437 | 0.0334 |
| | (0.00436) | (0.114) | (0.123) | (0.199) | (0.134) |
| Observations | 3,136 | 3,136 | 3,136 | 3,136 | 3,136 |
| R-squared | 0.002 | 0.003 | 0.014 | 0.028 | 0.047 |
| Number of countries | 75 | 75 | 75 | 75 | 75 |

Table 2: The dependent variable is Reserve Transfers as a % of GDP. The symbol # represents interacted variables. All regressions include country-fixed effects. Robust standard errors in parentheses clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1

| Reserve Transfers$_{i,t}$ | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| $\Delta interest_{i,t-1}$ | 0.243*** | 0.315** | 0.205* | 0.235* | 0.175 |
| | (0.0808) | (0.119) | (0.116) | (0.128) | (0.118) |
| Advanced | | -0.534* | -0.510* | -0.618** | -0.622* |
| | | (0.272) | (0.278) | (0.293) | (0.353) |
| Global Financial Crisis$_{USA,t}$ | 0.0165 | 0.0641 | 0.220 | 0.342* | 0.190 |
| | (0.0893) | (0.131) | (0.144) | (0.197) | (0.153) |
| Crisis$_{i,t}$ | | | -0.685*** | -0.712*** | -0.706*** |
| | | | (0.216) | (0.247) | (0.221) |
| $\Delta interest_{i,t-1}$# GFC$_{US,t}$ | -0.747*** | -1.174*** | -0.926** | -1.092*** | -0.914** |
| | (0.262) | (0.379) | (0.376) | (0.400) | (0.382) |
| Advanced # $\Delta interest_{i,t-1}$ | | -0.0625 | -0.0585 | -0.0846 | -0.0386 |
| | | (0.164) | (0.161) | (0.170) | (0.164) |
| Advanced # GFC$_{US}$ | | -0.125 | -0.0671 | -0.0683 | -0.0417 |
| | | (0.168) | (0.176) | (0.181) | (0.190) |
| Advanced # $\Delta interest_{i,t-1}$# GFC$_{US,t}$ | | 1.039** | 1.020** | 1.127** | 1.016** |
| | | (0.480) | (0.483) | (0.479) | (0.488) |
| Year Fixed Effects | | | | X | |
| Country-specific time-trends | | | | | X |
| Constant | -0.0720*** | 0.151 | 0.171 | -0.0372 | -0.0408 |
| | (0.00812) | (0.116) | (0.121) | (0.196) | (0.139) |
| Observations | 3,136 | 3,136 | 3,136 | 3,136 | 3,136 |
| R-squared | 0.005 | 0.008 | 0.019 | 0.033 | 0.052 |
| Number of countries | 75 | 75 | 75 | 75 | 75 |

Table 3: The dependent variable is Reserve Transfers as a % of GDP. The symbol # represents interacted variables. All regressions include country-fixed effects. Robust standard errors in parentheses clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1

| Reserve Transfers$_t$ | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| $\Delta interest_{t-1}$ | 0.225 | 0.325** | 0.189 | 0.259* | 0.145 |
| | (0.139) | (0.130) | (0.113) | (0.126) | (0.121) |
| $\Delta interest_{t-1}$#GFC$_{US}$ | | -0.802* | -0.563 | -0.668 | -0.476 |
| | | (0.408) | (0.469) | (0.547) | (0.477) |
| Global Financial Crisis$_{US}$ | | 0.137 | 0.321 | 0.477 | 0.346 |
| | | (0.174) | (0.241) | (0.451) | (0.249) |
| Crisis$_i$ | | | -0.855* | -0.876 | -0.991* |
| | | | (0.492) | (0.606) | (0.495) |
| Year Fixed Effects | | | | X | |
| Country-specific time-trends | | | | | X |
| Constant | -0.0708 | -0.0776 | -0.0417 | -0.121 | -0.179 |
| | (0.0757) | (0.0809) | (0.0809) | (0.167) | (0.216) |
| Observations | 990 | 990 | 990 | 990 | 990 |
| R-squared | 0.002 | 0.005 | 0.015 | 0.026 | 0.046 |
| Number of countries | 20 | 20 | 20 | 20 | 20 |

Table 4: The dependent variable is Reserve Transfers as a % of GDP. The symbol # represents interacted variables. Robust standard errors in parentheses clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1

| Reserve Transfers$_t$ | (1) | (2) | (3) |
|---|---|---|---|
| $\Delta interest_{t-1}$ | 0.0425 | | |
| | (0.0858) | | |
| Low income # $\Delta interest_{t-1}$ | | 1.498*** | 1.519*** |
| | | (0.111) | (0.115) |
| Lower and Upper Middle Income# $\Delta interest_{t-1}$ | | 0.240 | 0.181 |
| | | (0.161) | (0.162) |
| Advanced #$\Delta interest_{t-1}$ | | -0.0412 | -0.189* |
| | | (0.111) | (0.0945) |
| Year FE | | | X |
| Constant | -0.0879*** | -0.0919*** | -0.330* |
| | (0.00171) | (0.00248) | (0.178) |
| Observations | 1,265 | 1,265 | 1,265 |
| R-squared | 0.000 | 0.002 | 0.036 |
| Number of countries | 60 | 60 | 60 |

Table 5: The dependent variable is Reserve Transfers as a % of GDP. The symbol # represents interacted variables. All regressions include country-fixed effects. Robust standard errors in parentheses clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1

sample, based on the World Bank income groups and geographical groups.[16] Tables 5 and 6 show that the effects studied in this paper were more relevant for lower income economies and for Asian economies. Although these results should be interpreted with caution, if the relationship between reserve transfers and interest rates did not change in the last 10 years, a post-crisis world with higher interest rates should see increases in reserve transfers in these groups of countries.

[16]We have minor variations as for some groups we have very few observations. We lump lower and middle income groups, and we also lump South Asia (which was only India in our sample) with East Asia & Pacific.

| Reserve Transfers$_t$ | (1) | (2) | (3) |
|---|---|---|---|
| $\Delta interest_{t-1}$ | 0.0425 | | |
| | (0.0858) | | |
| Asia # $\Delta interest_{t-1}$ | | 0.468* | 0.260 |
| | | (0.254) | (0.239) |
| Europe & Central Asia# $\Delta interest_{t-1}$ | | -0.688** | -0.666* |
| | | (0.336) | (0.341) |
| Industrial# $\Delta interest_{t-1}$ | | -0.414 | -0.339 |
| | | (0.261) | (0.261) |
| Latin America & Caribbean# $\Delta interest_{t-1}$ | | -0.221 | -0.222 |
| | | (0.295) | (0.304) |
| Middle East & North Africa # $\Delta interest_{t-1}$ | | -0.980 | -0.827 |
| | | (0.947) | (0.916) |
| Sub-Saharan Africa# $\Delta interest_{t-1}$ | | -0.0753 | -0.128 |
| | | (0.254) | (0.277) |
| Year FE | | | X |
| Constant | -0.0879*** | -0.0919*** | -0.330* |
| | (0.00171) | (0.00248) | (0.178) |
| Observations | 1,265 | 1,265 | 1,265 |
| R-squared | 0.000 | 0.002 | 0.036 |
| Number of countries | 60 | 60 | 60 |

Table 6: The dependent variable is Reserve Transfers as a % of GDP. The symbol # represents interacted variables. All regressions include country-fixed effects. Robust standard errors in parentheses clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1

# 4 Conclusion

This paper has presented a framework to think about the relationship between foreign currency international reserves and interest rate fluctuations on the assets kept as reserves. In the model, we have focused on the problem of the central bank that wishes to smooth inflation but faces shocks to demands on its foreign liquidity. We show that increases in interest rates are associated with increases in reserve transfers (defines as international reserve changes minus interest earned on reserves). The model highlights how this relationship works through changes in interest rates, and not through the level of interest rates. Turning to the empirics, we used data on currency denomination and asset composition of foreign currency international reserves to identify shocks to interest rates earned by different countries on their foreign currency international reserves. We document that between 2000 and 2014, changes to interest rates are positively associated with reserve transfers, as predicted by the model.

We have taken the perspective that interest rate shocks are exogenous and unexpected to developing economies. We could solve for a more complicated model with expected interest rate shocks. The solution would fall inbetween the two long-run solutions we have focused on, but some interesting insights on changing probabilities of future rates could be obtained. On the empirical side, it would be interesting to extract shocks to interest rates in developed economies that are also exogenous in developed economies, and use these policy surprises to study reserves and interest rates.

One challenge with our approach is that it is hard to isolate the impact of interest rate shocks from global cycles, in particular given that our sample includes a global financial crisis and a post-crisis world that is rather unique. Furthermore, it remains difficult to establish causality between interest rates and international reserve transfers. We note that results for the period before the global financial crises are similar to the full sample, in particular for low-income countries and in Asia. Future work may benefit from more and better data, and should test if the relationship we document in this paper is indeed causal.

Finally, we have focused on interest rates but omitted the role of the social return on capital. Future work should incorporate both dimensions of holding international reserves, costs and returns, to compute the fiscal impact of the opportunity cost of international reserves and provide a clearer picture of international reserve management in a post-crisis world with potentially higher interest rates.

# References


**Aizenman, Joshua and Jaewoo Lee**, "International reserves: precautionary versus mercantilist views, theory and evidence," *Open Economies Review*, 2007, *18* (2), 191–214.

_ **and** _ , "Financial versus Monetary Mercantilism: Long-run View of Large International Reserves Hoarding," *The World Economy*, 2008, *31* (5), 593–611.

_ **and Nancy Marion**, "The high demand for international reserves in the Far East: What is going on?," *Journal of the Japanese and International Economies*, 2003, *17* (3), 370–400.

_ **, Yothin Jinjarak, and Donghyun Park**, "International reserves and swap lines: Substitutes or complements?," *International Review of Economics & Finance*, 2011, *20* (1), 5–18.

**Beck, Roland and Ebrahim Rahbari**, "Optimal reserve composition in the presence of sudden stops," *Journal of International Money and Finance*, 2011, *30* (6), 1107–1127.

**Burnside, Craig, Martin Eichenbaum, and Sergio Rebelo**, "Prospective Deficits and the Asian Currency Crisis," *Journal of Political Economy*, 2001, *109* (6), 1155–1197.

_ **,** _ **, and** _ , "Government finance in the wake of currency crises," *Journal of Monetary Economics*, 2006, *53* (3), 401–440.

**Calvo, Guillermo A**, "Balance of payments crises in a cash-in-advance economy," *Journal of Money, Credit and Banking*, 1987, pp. 19–32.

**Dominguez, Kathryn ME**, "Foreign reserve management during the global financial crisis," *Journal of International Money and Finance*, 2012, *31* (8), 2017–2037.

— , **Yuko Hashimoto, and Takatoshi Ito**, "International reserves and the global financial crisis," *Journal of International Economics*, 2012, *88* (2), 388–406.

**Edwards, Sebastian**, "On the interest-rate elasticity of the demand for international reserves: some evidence from developing countries," *Journal of International Money and Finance*, 1985, *4* (2), 287–295.

**Gourinchas, Pierre-Olivier and Olivier Jeanne**, "Capital flows to developing countries: The allocation puzzle," *The Review of Economic Studies*, 2013, p. rdt004.

**Hauner, David**, "A Fiscal Price Tag for International Reserves," *International Finance*, 2006, *9* (2), 169–195.

**Heller, Heinz Robert**, "Optimal international reserves," *The Economic Journal*, 1966, *76* (302), 296–311.

**ichi Fukuda, Shin and Yoshifumi Kon**, "5. Macroeconomic impacts of foreign exchange reserve accumulation: theory and international evidence," *Monetary and Currency Policy Management in Asia*, 2012, *1500*, 120.

**Jeanne, Olivier**, "International reserves in emerging market countries: too much of a good thing?," *Brookings papers on Economic activity*, 2007, *2007* (1), 1–79.

**Laeven, Luc and Fabian Valencia**, "Systemic banking crises database," *IMF Economic Review*, 2013, *61* (2), 225–270.

**Lim, Mr Ewe-Ghee**, *Do reserve portfolios respond to exchange rate changes using a portfolio rebalancing strategy? An econometric study using COFER data* number 7-293, International Monetary Fund, 2007.

**Obstfeld, Maurice, Jay C Shambaugh, and Alan M Taylor**, "Financial Instability, Reserves, and Central Bank Swap Lines in the Panic of 2008," *The American Economic Review*, 2009, pp. 480–486.

**Pina, Gonçalo**, "The recent growth of international reserves in developing economies: A monetary perspective," *Journal of International Money and Finance*, 2015, *58*, 172 – 190.

**Rigobon, Roberto**, "Disinflation and fiscal reform: A neoclassical perspective," *Journal of International Economics*, 2002, *58* (2), 265–297.

**Wong, Anna**, "Measurement and inference in international reserve diversification," *Peterson Institute for International Economics Working Paper*, 2007, (07-6).

**Wooldridge, Philip D**, "The changing composition of official reserves," *BIS Quarterly Review, September*, 2006.

# A Consumer Problem

$$Max_{c_t} \int_0^{\infty} log\left(c_t\right) e^{-\rho t} dt$$
$$s.t.\dot{a_t} = \rho a_t + y - c_t\left(1 + i_t\right)$$

Write the Lagrangian under the assumption of perfect foresight:

$$L = \int_0^{\infty} log\left(c_t\right) e^{-\rho t} dt + \lambda \left[a_0 + \frac{y}{\rho} - \int_0^{\infty} c_t\left(1 + i_t\right) e^{-\rho t}\right]. \tag{30}$$

Take first order conditions:

$$\frac{e^{-\rho t}}{c_t} = \lambda e^{-\rho t}\left(1 + i_t\right). \tag{31}$$

Define $\tilde{c_t} = c_t\left(1 + i_t\right)$, apply logs and differentiate totally to obtain:

$$\frac{\frac{d\tilde{c_t}}{dt}}{\tilde{c_t}} = 0. \tag{32}$$

We can see that the growth rate of $\tilde{c_t}$ is zero. Solving:

$$c_t\left(1+i_t\right)=c_0\left(1+i_0\right). \tag{33}$$

Replacing back in the present value budget constraint, obtain:

$$c_0=\frac{\rho a_0+y}{1+i_0}, \tag{34}$$

$$c_t=\frac{\rho a_0+y}{1+i_t}. \tag{35}$$

# B Central Bank Problem

## B.1 Solution

Define $X=\rho a_0+y$, then we can write the problem as:

$$\rho V^L\left(b_t\right)=max_{i_t^L} log\left(\frac{X}{1+i_t^L}\right)+V_b^L\left(\phi b_t+g^L-\frac{i_t^L+\phi_t-\rho}{1+i_t^L}X\right)+q_1\left(V^H-V^L\right) \tag{36}$$

$$\rho V^H\left(b_t\right)=max_{i_t^H} log\left(\frac{X}{1+i_t^H}\right)+V_b^H\left(\phi b_t+g^H-\frac{i_t^H+\phi_t-\rho}{1+i_t^H}X\right)+q_2\left(V^L-V^H\right) \tag{37}$$

together with the constraints and the boundary conditions denoted in the main text.

To solve, first take FOCs with respect to $i$, and omit time subscripts for simplicity:

$$V_b^L=-\frac{1+i^L}{\left(1+\rho-\phi\right)X} \tag{38}$$

$$V_b^H=-\frac{1+i^H}{\left(1+\rho-\phi\right)X} \tag{39}$$

Differentiate (38)-(39) to obtain:

$$V_{bb}^{L} = -\frac{1}{(1+\rho-\phi)X}\frac{\partial i^{L}}{\partial b} \tag{40}$$

$$V_{bb}^{H} = -\frac{1}{(1+\rho-\phi)X}\frac{\partial i^{H}}{\partial b} \tag{41}$$

Envelope conditions:

$$\rho V_{b}^{L} = \phi V_{b}^{L} + V_{bb}^{L}\left(\phi b + g^{L} - \frac{i_{t}^{L}+\phi_{t}-\rho}{1+i_{t}^{L}}X\right) + q_{1}\left(V_{b}^{H}-V_{b}^{L}\right) \tag{42}$$

$$\rho V_{b}^{H} = \phi V_{b}^{H} + V_{bb}^{H}\left(\phi b + g^{H} - \frac{i_{t}^{H}+\phi_{t}-\rho}{1+i_{t}^{H}}X\right) + q_{2}\left(V_{b}^{L}-V_{b}^{H}\right) \tag{43}$$

Replacing (38)-(41) in (42)-(43), we obtain the solution to this problem as a system of two differential equations:

$$\frac{\partial i_{t}^{L}}{\partial b_{t}} = \frac{(\rho-\phi)\left(1+i_{t}^{L}\right)+q_{1}\left(i_{t}^{L}-i_{t}^{H}\right)}{\phi b_{t}+g^{L}-\frac{i_{t}^{L}+\phi_{t}-\rho}{1+i_{t}^{L}}X} \tag{44}$$

$$\frac{\partial i_{t}^{H}}{\partial b_{t}} = \frac{(\rho-\phi)\left(1+i_{t}^{H}\right)+q_{2}\left(i_{t}^{H}-i_{t}^{L}\right)}{\phi b_{t}+g^{H}-\frac{i_{t}^{H}+\phi_{t}-\rho}{1+i_{t}^{H}}X} \tag{45}$$

We turn now to the proof of Proposition 1.

## B.2 Proposition 1

**Proof.**

Remember that $b_t = m_t - r_t$ A break-even level of $b$ for state $L$ exists because reserves flow start of positive at high b levels, and are negative at low $b$ levels. At high levels of $b$ (low levels of $r$), $i^{H}$ approaches $\bar{i^{H}} = \infty$, and $V_{b}^{H}$ decreases indefinitely. Then,

$$\underbrace{(\phi-\rho)V_{b}^{L}+q_{1}\left(V_{b}^{H}-V_{b}^{L}\right)}_{negative} + \underbrace{V_{bb}^{L}}_{negative}\underbrace{\left(\phi b+g^{L}-\frac{i_{t}^{L}+\phi_{t}-\rho}{1+i_{t}^{L}}X\right)}_{negative} = 0 \tag{46}$$

that is, $\dot{b}_t^L = \phi b + g^L - \frac{i_t^L+\phi_t-\rho}{1+i_t^L} X < 0$ at high $b$. At low $b$ (high $r$), the central bank spends reserves since $\rho > \phi$ and $b$ increases. Then, there exists a level $b_s$ such that $\dot{b}_t^L(b_s) = 0$. Furthermore, at $b_s$, the inflation rate is such that $\phi b_s + g^L - \frac{i_t^L+\phi_t-\rho}{1+i_t^L} X = 0$ which is constant. Therefore, $m_t(b_s)$ is constant and given that $b_t = m_t - r_t$, $r_t$ is also constant. This implies that $\dot{b}_t^L(b_s) = \dot{r}_t^L(b_s) = \dot{m}_t^L(b_s) = 0$. Finally, in state-H there is no target level of reserves and $b^H \geq 0$ for all $b$. To show this, note that given $\rho > \phi$ and $V_b^H < V_b^L$, $(\phi - \rho) V_b^H + q_2 \left(V_b^L - V_b^H\right) > 0$ so that $V_{bb}^H \left(\phi b + g^H - \frac{i^H+\phi_t-\rho}{1+i^H} X_t\right) < 0$ and $\dot{b}^H = \phi b + g^H - \frac{i^H+\phi_t-\rho}{1+i^H} X_t > 0$ except when $b = b_s$, where $\dot{b}^H = 0$.

■

## B.3 Numerical solution and further results

At the break-even level $b_s$:

$$i^L(b_s) = \frac{\phi b_s + g^L}{X + \phi_t - \rho - \phi b_s - g^L} \tag{47}$$

Substituting into the envelope condition obtain that $(\phi - \rho) V_b^L + q_1 \left(V_b^H - V_b^L\right) = 0$. Replacing with first order conditions, obtain that: $-(\phi - \rho)\left(1 + i^L\right) + q_1\left(i^L - i^H\right) = 0$. The numerator of the differential equation is equal to zero. Since both the numerator and the denominator are zero at $b_s$ the differential equation (44) has a singularity at $b_s$. Then:

$$i^H(b_s) = \frac{(\rho - \phi)\left(1 + i^L(b_s)\right) + q_1 i^L(b_s)}{q_1} > i^L(b_s) \tag{48}$$

If $\rho = \phi$, the interest rates would be equal. We can also use another result at the singularity that will facilitate the numerical solution. Applying L'Hopital's rule at $b_s$ to equation (44), we obtain:

$$\frac{\partial i^L}{\partial b} = \frac{(\rho - \phi)\frac{\partial i^L}{\partial b} + q_1\left(\frac{\partial i^L}{\partial b} - \frac{\partial i^H}{\partial b}\right)}{\phi - \frac{\partial i^L}{\partial b}\frac{1-\phi+\rho}{(1+i^L)^2} X} \tag{49}$$

which yields a quadratic equations with two solutions. We can eliminate the solution that yields a negative slope.

The numerical strategy then is the following, iterate on $b_s$ such that, at $b_s$:

$$i^L\left(b_s\right) = \frac{\phi b_s + g^L}{X + \phi_t - \rho - \phi b_s - g^L} \tag{50}$$

$$i^H\left(b_s\right) = \frac{\left(\rho - \phi\right)\left(1 + i^L\left(b_s\right)\right) + q_1 i^L\left(b_s\right)}{q_1} \tag{51}$$

$$\frac{\partial i^H}{\partial b} = \frac{\left(\rho - \phi\right)\left(1 + i_t^H\right) + q_2\left(i^H - i^L\right)}{\phi b + g^H - \frac{i^H + \phi_t - \rho}{1 + i^H} X} \tag{52}$$

and $\frac{\partial i^L}{\partial b}$ determined by the positive solution of the quadratic equation given by (49), while checking if the boundary conditions given by equations (18) and (19) are satisfied.