Optimal Foreign Reserve Intervention and Financial Development

J. Scott Davis, Kevin X.D. Huang, Zheng Liu and Mark M. Spiegel

Working Paper 2538 November 2025 (Revised August 2026)

Research Department

https://doi.org/10.24149/wp2538r1

Optimal Foreign Reserve Intervention and Financial Development*

J. Scott Davis†, Kevin X.D. Huang‡, Zheng Liu§ and Mark M. Spiegel±

October 29, 2025
Revised: August 19, 2026

Abstract

We document evidence of a U-shaped relationship between financial development and the adjustments of foreign exchange (FX) reserve holdings in response to a U.S. interest rate increase. Countries with intermediate levels of financial development sell reserves aggressively, while those with low or high levels adjust little. A model with borrowing constraints and foreign-currency debt rationalizes these findings. Optimal FX reserve policy faces a tradeoff between the rate of return on capital outflows and a pecuniary externality linked to foreign currency debt in the borrowing constraints. This pecuniary externality is maximized at intermediate levels of financial development.

Keywords: foreign reserves, financial development, capital flows, optimal policy.

JEL classification: F32, F38, E52.

* For helpful comments, we thank Paul Bergin, Michael Devereux, Ippei Fujiwara, Oleg Itskhoki, Robert Kollman, Nicolas Magud, Hidehiko Matsumoto, Ignacio Presno, Vincezo Quadrini, Romaine Ranciere, Noah Williams, and participants at the 2025 Econometric Society World Congress (Seoul), the 10th West Coast Workshop in International Finance (Santa Clara), the 2026 ASSA meeting (Philadelphia), the KMFA-BOK-CEPR 10th International Macroeconomics and Finance Conference (Seoul), the 2026 Federal Reserve System Committee on International Economic Analysis (SCIEA) Conference (San Francisco), the 30th International Conference on Macroeconomics and International Finance (Crete), and the 2026 North American Summer Meeting of the Econometric Society (Atlanta). We also thank Anton Bobrov, Naomi Halbersleben, Ethan Po, and Aayush Singh for excellent research assistance. The views expressed herein are those of the authors and do not necessarily reflect the views of the Federal Reserve Banks of Dallas or San Francisco, or of the Federal Reserve System.

† J. Scott Davis, Federal Reserve Bank of Dallas, email: scott.davis@dal.frb.org.

‡ Kevin X.D. Huang, Vanderbilt University, email: kevin.huang@vanderbilt.edu.

§ Zheng Liu, Federal Reserve Bank of San Francisco, email: Zheng.Liu.@sf.frb.org.

± Mark M. Spiegel, Federal Reserve Bank of San Francisco, email: Mark.Spiegel@sf.frb.org.

I. Introduction

Empirical evidence suggests that, under free capital mobility, a country's domestic monetary policy can be constrained by a global financial cycle that affects global capital flows, regardless of the exchange rate regime. Based on this evidence, Rey (2015) argues that "independent monetary policies are possible if and only if the capital account is managed." Central banks often conduct capital account policies through foreign exchange (FX) interventions. This paper studies the optimal use of FX interventions for macroeconomic stabilization in response to global financial shocks. We show empirically how the use of FX interventions varies with a country's level of financial development. We rationalize our empirical findings using a DSGE model of a small open economy to highlight the particular sources of externality that FX interventions address.

Empirically, we identify a statistically-significant U-shaped relation between financial development and the adjustments of FX reserve holdings in response to a U.S. interest rate increase: those economies with an intermediate level of financial development sell FX reserves aggressively, while those countries with low or high levels of financial development are much less active in adjusting their holdings of FX reserves.[1]

To examine the economic forces driving these empirical observations, we develop a model of a small open economy with heterogeneous agents and financial frictions. The model features households optimizing consumption and portfolio holdings, firms producing differentiated goods under monopolistic competition and setting prices subject to nominal rigidities, and entrepreneurs using both domestic and foreign currency debt to finance investment, subject to collateral constraints. The central bank sets the domestic interest rate and manages FX reserves. A simple adjustment cost on the holdings of foreign debt implies imperfect substitution between domestic and foreign assets, creating room for the central bank to use FX reserves as a second policy instrument. We assume that the central bank sets its two policy instruments optimally to maximize social welfare.

When there is a positive shock to the foreign interest rate, domestic agents want to save more and borrow less, leading to capital outflows. The currency depreciates and the current account surplus increases. Borrowing constraints, with a share of the debt denominated in foreign currency units, introduce a key source of frictions in our model, setting up the trade-off that leads to the U-shape in reserve sales. As in the standard model with collateral constraints, agents do not internalize the effects of their collective net saving on the real value of foreign currency denominated debt and thus the tightness of the borrowing constraint.

[1]Aizenman et al. (2024) also finds that financial development levels are empirically linked to the efficacy of international reserve holdings as a buffer against external shocks.

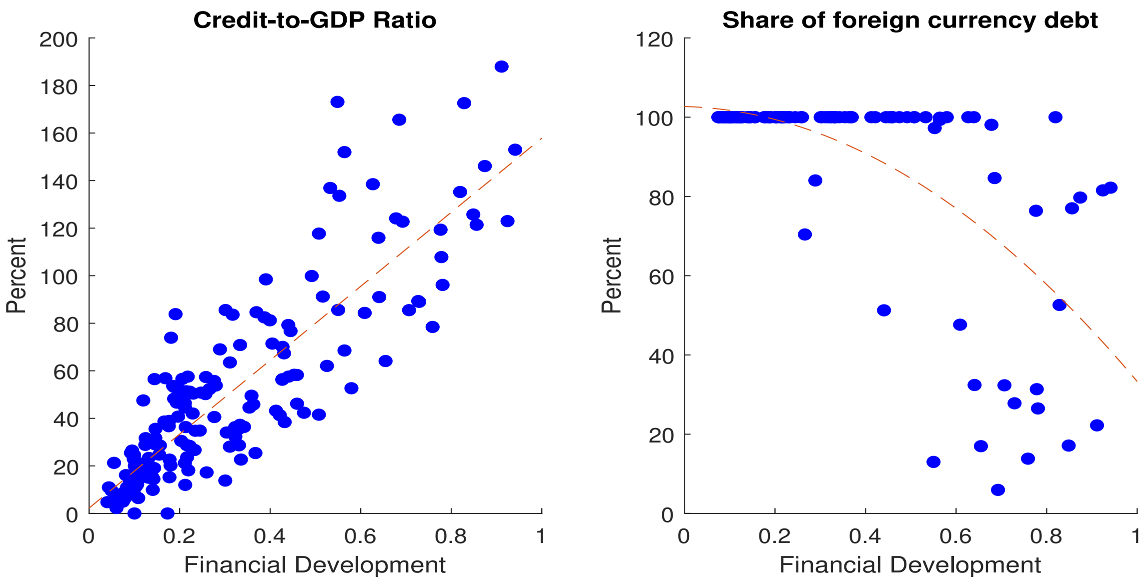

FIGURE 1. Cross-country relations of financial development with the average credit-to-GDP ratio (left panel) and with the share of foreign currency debt (right panel).

Note: The left panel of this figure shows a scatter plot of the average ratio of private credit to GDP against the financial development index (FD) across 178 countries, with a quadratic trend indicated by the dashed line. The right panel shows a scatter plot of the share of external debt denominated in foreign currency against the financial development index for 115 countries, with a quadratic trend indicated by the dashed line.
Sources: The financial development index is from the IMF. The data for the private credit-to-GDP ratio is from the World Bank's World Development Indicators. The share of external debt denominated in foreign currency is from Bénétrix et al. (2015).

The central bank does internalize the effect of its policy on this externality. The central bank can lean against the wind, it can sell reserves and dissave when the rest of the economy is saving, in order to limit the exchange rate depreciation and the rise in the real value of foreign currency debt. Under Ramsey optimal policy, the central bank faces a tradeoff between the rise in the rate of return on capital outflows and this pecuniary externality stemming from the tightened borrowing constraints.

This trade-off gives rise to the U-shape in the reserve response that we observe in the data. The size of the externality associated with the borrowing constraints depends on two key parameters in the model: one is the steady-state loan-to-value ratio (LTV), which determines the average leverage, and the other is the share of the debt denominated in foreign-currency units. In the data, both the leverage and the share of foreign-currency debt vary with the level of financial development. Figure 1 shows that an economy's average credit-to-GDP ratio—a measure of the country's aggregate leverage—increases monotonically with the level of financial development (left panel). In comparison, the share of foreign currency debt (right panel) remains close to 100 percent for economies with low levels of financial development, reflecting the inability of those countries to issue domestic-currency debt, possibly because of the lack of credibility in contract enforcement, or the "original sin" (e.g. Eichengreen et al. (2005) and Devereux and Wu (2023)). The share of foreign currency debt starts to decline as a country becomes more financially developed only after the country passes an intermediate level of financial development.

These observations suggest that the externality associated with the borrowing constraints might be nonlinear in the level of financial development. For countries with low levels of financial development, most debt is denominated in a foreign currency, but there is not much debt. For countries with high levels of financial development, there is more debt, but it is mostly denominated in the domestic currency. In both cases, the externality associated with foreign currency debt in the borrowing constraints is small. If the central bank is setting optimal FX reserve policy to balance this trade-off between private sector net saving and the borrowing constraint externality, the externality receives less weight at high or low levels of financial development, resulting in less leaning against the wind.

In contrast, a country with an intermediate level of financial development has both a relatively high level of debt and a relatively large share of foreign currency debt. When setting optimal reserve policy, the borrowing constraint externality is a bigger issue for such an economy, and the central bank responds by selling reserves when the foreign interest rate increases.

In the model, when we vary the LTV ratio and the share of foreign-currency debt systematically with the economy's level of financial development based on their empirical relations while holding all else constant, we obtain a U-shaped relationship between financial development and the adjustments of FX reserve holdings, as observed in the data. This U-shaped relation does not hinge upon Ramsey optimal policy for the interest rate; it also obtains when the central bank sets the domestic interest rate based on a Taylor rule which targets inflation, output gap, and the real exchange rate. This finding suggests that the externality that motivates the foreign exchange intervention that we see in the data is tied to a country's average indebtedness as well as the share of the debt denominated in foreign currencies.

Our model provides a theoretical explanation for our empirical finding that shows a U-shaped relationship between *changes* in foreign reserve holdings following a global financial shock, a flow variable, and the level of financial development. To the best of our knowledge, this result is new and goes beyond the known empirical observation on a hump-shaped relation between the reserve-to-GDP ratio, a *stock* variable, and financial development. It also complements the empirical study of Arango-Lozano et al. (2020). Our flow results speak directly to the intensity of the usage of reserves for short-run stabilization purposes, while the patterns in reserve holdings could be motivated by other longer-run considerations, such as reputation enhancement through the buildup of a precautionary reserve war chest.

This way of seeing optimal reserve policy as a trade-off between a private sector that wants to save more/borrow less and a pecuniary externality is simply the mirror image of the trade-off described by Ottonello (2021), where the central bank allows the currency to depreciate following a foreign rate shock to stimulate net exports.[2] However, Ottonello (2021) discusses this trade-off for a representative emerging market economy. We instead consider how this tradeoff varies with an economy's level of financial development. Leaning against the wind and selling reserves to stabilize the exchange rate is the optimal policy for the representative emerging market with a sufficiently large stock of foreign currency denominated debt. But for countries with low or high levels of financial development, the externality related to foreign currency debt may be rather small, and optimal policy faces less incentive to lean against the wind. Our empirical results confirm this.

Our paper contributes to the literature on foreign exchange intervention that emphasizes a portfolio balance channel through which foreign exchange intervention can affect capital flows and the exchange rate as well as the macroeconomy at large. This line of research can be traced back at least to Kouri (1976) and Driskill and McCafferty (1980). Our New Keynesian small open economy model features financial frictions with imperfect substitution between domestic and foreign assets and frictional portfolio decisions faced by domestic agents. These constitute minimal frictions within our model framework (which intentionally abstracts from both the signaling channel and the coordination channel of foreign exchange intervention previously studied in the literature) that can make foreign exchange intervention a potentially valuable stabilization tool in addition to the policy interest rate available to the central bank (e.g., Backus and Kehoe (1989), Benigno et al. (2022) and Bianchi and Sosa-Padilla (2024)).

Financial frictions are also at the core of Céspedes and Chang (2024), but their focus is on how the central bank may combine ex-ante foreign reserves accumulation with ex-post liquidity provision when the financial constraint binds, where maturity mismatch between

[2]Increased private sector net savings and increased net exports are linked by the identity that the current account is equal to the trade balance plus net factor payments, which is equal to net capital outflows, which is equal to saving minus investment for the economy as a whole.

two sides of the central bank's balance sheet and a liquidity premium that the central bank must pay to hold foreign reserves while borrowing long-term are essential for their analysis.

Similarly, in Davis et al. (2023) the central bank can sell foreign currency denominated bonds to avoid a sudden stop in a model with multiple equilibria. Liquidity mismatch together with a fire-sale externality on foreign debt are the key frictions to motivate foreign reserves management in Jeanne and Sandri (2023); see, also, Ma and Matsumoto (2024). As in our paper, pecuniary externality also plays a central role in Fanelli and Straub (2021). Our results show that foreign exchange intervention can play an important stabilization role even if all assets and liabilities in our model are liquid and the cost for the central bank to hold foreign reserves is nil. Instead, our model suggests that the level of financial development is a key factor in determining the optimal adjustments in FX reserves following a global financial shock.

Using foreign exchange intervention as a second policy instrument in addition to the policy interest rate also has a stabilization role in Ghosh et al. (2016), but this comes as a direct result of assuming a central bank loss function that penalizes exchange rate volatility in addition to those of inflation and output. Similar assumptions are also made by Devereux and Yetman (2014), Benes et al. (2015), and Montoro et al. (2016) in analyzing the role of sterilized foreign exchange intervention. We take a micro-founded, utility-maximizing approach to analyzing optimal foreign reserve policy. In this aspect, our work is related to Chang et al. (2015), who study optimal monetary policy under capital controls in the context of China (see also Liu and Spiegel (2015)). Our utility-based optimal policy analysis is also similar to Cavallino (2019), although we abstract financial intermediation in order to isolate the effects of the simple form of financial frictions, whereas frictions in the intermediation process of international capital flows are the core of his analysis following the lead of Gabaix and Maggiori (2015). See, also, Agénor et al. (2020) and Castillo et al. (2024) where financial intermediation or agency costs also play the central roles.

II. Empirical evidence

II.1. **Specification.** In this section, we present cross-country evidence on how the adjustments of FX reserves and domestic interest rates to changes in global financial conditions depend on the level of financial development. We measure changes in global financial conditions empirically by changes in 1-year U.S. Treasury yields. To address potential endogeneity concerns, we also examine a case in which the U.S. Treasury yields are instrumented by high-frequency monetary policy surprises around FOMC announcement events constructed by Acosta et al. (2025). Following a change in the U.S. interest rate, the central bank in a small open economy can adjust domestic interest rates or, in environments where domestic assets are imperfect substitutes for foreign assets, it can also adjust holdings of FX reserves.

We measure changes in FX reserves using data from the Balance Of Payments (BOP) of the IMF. We measure domestic interest rates using data from the International Financial Statistics (IFS) of the IMF. We examine how the responses of a country's FX reserves and domestic interest rates to changes in the U.S. Treasury yields depend on the level of its financial development. We measure financial development also using IMF data.

We implement our empirical approach in two steps. In the first step, we estimate country-specific responses of FX reserves and of domestic interest rates to changes in the U.S. interest rate, based on individual time-series regressions. In particular, for each country i, we estimate the following univariate specification for FX reserve adjustments to changes in the U.S. interest rate according to the specification

$$\Delta RES_{it} = c_i + \beta_{R,i}\Delta US1T_t + \beta_{1,i}PCGDP_{it} + \beta_{2,i}CAOPEN_{it} + \epsilon_{it}, \tag{1}$$

where ΔRES_{it} represents the change in the log of reserve holdings of country i from year $t-1$ to year t, $\Delta US1T_t$ represents the change in the one-year treasury rate, $\beta_{R,i}$ measures the responsiveness of country i's FX reserves to the U.S. interest rate shock, $PCGDP_{it}$ represents per capita income, $CAOPEN_{it}$ represents capital account openness as measured by the Chinn-Ito data set, and ϵ_{it} is the regression residual.

We estimate a similar univariate specification for interest-rate adjustments for each country, which is given by

$$\Delta DOMINT_{it} = c_i + \beta_{Ii}\Delta US1T_t + \beta_{1,i}PCGDP_{it} + \beta_{2,i}CAOPEN_{it} + \upsilon_{it} \tag{2}$$

where $\Delta DOMINT_{it}$ represents the change in log of domestic one-year interest rates from $t-1$ through t, $\beta_{I,i}$ captures the response of country i's domestic interest rate to changes in the U.S. interest rate, $PCGDP_{it}$ and $CAOPEN_{it}$ again per capita GDP and capital account openness as measured by the Chinn-Ito data set, and υ_{it} is the regression residual.

We first estimate the country-specific responsiveness measures (β_{Ri} and β_{Ii}) using an ordinary least squares (OLS) specification. However, while it is likely that movements in US interest rates are primarily determined by fundamentals in the United States, and hence represent global financial condition shocks to foreign countries, one might be concerned about the possibility that global factors could affect both US interest rates and foreign central bank policy responses. To address this concern, we also estimate our specification using an instrumental variables (IV) approach to identifying the shock component of movements in the U.S. interest rate.

We then examine how the sensitivities of FX reserves and domestic interest rates to U.S. interest rate shocks vary with the level of financial development across countries. For this purpose, we estimate cross-sectional specifications using ordinary least squares. We restrict our sample to countries with a financial development index of 0.2 or higher, since the responses of countries with very low financial development scores are quite erratic.[3] Our estimates of individual country reserve and domestic interest rate sensitivities ($\hat{\beta}_{R,i}$ and $\hat{\beta}_{I,i}$) are likely to be measured with error. However, since they are the dependent variables in our specifications, estimates of these coefficients of interest should be consistent and unbiased.

We estimate the following cross-sectional specification for FX reserve adjustments

$$\hat{\beta}_{R,i} = c + \beta_R FD_i + \delta_R FD_i^2 + \gamma_R X_i + \varepsilon_i, \tag{3}$$

where $\hat{\beta}_{R,i}$ is the estimated responsiveness of country i's FX reserves to the U.S. interest rate shock in the specification (1). The key independent variables of interest are the country's level of financial development (FD_i) and the squared level of financial development (FD_i^2) that captures potential nonlinearity. We control for the mean values of the country-specific conditioning variables (X_i). The term ε_i denotes the regression residual.

Our country-specific conditioning variables (X_i) include capital account openness, as measured by the Chinn-Ito data set, $CAOPEN_{i,t}$, population, $POP_{i,t}$, GDP per capita, $PCGDP_{i,t}$, $USPEG_i$ which indicates exchange rate pegging to the dollar based on Shambaugh (2004) with value 1 if the country was pegged to the dollar in 2004 and 0 otherwise, $CURR$, the current account balance, and RES, the current stock of reserves. To mitigate the influence of outliers, all data and sensitivity estimate samples are winsorized at 2.5-97.5 percent levels, except for the $USPEG$ dummy. Estimation is done under ordinary least squares with heteroskedasticity-consistent robust standard errors.

We also evaluate the robustness of our results to the use of separate indicators of controls on capital inflows and outflows from Fernández et al. (2016), which we designate as CAI and CAO respectively.

Similarly, to examine how the responsiveness of domestic interest rates depends on financial development, we estimate the cross-sectional specification

$$\hat{\beta}_{I,i} = c + \beta_I FD_i + \delta_I FD_i^2 + \gamma_I X_i + \nu_i, \tag{4}$$

where $\hat{\beta}_{I,i}$ is the estimated responsiveness of country i's interest rate to the U.S. interest rate shock in the specification (2). Again, the key independent variables of interest are the country's level of financial development (FD_i) and the square of that term (FD_i^2). We

[3] The list of the 85 countries included in our sample is reported in Table A2.

include the same set of control variables (X_i). The term ν_i denotes the regression residual. The key parameter of interest is β_I.

II.2. **OLS Results.** Summary statistics for the country-specific reserve response sensitivities ($\hat{\beta}_{R,i}$) and interest rate response sensitivities ($\hat{\beta}_{I,i}$) are shown in Appendix Table A1. We obtain a much wider dispersion of estimated for reserve management sensitivity than we do for responses in domestic interest rates. The distribution of OLS estimation results for $\hat{\beta}_{R,i}$ for our base sample with the conditioning variables included using the Chinn-Ito measure of capital account openness has mean -0.87 and standard deviation 5.14, while that for country-specific interest rate response sensitivities ($\hat{\beta}_{I,i}$) for our base sample have mean 0.08 and standard deviation 0.13.[4]

Our regression results are shown in Table 1. In all of the specifications for sensitivity to interest rate changes in reserve holdings (Models 1 through 3), changes in FX reserve holdings following a U.S. interest rate shock depend negatively on the level of financial development (FD) and positively on the squared level of financial development (FD^2). For our base specification using the Chinn-Ito capital account openness measure (Column 2), the estimated coefficients on the linear and the squared terms are statistically significant at the 5% and 1% confidence levels respectively.

These estimates suggest a U-shaped relationship between financial development and the changes in FX reserve holdings following a U.S. interest rate shock. This pattern is robust to dropping the country-specific conditional variables (Column (1)), as well as substituting the alternative Fernández et al. (2016) separate measures of controls on capital inflows and outflows (Column (3)).

For example, consider the point estimates for our base specification with conditioning variables included and the Chinn-Ito capital account openness measure (Column (2)). The point estimates of the coefficients for FD and FD^2 of -34.78 and 34.75 respectively indicate that the change in reserves is decreasing in FD for values of FD below 0.5 and increasing in FD for values of FD above 0.5. The sample of countries in our Model 2 specification are relatively equally split between being above or below the 0.5 threshold for FD, with 36 countries below the threshold, and 31 countries above the threshold. Intuitively, once countries pass a threshold level of financial development, their relative reliance on reserve adjustment to counter global interest rate shocks diminishes.

In contrast, the responses of domestic interest rates to U.S. interest rate shocks are not systematically related to financial development at statistically significant levels across all our

[4]Our base sample includes 67 countries, Models 2 and 5 in Tables 1 and 2.

TABLE 1. OLS-estimated adjustment sensitivities and financial development

	(1)	(2)	(3)	(4)	(5)	(6)
Depvar :	$\hat{\beta}_{R,i}$	$\hat{\beta}_{R,i}$	$\hat{\beta}_{R,i}$	$\hat{\beta}_{I,i}$	$\hat{\beta}_{I,i}$	$\hat{\beta}_{I,i}$
FD	-37.49***	-34.78**	-38.60***	0.23	0.12	0.31
	(14.19)	(14.19)	(14.09)	(0.34)	(0.37)	(0.47)
FD^2	34.91**	34.75***	38.16***	0.00	-0.03	-0.25
	(13.44)	(11.69)	(11.77)	(0.32)	(0.35)	(0.40)
CAOPEN		-3.57			0.02	
		(2.66)			(0.06)	
CAI			-1.42			-0.03
			(3.86)			(0.11)
CAO			4.15			-0.05
			(2.70)			(0.08)
POP		-0.00	-0.00		0.00	0.00
		(0.00)	(0.00)		(0.00)	(0.00)
PCGDP		0.00	-0.00		0.00	0.00
		(0.00)	(0.00)		(0.00)	(0.00)
PEG		-3.71**	-4.17**		0.03	0.07
		(1.80)	(1.83)		(0.05)	(0.05)
CURR		-0.08	0.16		0.01*	0.00*
		(0.16)	(0.11)		(0.00)	(0.00)
RES		-0.06*	-0.11***		0.00	0.00
		(0.04)	(0.03)		(0.00)	(0.00)
CONS	7.76**	10.57***	9.62***	-0.04	-0.04	-0.03
	(3.07)	(3.42)	(3.34)	(0.08)	(0.10)	(0.12)
Observations	85	67	59	85	67	59

Note: Estimation by OLS with heteroscedasticity-robust standard errors. Dependent variable for models 1 through 3 is $\hat{\beta}_{R,i}$, the intensity of reserve response to US interest rate shocks. Dependent variable for models 4 through 6 is $\hat{\beta}_{I,i}$, the intensity of domestic interest rate responses to US interest rate shocks. Both $\hat{\beta}_{R,i}$ and $\hat{\beta}_{I,i}$ estimated by OLS. FD^2 represents the square of financial development index FD. See the text for other variable definitions. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

empirical specifications, either in levels or the square of levels, as shown in Columns (4)-(6) in the table.

II.3. **IV estimation.** We first report our results for OLS-based estimates of adjustment sensitivities because it seems plausible that changes in global rates, from any source, are likely to impact on economies in ways that warrant responses through changes in domestic monetary policy and adjustments to holdings of international reserves. Still, it seems likely that the quarterly interest rate movements in the 1 year treasury rate do not only represent monetary shocks. We therefore also estimate individual country policy responsiveness using an IV specification.

To instrument for monetary shocks, we use the Acosta et al. (2025) high-frequency shock data from the Federal Reserve Bank of San Francisco Event-Study Database. This database reports market movements and returns for a variety of series based on high-frequency market data and calculated over intraday windows. The data covers FOMC policy statements, press conferences, and meeting minutes releases. As our data is of a quarterly frequency, we sum over high-frequency change values in a quarter to obtain our quarterly shock values.

As we are trying to instrument for changes in 1-year US treasuries, in addition to the change in the federal funds rate relative to futures markets, we concentrate on the reported shocks to longer series, including changes in 4-quarter eurodollar futures, changes in the 1-year OIS rate, changes in the 3-month treasury rate, and changes in the 6-month treasury rate. We introduce all of these quarterly shock series as potential instruments for changes in the one-year US treasury rate. We then run the same specifications as reported above with our instrumented responsiveness measures as the dependent variable to obtain our country-specific reserve response sensitivities ($\hat{\beta}_{R,i}$) and interest rate response sensitivities ($\hat{\beta}_{I,i}$).

Summary statistics for the estimated responsiveness measures ($\hat{\beta}_{R,i}$ and $\hat{\beta}_{I,i}$) are shown in Appendix Table A1. We again obtain a much wider dispersion of estimated for reserve management sensitivity than we do for responses in domestic interest rates. The distribution of our IV estimation results for $\hat{\beta}_{R,i}$ for our base sample with the conditioning variables included using the Chinn-Ito measure of capital account openness has mean 0.99 and standard deviation 10.04, while that for country-specific interest rate response sensitivities ($\hat{\beta}_{I,i}$) for our base sample have mean 0.05 and standard deviation 0.14.

Our regression results with policy sensitivities estimated by IV are shown in Table 2. Our results are qualitatively similar to those we obtain with OLS sensitivity estimates. In all of the specifications for sensitivity to interest rate changes in reserve holdings (Models 1 through 3), changes in FX reserve holdings following a U.S. interest rate shock again depend negatively on the level of financial development (FD) and positively on the squared level of financial development (FD^2). For our base specification with conditioning variables included and the Chinn-Ito capital account openness measure (Column 2), the estimated coefficients on the linear and the squared terms are both statistically significant at 5% confidence levels.

TABLE 2. IV-estimated adjustment sensitivities and financial development

	(1)	(2)	(3)	(4)	(5)	(6)
Depvar :	$\hat{\beta}_{R,i}$	$\hat{\beta}_{R,i}$	$\hat{\beta}_{R,i}$	$\hat{\beta}_{I,i}$	$\hat{\beta}_{I,i}$	$\hat{\beta}_{I,i}$
FD	-63.53*	-80.23**	-60.78**	-0.37	-0.40	-0.22
	(32.38)	(35.38)	(26.38)	(0.40)	(0.44)	(0.51)
FD^2	50.22*	73.25**	55.48**	0.54	0.54	0.34
	(30.14)	(28.61)	(21.31)	(0.36)	(0.38)	(0.44)
CAOPEN		-5.38			0.05	
		(5.14)			(0.05)	
CAI			-7.27			-0.12
			(6.76)			(0.15)
CAO			8.16			0.03
			(6.07)			(0.12)
POP		-0.00	-0.00		0.00	0.00
		(0.00)	(0.00)		(0.00)	(0.00)
PCGDP		-0.00	-0.00		-0.00	-0.00
		(0.00)	(0.00)		(0.00)	(0.00)
PEG		-5.32	-6.08*		0.10***	0.10**
		(3.52)	(3.23)		(0.04)	(0.05)
CURR		-0.01	0.42*		0.01**	0.00
		(0.33)	(0.21)		(0.00)	(0.00)
RES		-0.05	-0.16***		0.00	0.00
		(0.11)	(0.06)		(0.00)	(0.00)
CONS	18.12**	27.46***	20.96***	0.07	0.02	0.03
	(7.30)	(9.10)	(6.42)	(0.09)	(0.12)	(0.13)
Obs	85	67	59	85	67	59

Note: Estimation by OLS with heteroscedasticity-robust standard errors. Dependent variable for models 1 through 3 is $\hat{\beta}_{R,i}$, the intensity of reserve response to US interest rate shocks. Dependent variable for models 4 through 6 is $\hat{\beta}_{I,i}$, the intensity of domestic interest rate responses to US interest rate shocks. Both $\hat{\beta}_{R,i}$ and $\hat{\beta}_{I,i}$ estimated by instrumental variables, with Acosta et al. (2025) high-frequency shock measures as instruments. FD^2 represents the square of financial development index FD. See the text for estimation details as well as other variable definitions. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

These estimates therefore again suggest a U-shaped relationship between financial development and the changes in FX reserve holdings following a U.S. interest rate shock. Moreover, the point estimates for our base specification with conditioning variables included and the

Chinn-Ito capital account openness measure (Column (2)) for FD and FD^2 are now -80.23 and 73.25 respectively, suggesting a similar threshold for the maximum level of reserve adjustment in response to global interest rate shocks. Our point estimates indicate that the change in reserves is decreasing in FD for values of FD below 0.46 and increasing in FD for values of FD above that level, similar to the 0.5 value we obtained for our base specification above with the sensitivity estimates obtained under OLS.

Our point estimates for the responses of domestic interest rates to U.S. interest rate shocks also suggest a nonlinear relationship with financial development across all of our empirical specifications, as shown in Columns (4)-(6) in the table. However, as under our OLS estimation above, these estimates are all statistically insignificant.

III. The Model

To examine the economic forces that drive the U-shaped relation between financial development and changes in FX reserve holdings, we now present a DSGE model of a small open economy. The economy is populated by a representative household, a representative entrepreneur, a representative final goods firm, and a continuum of intermediate goods firms. The central bank has two policy instruments: the nominal interest rate and holdings of foreign reserves. Households buy or sell foreign bonds subject to portfolio adjustment costs.[5]

III.1. **Households.** The representative household chooses consumption $C_{h,t}$, real money balances $\frac{M_t}{P_t}$, labor effort $H_{h,t}$, and holdings of domestic and foreign currency denominated bonds $B_{h,t}$ and F_t, to maximize the expected lifetime utility

$$\max E_0 \sum_{t=0}^{\infty} \beta_h^t \left(\ln \left(C_{h,t}\right) + \phi_m \ln \left(\frac{M_t}{P_t} \right) - \psi \frac{H_{h,t}^{1+\eta}}{1+\eta} \right), \tag{5}$$

subject to the sequence of budget constraints

$$\begin{aligned} & P_t C_{h,t} + M_t + B_{h,t} + S_t F_t + P_t \chi \Omega \left(\frac{S_t \hat{F}_t}{P_t} \right) \\ & = W_t H_{h,t} + M_{t-1} + \left(1+i_{t-1}\right) B_{h,t-1} + \left(1+i_{t-1}^*\right) S_t F_{t-1} + \Pi_t + \Pi_t^{cb}, \end{aligned} \tag{6}$$

where P_t denotes the price index, W_t denotes the nominal wage rate, i_t denotes the nominal interest rate on home currency bonds, i_t^* denotes the nominal interest rate on foreign currency bonds, S_t denotes the nominal exchange rate (in units of the home currency per unit of the

[5]If households faced no cost to buying and selling foreign bonds, then they would simply do the exact opposite of the central bank, and sterilized foreign exchange intervention would have no effect on the economy's total borrowing or any macroeconomic variables in the model (see e.g. Backus and Kehoe 1989 and Davis et al. (2021)). But when households face portfolio adjustment costs of buying and selling foreign bonds, the sterilized intervention would have real effects on equilibrium allocations.

foreign currency), Π_t and Π_t^{cb} are the profits of firms and the central bank, respectively, both are lump-sum transfers to the household. The parameter β_h is the household's discount factor.

The term $\chi\Omega\left(\frac{S_t\hat{F}_t}{P_t}\right)$ is the portfolio adjustment costs, which is a function of the household's holdings of foreign bonds, where $\hat{F}_t = F_t - F_{ss}$ and F_{ss} is the steady state value of F_t. The function $\Omega(\cdot)$ is differentiable and strictly convex and satisfies $\Omega(0) = \Omega_F(0) = 0$, where Ω_F denotes the first derivative of $\Omega(\cdot)$ with respect to F, as in Schmitt-Grohé and Uribe (2003).[6] For our analysis, we focus on the quadratic adjustment cost function

$$\Omega(\hat{x}_t) = \frac{1}{2}\left(\frac{S_t}{P_t}\right)^2 (x_t - x_{ss})^2, \tag{7}$$

where $x_t = F_t$.

The household's optimizing decisions with respect to $B_{h,t}$ and F_t lead to the generalized uncovered interest parity (UIP) condition

$$\frac{(1+i_t)}{(1+i_t^*)} = \frac{\mathrm{E}_t(\lambda_{h,t+1}S_{t+1})}{(1+\chi\Omega_{Ft})\,S_t\mathrm{E}_t(\lambda_{h,t+1})}, \tag{8}$$

where $\lambda_{h,t}$ denotes the household's marginal utility of income. The term $(1+\chi\Omega(F_t))$ is a UIP wedge stemming from costly portfolio adjustments. Since domestic and foreign bonds are imperfect substitutes, the central bank is able to influence capital flows and the exchange rate by adjusting its holdings of FX reserves.[7]

The household's optimizing decisions also imply the labor supply equation

$$C_{h,t}\psi H_{h,t}^{\eta} = \frac{W_t}{P_t}, \tag{9}$$

and the money demand equation

$$\frac{M_t}{P_t} = \phi_m C_{h,t}\frac{1+i_t}{i_t}. \tag{10}$$

III.2. **Entrepreneurs.** The representative entrepreneur maximizes the expected utility

$$\max E_0 \sum_{t=0}^{\infty} \beta_e^t \left(\log(C_{e,t}) - \psi\frac{H_{e,t}^{1+\eta}}{1+\eta}\right), \tag{11}$$

[6] Yakhin (2022) shows that to a first-order approximation, this adjustment cost is isomorphic to micro-founded models of imperfect bond substitution in Gabaix and Maggiori (2015) and Fanelli and Straub (2021).

[7] In a linearized model, we can ignore the covariance between $\lambda_{h,t+1}$ and S_{t+1}, and the $\mathrm{E}_t(\lambda_{h,t+1})$ terms cancel out of the numerator and denominator, leading to the familiar uncovered interest parity (UIP) condition with a bond adjustment cost.

subject to the flow-of-funds constraints

$$
\begin{aligned}
& P_t C_{e,t} + \left((1-\gamma_f) + \gamma_f S_t\right) B_{et} + P_t I_t \\
& = W_t H_{e,t} + R_t K_{t-1} + \left((1-\gamma_f)\left(1+i_{t-1}\right) + \gamma_f \left(1+i^*_{t-1}\right) S_t\right) B_{e,t-1},
\end{aligned} \tag{12}
$$

where $C_{e,t}$ denotes the entrepreneur's consumption, $H_{e,t}$ denotes their labor effort. B_{et} denotes the entrepreneur's debt, a fraction γ_f of which is denoted in foreign currency,[8] I_t denotes capital investment, K_{t-1} is the capital stock at the beginning of period t, R_t is the capital rental rate, and β_e is the entrepreneur's discount rate. We assume that $\beta_e < \beta_h$, such that the entrepreneur's borrowing constraint is binding in the steady state.

The capital stock evolves according to the law of motion

$$
K_t = (1-\delta) K_{t-1} + \left(1 - \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right) I_t \tag{13}
$$

where δ is the depreciation rate and $\kappa > 0$ measures the scale of investment adjustment costs.

The entrepreneur's borrowing is subject to a collateral constraint, under which the borrowing capacity is limited by a fraction θ of the value of capital. In particular, the collateral constraint is given by

$$
-\left((1-\gamma_f) + \gamma_f S_t\right) B_{e,t} \leq \theta P^k_t K_t \tag{14}
$$

where P^k_t denotes the relative price of capital (or Tobin's q).

III.3. **Final Goods Sector.** In each country there is a representative final goods firm that aggregates home and foreign intermediate goods according to

$$
Y_t = \left((1-\lambda)^{\frac{1}{\rho}} \left(Y^H_t\right)^{\frac{\rho-1}{\rho}} + \lambda^{\frac{1}{\rho}} \left(Y^F_t\right)^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}, \tag{15}
$$

where ρ is the elasticity of substitution between home and foreign goods.

The demand schedules for domestic final goods and imported goods are, respectively, given by

$$
Y^H_t = (1-\lambda)\left(\frac{P^H_t}{P_t}\right)^{-\rho} Y_t, \quad Y^F_t = \lambda \left(\frac{S_t}{P_t}\right)^{-\rho} Y_t, \tag{16}
$$

where we have normalized the foreign price level to one.

Similarly, the demand schedule for exported goods is given by

$$
Y^X_t = \left(\frac{P^H_t}{S_t}\right)^{-\rho} Y^X, \tag{17}
$$

[8] To keep the analysis tractable, we do not model the entrepreneur's portfolio choice problem with regards to the currency of denomination of their debt. Instead, we assume that a constant share γ_f of the entrepreneur's debt is denominated in the foreign currency and $1-\gamma_f$ is denominated in the local currency. We show the effects of varying this parameter from 0 to 1.

where we set the constant $Y^X = \lambda Y$ to ensure that trade is balanced in the steady state, where Y denotes steady state output in the small open economy.

The domestically produced goods are a Dixit-Stiglitz (CES) aggregation of differentiated varieties produced by a continuum of monopolistically competitive firms. In particular, the aggregation technologies are given by

$$Y_t^H = \left(\int_0^1 Y_t^H (i)^{\frac{\sigma-1}{\sigma}} \, di \right)^{\frac{\sigma}{\sigma-1}}, \quad Y_t^X = \left(\int_0^1 Y_t^X (i)^{\frac{\sigma-1}{\sigma}} \, di \right)^{\frac{\sigma}{\sigma-1}}, \tag{18}$$

where $\sigma > 1$ is the elasticity of substitution between differentiated products produced by domestic firms.

Under the CES aggregation technology, the price index of home-produced goods is given by

$$P_t^H = \left(\int_0^n P_t^H (i)^{1-\sigma} \, di \right)^{\frac{1}{1-\sigma}}, \tag{19}$$

and the consumer price index is given by

$$P_t = \left[(1-\lambda) \left(P_t^H \right)^{1-\rho} + \lambda \left(S_t \right)^{1-\rho} \right]^{\frac{1}{1-\rho}}. \tag{20}$$

III.4. **Intermediate Goods Firms.** There is a continuum of domestic intermediate goods firms, each producing a differentiated product indexed by $i \in [0,1]$, using labor and capital as inputs. Firms face monopolistic competition in the product markets and they are price-takers in the input markets. Intermediate goods can be sold in the domestic markets or exported. Each firm sets a price for its own variety, taking as given the downward-sloping demand schedules in Equations (16) and (17).

A firm producing intermediate goods of type i operates the Cobb-Douglas production technology

$$Y_t^H(i) + Y_t^X(i) = A_t N_t(i)^\alpha k_t(i)^{1-\alpha} \tag{21}$$

Firm i takes the demand schedules (16) and (17) as given and chooses its product price $P_t^H(i)$ to maximize the expected profit. Following Rotemberg (1982), we assume that firms face a quadratic price adjustment cost function. Specifically, the firm solves the profit-maximizing problem

$$\max_{P_t^H(i)} E_t \sum_{\tau=0}^{\infty} \beta^\tau \lambda_{h,t+\tau} \left[\left(P_t^H (i) - MC_t \right) \left(Y_t^H (i) + Y_t^X (i) \right) - \frac{\Omega_p}{2} \left(\frac{P_t^H (i)}{\pi P_{t-1}^H (i)} - 1 \right)^2 P_t C_{h,t} \right], \tag{22}$$

where $MC_t = \frac{1}{A_t} \left(\frac{W_t}{\alpha} \right)^\alpha \left(\frac{R_t}{1-\alpha} \right)^{1-\alpha}$ denotes the marginal cost derived from the cost-minimizing problem.

The optimal pricing decision implies the Phillips curve relation[9]

$$P_t^H(i) = \frac{\sigma}{\sigma-1} MC_t - \frac{\Omega_p}{\sigma-1} \frac{P_t C_{h,t}}{Y_t^H + Y^X} \left[\left(\frac{\pi_t^H}{\pi} - 1 \right) \frac{\pi_t^H}{\pi} - \beta E_t \left(\frac{\pi_{t+1}^H}{\pi} - 1 \right) \frac{\pi_{t+1}^H}{\pi} \right] \quad (23)$$

III.5. **Monetary Policy.** The central bank has two instruments. The first is the nominal interest rate i_t. With the second instrument, the central bank can buy and sell foreign bonds. In our baseline model, the central bank sets both instruments to maximize the sum of household and entrepreneur welfare (Ramsey policy). To highlight the role of optimal FX reserve policy, we compare the impulse responses from the baseline model with those in a counterfactual where FX reserves are held constant.

The assumption that the central bank sets the nominal interest rate to maximize the sum of household and entrepreneur welfare is a convenient benchmark to analyze the effect of giving the central bank a second instrument. Since we know that the central bank is already doing the best it can with its interest rate instrument, FX reserve policy is not making up for a deficiency in the other instrument. Later in the results section, we will experiment with setting the nominal interest rate through a simple Taylor-type feedback rule. We show that the way financial development affects optimal FX intervention, and the U-shape highlighted in the empirical section, are robust.

As shown by the household's money demand equation in equation 10, by setting the interest rate the central bank sets real money balances. Nominal money balances make up the liability side of the central bank's balance sheet, and on the asset side of the balance sheet it holds stocks of domestic and foreign currency denominated bonds:

$$M_t = B_t^{cb} + S_t F_t^{cb} \quad (24)$$

With its second instrument the central bank can adjust its stock of foreign currency denominated bonds, F_t^{cb}. We assume that this instrument is set by Ramsey optimal policy where the central bank sets policy to maximize the sum of household and entrepreneur welfare.

The other term on the asset side of the central bank's balance sheet are home currency denominated bonds that are held exclusively by home country households, entrepreneurs, and the central bank. Thus the market clearing condition for home currency denominated bonds is:

$$B_{h,t} + B_t^{cb} + (1-\gamma_f) B_{e,t} = 0 \quad (25)$$

[9]Under the log utility function, the household's optimizing problem implies that $\lambda_{ht} P_t C_{ht} = 1$.

The central bank earns a positive interest rate its bond portfolio but pays no interest on its money liabilities, so its seigniorage revenue is given by:

$$
\begin{aligned}
&(M_t - M_{t-1}) - \left(B_t^{cb} - (1 + i_{t-1}) B_{t-1}^{cb}\right) - \left(S_t F_t^{cb} - \left(1 + i_{t-1}^*\right) S_t F_{t-1}^{cb}\right) \\
&= i_{t-1} B_{t-1}^{cb} + (S_t - S_{t-1}) F_{t-1}^{cb} + i_{t-1}^* S_t F_{t-1}^{cb}
\end{aligned} \tag{26}
$$

The central bank also faces an adjustment cost, denoted by $\chi^{cb}\Omega\left(\frac{B_t^{cb}}{B_t^{cb}+S_t F_t^{cb}}\right)$, to adjusting the ratio of home to foreign bonds on its balance sheet. The function $\Omega(\cdot)$ is differentiable and strictly convex and satisfies $\Omega\left(\bar{\psi}\right) = \Omega'\left(\bar{\psi}\right) = 0$, where $\bar{\psi}$ is the steady state ratio of home to total bonds on the central bank's balance sheet.

Thus the central bank profits are given by seigniorage revenue net of any bond adjustment cost:

$$
\Pi_t^{cb} = i_{t-1} B_{t-1}^{cb} + (S_t - S_{t-1}) F_{t-1}^{cb} + i_{t-1}^* S_t F_{t-1}^{cb} - P_t \chi^{cb} \Omega\left(\frac{B_t^{cb}}{B_t^{cb} + S_t F_t^{cb}}\right) \tag{27}
$$

For purely technical reasons, χ^{cb} must be a positive number. While the overall size of the central bank's balance sheet is pinned down by money demand and is stationary, the share of home or foreign bonds on the balance sheet is not. Setting χ^{cb} to a small positive constant ensures these components of the balance sheet are also stationary.

By setting χ^{cb} to a small positive number, we are assuming that the central bank's two instruments are independent. Central bank foreign exchange actions are sterilized, and the central bank can offset the sale of foreign bonds, F_t^{cb}, by the purchase of an equivalent amount of domestic bonds, B_t^{cb} in order to keep the overall size of its balance sheet, M_t, constant. In that way the central bank's policy regarding the composition of the balance sheet and F_t^{cb} does not affect the policy regarding the overall size of the balance sheet, M_t, and vice versa.

Since M_t is linked to the nominal interest rate through the money demand equation, this sterilization allows the central bank to set the two instruments independently. In terms of the equations in the model, when $\chi^{cb} \to 0$, the central bank's balance sheet expression and the stock of money become redundant and do not affect the model. By substituting the central bank's balance sheet in (24) and the central bank's cash flow in (27) into the household's budget constraint in (6), $B_{h,t}+B_t^{cb}$ appears on the left- and right-hand sides of the household budget constraint (lagged by one period on the right-hand side). By substituting in the market clearing condition for domestic currency bonds in (25), $-(1-\gamma_f) B_{e,t}$ appears on the left and right hand sides of the household's budget constraint (again, lagged by one period on the right hand side). Once making these substitutions, the central bank's stock of domestic currency bonds disappears from the model except for the central bank's balance sheet. Thus the central bank can always adjust the two instruments freely and the central bank's stock of domestic bonds will adjust to make sure the balance sheet condition holds.

This is not true when χ^{cb} is non-trivial. Now the central bank faces a resource cost for deviating from its steady state ratio of home and foreign bonds. After a sale of foreign bonds, the central bank faces a cost for sterilizing this foreign exchange intervention by conducting an equivalent purchase of domestic bonds, since this will raise the ratio $\frac{B_t^{cb}}{B_t^{cb}+S_t F_t^{cb}}$. It will instead buy fewer domestic bonds, resulting in a contraction of the overall balance sheet. In this way the central bank sale of foreign bonds is only partially sterilized. Since the overall size of the balance sheet is equal to the money supply, which is linked to the nominal interest rate through the money demand equation, the central bank faces a resource cost to discourage it from adjusting one instrument without adjusting the other.

When foreign exchange reserve sales or purchases are not sterilized, the central bank's balance sheet is not redundant. The focus of this paper is on the trade-offs inherent in FX reserve policy, and thus we abstract from these complicating factors like unsterilized intervention. We leave unsterilized intervention and the trade-offs the central bank faces when it can't adjust its two instruments independently, as an interesting direction for further research.

III.6. **Market clearing and the balance of payments.** In an equilibrium, the domestic bond market, the labor market, and the final goods market all clear. Bond market clearing was discussed in the last subsection. The labor market clearing condition is given by

$$H_{h,t} + H_{e,t} = N_t. \tag{28}$$

The final goods market clearing condition is given by

$$Y_t = C_{h,t} + C_{e,t} + I_t + \frac{\Omega_p}{2}\left(\pi_t^H - 1\right)^2 C_{h,t} + \chi\Omega\left(s_t \hat{f}_t\right) + \chi^{cb}\Omega\left(\frac{b_t^{cb}}{b_t^{cb} + s_t f_t^{cb}}\right) \tag{29}$$

Aggregating the budget constraints of the households, the entrepreneurs, and the central bank, we obtain the balance of payments identity

$$CA_t = KA_t + \Delta R_t, \tag{30}$$

where CA_t denotes the current account balances, KA_t denotes the capital account balances, and ΔR_t denotes changes in FX reserves held by the central bank.

Specifically, the current account is equal to net exports (national production minus national consumption and investment) plus net primary interest income (net interest income on foreign currency denominated bonds):

$$\begin{aligned} CA_t = {} & W_t H_{h,t} + W_t H_{e,t} + R_t K_{t-1} + \Pi_t - P_t C_t - P_t C_{e,t} - P_t I_t \\ & + i^*_{t-1} S_t F_{t-1} + i^*_{t-1} S_t F^{cb}_{t-1} - P_t \chi \Omega \left(\frac{S_t \hat{F}_t}{P_t} \right) - P_t \chi^{cb} \Omega \left(\frac{S_t \hat{F}^{cb}_t}{P_t} \right). \end{aligned} \tag{31}$$

The capital account is equal to the negative change in the household's stock of foreign currency denominated bonds:

$$KA_t = S_t F_t - S_t F_{t-1}. \tag{32}$$

Finally, the change in the central bank's stock of foreign currency denominated bonds is given by

$$\Delta R_t = S_t F^{cb}_t - S_t F^{cb}_{t-1}. \tag{33}$$

IV. Parameter calibration

We solve the model based on calibrated parameter values. Table 3 shows the calibrated parameters.

The first four parameters: the labor share in production, the capital depreciation rate, the elasticity of substitution across domestic varieties, and the inverse of the labor supply elasticity, are all set to values that are common in the literature.

The household discount factor is set such that the steady-state risk-free interest rate is about 4% annualized. The entrepreneur discount factor is set such that in the steady state, the spread between the entrepreneur's borrowing interest rate and the risk-free rate is about 8% annualized.

The investment adjustment cost is set to the estimated value in Christiano et al. (2005). The elasticity of substitution between home and foreign goods is set to 0.9 and is close to the value of the short-run trade elasticity estimated by Boehm et al. (2023).

The steady-state import share is set to 25%. The price stickiness parameter is set to the value from Chang et al. (2015). The household's adjustment cost for holding foreign bonds is also set to match the value from Chang et al. (2015), although their functional form for the adjustment cost is slightly different, so we need to do a slight transformation to their value. The central bank's cost for adjusting the share of domestic and foreign bonds on their balance sheet is simply set to a small positive number. It needs to be positive to ensure stationarity of the model, but we set it very small to reflect the fact that the central bank can buy and sell foreign bonds much more easily than the household.

The final two parameters in the table: the loan-to-value ratio, θ, and the share of entrepreneur debt denominated in foreign currency, γ_f, are the key parameters in the model for determining the size of the externality due to the presence of foreign currency debt in the

Table 3. Parameter Values

Parameter	Value	Description
α	0.66	Labor share in production
δ	0.025	capital depreciation rate
σ	10	elasticity of substitution across domestic varieties
η	1	inverse of labor supply elasticity
β_h	0.99	household discount factor
β_e	0.97	entrepreneur discount factor
κ	2.48	investment adjustment cost
ρ	0.9	elasticity of substitution between home and foreign goods
λ	0.25	steady-state import share
Ω_p	60	price stickiness parameter
χ^b	0.02	household foreign bond adjustment cost
χ^{cb}	0.001	central bank foreign bond adjustment cost
θ	0.44	loan to value ratio
γ_f	0.85	share of entrepreneur debt denominated in foreign currency

entrepreneur's borrowing constraint. As shown in Figure 1, both the credit-to-GDP ratio and the share of debt denominated in foreign currency vary systematically with an economy's level of financial development. We use that fact to calibrate θ and γ_f.

The red dashed line in each scatter plot in Figure 1 is a simple quadratic trend line showing how the credit-to-GDP ratio in country i, $cred_i$, or the share of external debt denominated in a foreign currency, fc_i, vary with the economy's level of final development, FD_i.

$$cred_i = 0.022 + 1.55FD_i - 0.003FD_i^2 \tag{34}$$

$$fc_i = 1.03 - 0.03FD_i - 0.66FD_i^2 \tag{35}$$

Before calibrating the θ and γ_f parameters in the model we need a mapping between $cred$ and fc in the data and these two parameters in the model. First, we simply assume that the share of external debt denominated in foreign currency in the data, fc, is a proxy for the share of entrepreneur debt denominated in foreign currency in the model, γ_f (for very small values of FD, the estimated trend line of fc is slightly above 1, here assume that γ_f takes a maximum value of 1). Second, $cred$ measures credit to annualized GDP, and the loan-to-value parameter θ measures credit to the value of the capital stock. Thus to convert the measure of $cred$ in the data into a calibrated value of θ in the model, we need to multiply by the steady state ratio of annualized GDP to capital in the model, $\frac{GDP}{K} = \frac{4r}{(1-\alpha)}$, where r is the steady state capital rental rate. Thus for a given value of $cred$, the calibrated value of θ is $\frac{4\left(\frac{1}{\beta^e}-1+\delta\right)cred}{1-\alpha-cred\frac{\beta^h-\beta^e}{\beta^e}}$.

The values of θ and γ_f in Table 3 are the values of these two parameters that the model needs to match $cred$ and fc for an emerging market country where $FD = 0.5$. Later, we present results from the model varying these two parameters. We will consider how θ and γ_f vary as FD varies from 0 to 1. Using this mapping θ varies from 0.02 to 0.75 and γ_f varies from 1 to 0.33.[10]

V. Model implications

To examine the model's quantitative implications, we solve the optimal Ramsey policy problem and simulate the model based on the calibrated parameters.

V.1. **Impulse responses.** To help understand the model's transmission mechanism, we compute impulse responses of a few key endogenous variables to a shock to the foreign interest rate. We highlight the importance of FX reserve adjustments by comparing the impulse responses in our baseline model with optimal Ramsey policy to those in a counterfactual environment where FX reserves are held constant at the steady-state level. We also illustrate how the optimal FX adjustments depend on the level of financial development by comparing the predictions of the baseline model with a calibrated level of financial development to those in a counterfactual economy with either a very low or a very high level of financial development.

V.1.1. *The role of optimal FX reserve adjustments.* Figure 2 shows the impulse responses in the baseline model where we calibrate θ and γ_f to match an economy with an intermediate level of financial development (i.e., with $FD = 0.5$). An exogenous increase in the foreign interest rate induces private households to increase their holdings of foreign-currency bonds, leading to outflows of private capital, reducing the loanable funds for domestic entrepreneurs and therefore tightening the entrepreneurs' borrowing constraints. The increased household saving and reduced entrepreneur borrowing lead to an increase in the current account and

[10]The household's foreign bond adjustment cost, χ_b, is probably another parameter that varies in obvious ways with financial development. This parameter is related to the concept of market depth, and it is likely smaller for financially developed countries. This paper however is focused on the externality caused by foreign currency debt in the borrowing constraint, which leads us to specifically focus on the parameters θ and γ_f. We leave the implications of varying market depth or χ_b as an interesting direction for further research.

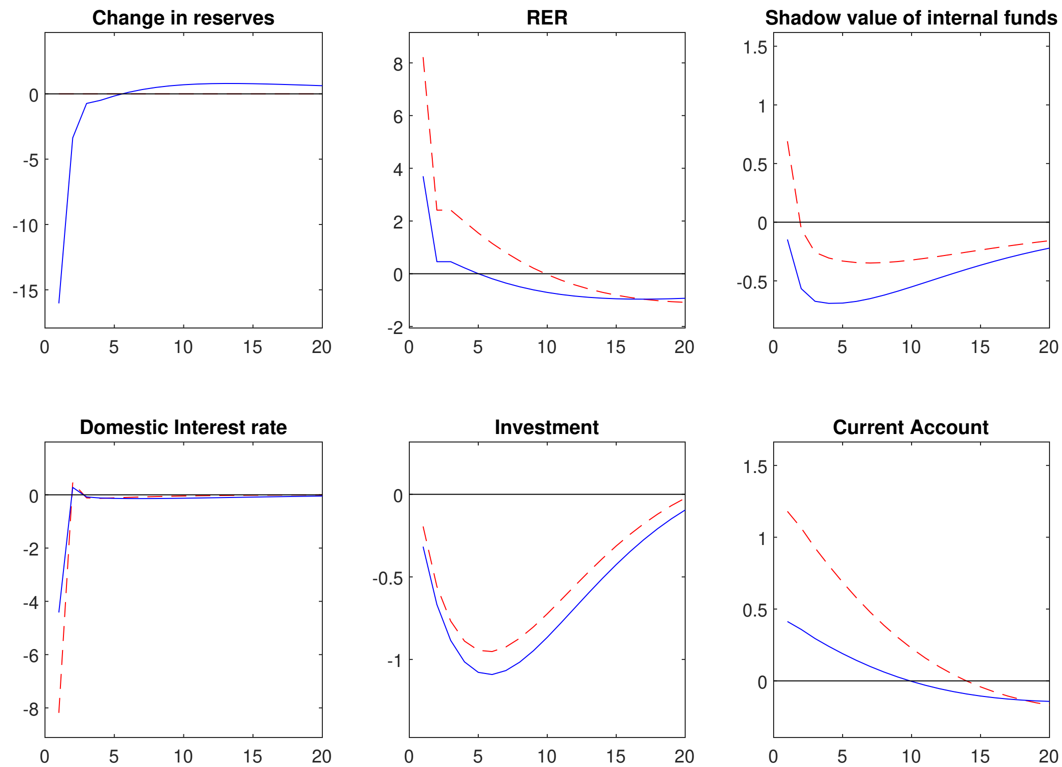

FIGURE 2. Impulse responses following a positive 1% foreign interest rate shock in the baseline economy under Ramsey optimal policy

Notes: Blue line is from the model where FX reserve policy is set to maximize welfare (Ramsey). The red dashed line is from the model where FX reserves are held constant. The θ and γ_f are calibrated to match a country with FD=0.5, $\theta = 0.44$ and $\gamma_f = 0.85$. All other parameters are set to the benchmark values in Table 3.

an appreciation of the exchange rate, which further tightens the borrowing constraint by raising the real value of entrepreneur debt.

The borrowing constraints create a pecuniary externality because households do not internalize the effects of their collective savings decisions on the exchange rate and the real value of debt. The tightening borrowing constraint leads to further reductions in entrepreneur borrowing and thus further increases in the current account and exchange rate depreciation. As the borrowing conditions are tightened, the shadow value of internal funds (i.e., the Lagrangian multiplier associated with the entrepreneurs' borrowing constraints) rises.

Figure 2 shows that, under Ramsey optimal policy (blue solid line), the central bank intervenes by selling its FX reserves (the left panel of the top row). The central bank leans against the wind and dis-saves when the private sector is saving. This reduces the current account (the right panel of the bottom row) and limits the depreciation of the exchange rate (the middle panel of the top row).

This mitigates the tightening of the entrepreneurs' borrowing constraints, lowering the shadow value of internal funds (the right panel of the top row). The required interest rate cut under optimal Ramsey policy is also smaller than that when FX reserves are held constant (the left panel of the bottom row). The more aggressive cut in the domestic interest rate in the counterfactual economy with fixed FX reserves alleviates the declines in domestic investment (the middle panel of the bottom row), reflecting that investment is sensitive to changes in domestic interest rate.

V.1.2. *Financial development and FX reserve policy.* The effectiveness of FX reserve intervention depends on the level of financial development. To illustrate this point, we now consider two extreme cases: one with a very low level of financial development (i.e., with $FD = 0$) and the other with a very high level of financial development ($FD = 1$). We compare the impulse responses in these extreme cases to those in the baseline economy with an intermediate level of financial development ($FD = 0.5$).

We calibrate the loan-to-value ratio θ and the share of foreign currency debt γ_f to target the level of financial development. In particular, for the economy with FD =0, we set $\theta = 0.02$ and $\gamma_f = 1$. Thus, this economy has very little leverage and 100 percent of the debt is denominated in the foreign currency. For the other economy with FD = 1, we set $\theta = 0.75$ and $\gamma_f = 0.33$, such that the economy has a high level of debt, but it is mostly denominated in the domestic currency.

Figure 3 shows that, in the economy with $FD = 0$, the central bank actually finds it optimal to buy foreign bonds after the shock. Instead of leaning against the wind, the central bank leans with the wind! Optimal FX reserve adjustments lead to sharper RER depreciation and tighter borrowing constraints than in the counterfactual with a constant level of FX reserves. Since entrepreneurs have very little external debt ($\theta = 0.02$) in this economy, the tightening of borrowing constraints has much smaller adverse impacts on investment than in the baseline economy, despite that all debt is denominated in the foreign currency and that RER depreciates sharply. Thus, the benefit of selling FX reserves is limited. With a higher foreign interest rate, the central bank optimally chooses to buy foreign reserves, reinforcing the private outflows, leading to a sharp increase in the current account surplus. With very little external debt, the foreign interest rate shock has also relatively muted impacts on the domestic interest rate under optimal policy. Overall, with very little debt, the central bank is not concerned about the pecuniary externality associated with borrowing constraints, and

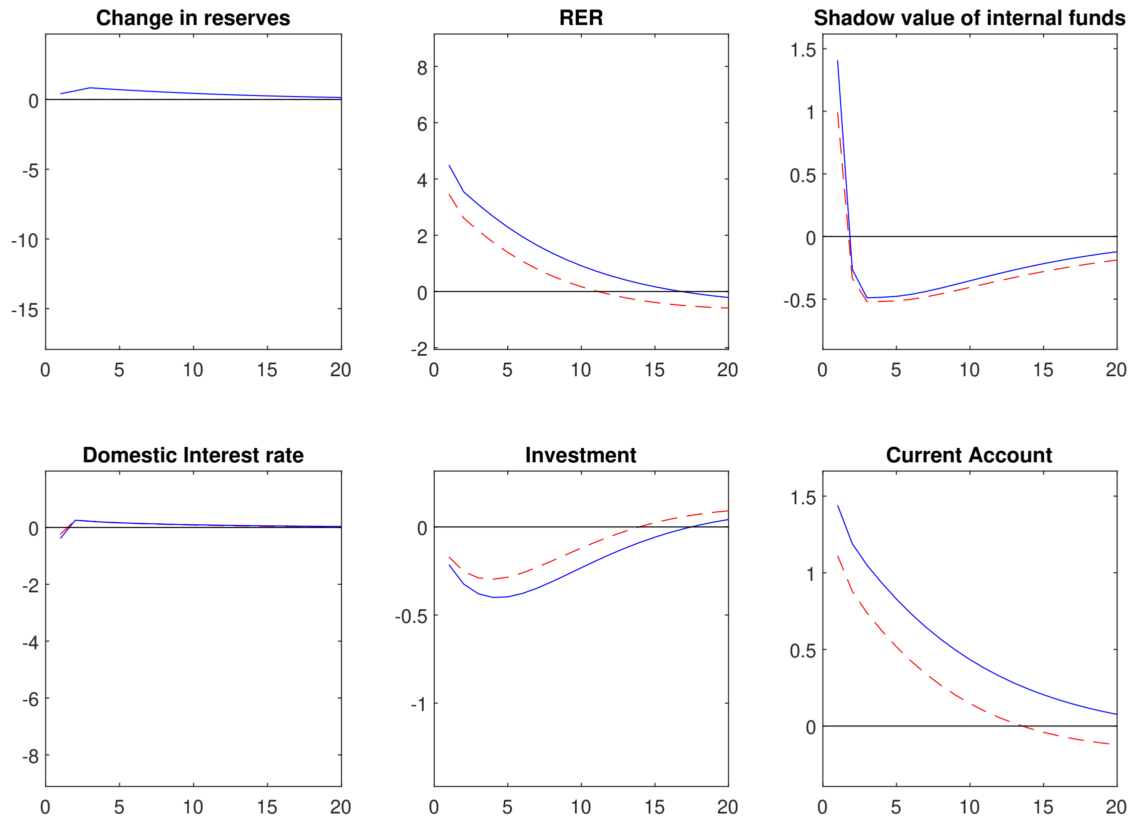

FIGURE 3. Impulse responses following a positive 1% foreign interest rate shock in an economy with a low level of financial development

Notes: Blue line is from the model where FX reserve policy is set to maximize welfare (Ramsey). The red dashed line is from the model where FX reserves are held constant. The θ and γ_f are calibrated to match a country with FD=0, $\theta = 0.02$ and $\gamma_f = 1$. All other parameters are set to the benchmark values in Table 3.

the search-for-yield motive dominates, raising the central bank's holdings of FX reserves following the increase in the foreign interest rate.

In the other extreme with $FD = 1$, entrepreneurs have high leverage ($\theta = 0.75$), but most debt is denominated in the domestic currency ($\theta_f = 0.33$). Figure 4 shows the impulse responses to an increase in the foreign interest rate under optimal Ramsey policy (blue solid line) and in the counterfactual with FX reserves held constant at the steady-state level (red dashed line). As in the baseline economy, the shock induces households to increase their holdings of foreign bonds and thus leads to private capital outflows and exchange rate depreciation. However, since entrepreneurs in this economy are more levered but less exposed to exchange rate fluctuations, selling FX reserves is less effective in stabilizing the macroeconomic effects of the shock. Here, again, the central bank leans with the wind and

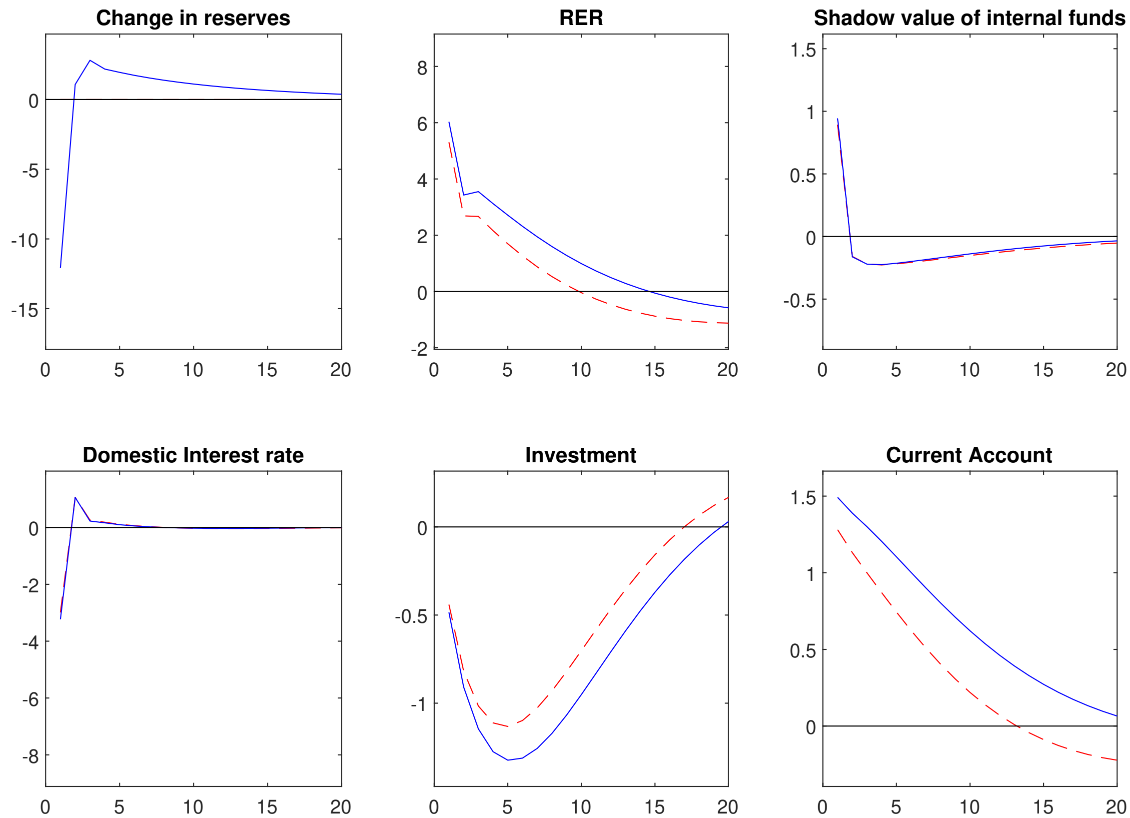

FIGURE 4. Impulse responses following a positive 1% foreign interest rate shock in an economy with a high level of financial development

Notes: Blue line is from the model where FX reserve policy is set to maximize welfare (Ramsey). The red dashed line is from the model where FX reserves are held constant. The θ and γ_f are calibrated to match a country with FD=1, $\theta = 0.75$ and $\gamma_f = 0.33$. All other parameters are set to the benchmark values in Table 3.

engages in a policy that supports increased private sector saving, leading to further exchange rate depreciation.

V.2. **Non-linear relations between FX reserve adjustments and financial development.** Section II presents evidence that,following an increase in the U.S. interest rate, the adjustments of FX reserves are a nonlinear function of a country's level of financial development. The evidence suggests a U-shaped relation: countries with intermediate levels of financial development sell FX reserves aggressively, whereas those with low or high levels adjust little. In comparison, the evidence indicates no clear relations of the domestic interest rate responses with financial development. We now show that our model's predictions are consistent with the evidence.

Figure 5 shows how the central bank FX reserves respond to fluctuations in the foreign interest rate as a function of FD. The vertical axes in the figure show the correlation between FX reserve adjustments and the foreign interest rate measured by

$$\beta_R = \frac{Cov\left(f^{cb}, i^*\right)}{16 var\left(i^*\right)},$$

where f^{cb} denotes the central bank's FX reserve adjustments following a shock to the foreign interest rate i^*.[11]

In our model, financial development depends on two parameters: the loan-to-value ratio θ and the share of foreign currency debt γ_f. We vary those two parameters—one at a time—such that FD varies between 0 and 1. The upper-left panel of Figure 5 shows that, when θ increases while γ_f remains at its calibrated value, β_R declines monotonically. At very low values of θ, the central bank buys FX reserves following an increase in the foreign interest rate, consistent with the impulse responses for a country with a very low level of financial development (shown in Figure 3). With a very low level of θ, entrepreneurs do not have much debt. The central bank is not concerned about the pecuniary externality associated with the borrowing constraints. Instead, it buys FX reserves to capture the higher yields on foreign assets. As θ increases, the entrepreneurs face higher leverage, and the central bank chooses to lean against the capital outflow pressures by selling FX reserves. Selling FX reserves helps mitigate the distortions from the pecuniary externality and also alleviates currency depreciation.

The upper-mid panel of Figure 5 shows that, when the share of domestic-currency debt (i.e., $1-\gamma_f$) rises (holding θ and the other parameters at their calibrated values), the central bank optimally chooses to slow the pace of selling FX reserves following the foreign interest rate shock. When there is less foreign-currency debt (moving from the left to the right of the x-axis), there is less need to stabilize the exchange rate by selling FX reserves. When the share of domestic-currency debt is sufficiently high (above 60 percent), the central bank finds it optimal to buy FX reserves to capture the higher yields on foreign assets.

[11]The 16 in the denominator comes from the fact that the model is quarterly model but all statistics in the data are annualized. The reserve-to-GDP ratio in the model measures reserves to quarterly GDP, but in the data it measures reserves to annual GDP, so the value of reserves-to-GDP in the model should be divided by 4 to compare the moment from the model to the moment from the data (and thus the covariance in the numerator of β_R should be divided by 4). In addition, the interest rates in the model are quarterly interest rates, but in the data the interest rates are annualized. Thus the covariance in the numerator of β_R should be divided by 4 and the variance in the denominator should be divided by 16. Taken together these two adjustments mean that the statistic β_R in the model should be divided by 16 to compare with the statistic in the data in Table 1.

When we combine the variations in θ and γ_f together such that FD increases from 0 to 1, the model predicts a U-shaped relation between the responses of FX reserves to the foreign interest rate shock and the level of FD, as shown in The upper-right panel of the figure. The response of reserve holdings is U-shaped, with the most active selling of foreign exchange reserves occurring when $FD \approx 0.44$ and less active selling of foreign exchange reserves, or even buying foreign exchange reserves, for low or high levels of FD.

This U-shaped relation of FX adjustments with FD does not hinge upon the specific Ramsey interest rate policy. The model continues to predict a U-shaped relation when the central bank sets the domestic interest rate following a Taylor rule. Specifically, we consider the Taylor rule

$$i_t - \bar{i} = \theta_i \left(i_{t-1} - \bar{i}\right) + (1 - \theta_i) \left[\theta_p \left(\pi_t - \pi\right) + \theta_Y \left(\frac{Y_t}{\bar{Y}} - 1\right) + \theta_s \left(\frac{S_t}{P_t} - 1\right)\right] \tag{36}$$

where $\bar{i}$ is the steady state level of the nominal interest rate, $\bar{Y}$ is the steady state level of output, and $\frac{S_t}{P_t}$ is the real exchange rate.[12] The inclusion of the real exchange rate in the Taylor rule reflects the "fear of floating," as documented by Calvo and Reinhart (2002) and recently modeled by Bianchi and Coulibaly (2026). The latter shows how this "fear of floating" can arise in a model with multiple equilibria, where exchange rate depreciation pushes the economy into the bad equilibria. We are not modeling that here, so instead we capture this "fear of floating" by replacing Ramsey policy for the interest rate with this Taylor rule with a term related to exchange rate stabilization.[13]

The bottom panels of Figure 5 show the variations in β_R for a range of variations in θ or γ_f (when we vary one parameter at a time) and for different levels of FD. When the domestic interest rate follows the Taylor rule instead of the Ramsey policy, the model continues to predict a U-shaped relation between β_R and FD.

Comparing the top and the bottom panels of Figure 5 shows that, when the interest rate is determined by a Taylor rule, all curves have the same shape but shift down. When the nominal interest rate instrument is constrained to match the Taylor rule, it is more restrictive than under Ramsey, so the central bank introduces more policy easing through FX reserve policy. But this leads to a shift in the curves, not a change in shape. Whether interest rate policy is determined by Ramsey policy or a Taylor rule, the trade-off between a private sector that wishes to save and a central bank that internalizes the borrowing constraint externality is the same.

[12] Recall that S_t is the nominal exchange rate in units of the home currency per units of the foreign currency, P_t is the home price level, and the foreign price level has been normalized to one.

[13] We parameterize the Taylor rule by assuming that $\theta_i = 0.9$, $\theta_p = 1.5$, $\theta_Y = 0.5/4$, and $\theta_s = 0.4$ as in Ghosh et al. (2016).

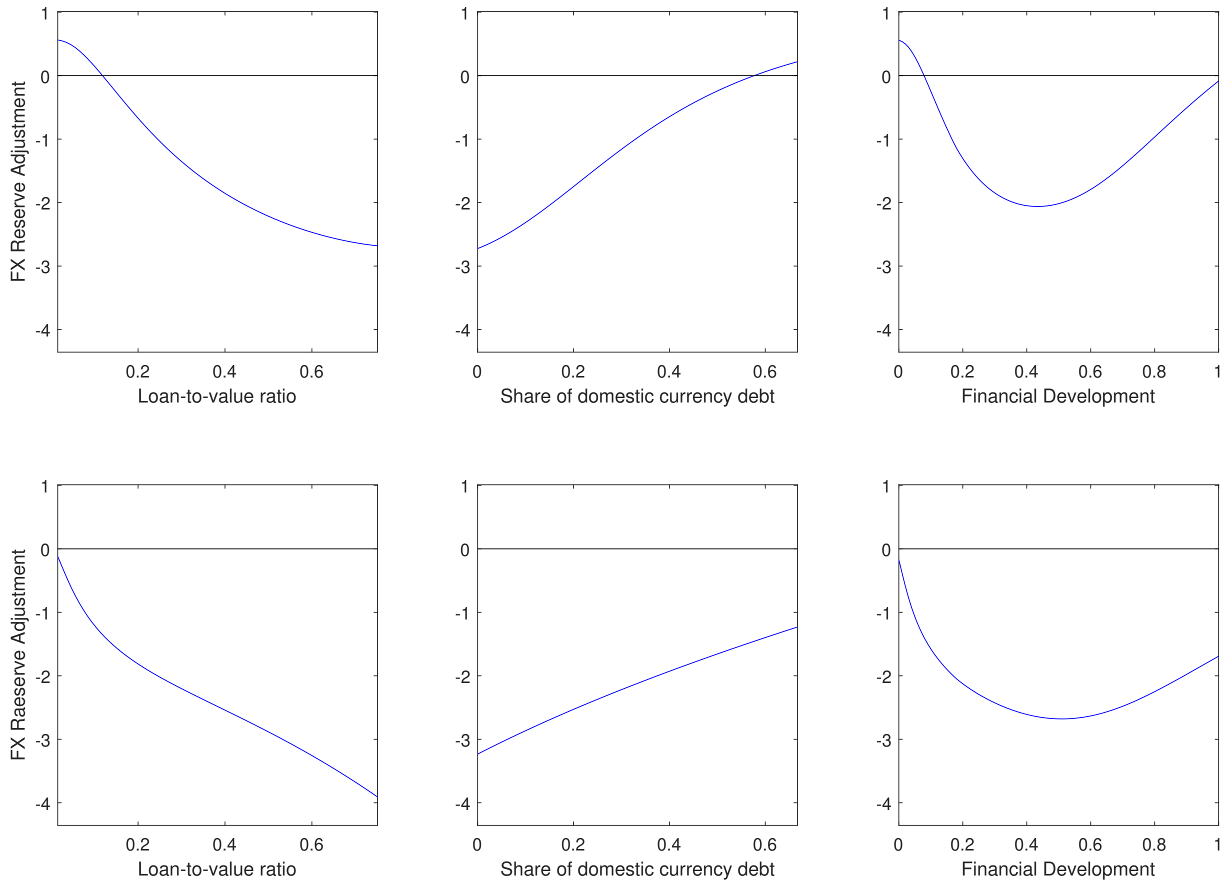

FIGURE 5. Covariance between the foreign interest rate and central bank foreign reserves

Notes: The top panel presents the response of FX reserves to a shock when the interest rate is determined by Ramsey optimal policy, the bottom panel presents the response when the interest rate is determined by a Taylor rule. The left panel varies the loan-to-value ratio, θ, holding all else constant. The middle panel varies the share of entrepreneur debt denominated in the foreign currency, γ_f, holding all else constant. The right panel varies both θ and γ_f as a function of financial development, as described in the text.

VI. CONCLUSION

We have documented empirical evidence that central banks use both FX reserves and domestic interest rates as policy instruments to respond to U.S. interest rate increases. The evidence shows a U-shaped relationship between financial development and the changes in FX reserve holdings following a U.S. interest rate shock. Those countries with an intermediate level of financial development sell FX reserves more aggressively than those with low or high levels of financial development.

We have presented a DSGE model of a small open economy that helps explain these empirical patterns. We show that two key features of the model—borrowing constraints and foreign-currency debt—are crucial for explaining the observed U-shaped relation between the FX reserve adjustments and financial development following a foreign interest rate shock. An increase in the foreign interest rate leads to private capital outflows, reducing the loanable funds to finance domestic investment. The shock also leads to domestic currency depreciation, raising the debt servicing costs for domestic firms, further tightening their borrowing constraints. We show that the size of the pecuniary externality associated with the borrowing constraints varies nonlinearly with financial development, depending on two parameters: the average loan-to-value ratio (LTV) and the share of foreign-currency debt. When we calibrate these two parameters to match their observed relations with financial development, the model reproduces the observed U-shaped relation between FX adjustments and financial development under optimal FX reserve policy. We further show that this U-shaped relation is robust to alternative assumptions about the conventional interest-rate policy.

For tractability of our analysis, we have assumed full commitment in adjusting FX reserve holdings under Ramsey policy. We have also assumed that the share of foreign currency debt is exogenously fixed. In reality, however, the share of foreign currency debt may be related to policy credibility. In our view, generalizing our model in these directions should be an important and promising avenue for future research.

References

Acosta, Miguel, Andrea Ajello, Michael D. Bauer, Francesca Loria, and Silvia Miranda-Agrippino, "Financial Market Effects of FOMC Communication: Evidence from a New Event-Study Database," Working Paper Series 2025-30, Federal Reserve Bank of San Francisco Dec 2025.

Agénor, Pierre-Richard, Timothy P Jackson, and Luiz A Pereira da Silva, *Foreign exchange intervention and financial stability*, Bank for International Settlements, Monetary and Economic Department, 2020.

Aizenman, Joshua, Sy-Hoa Ho, Luu Duc Toan Huynh, Jamel Saadaoui, and Gazi Salah Uddin, "Real exchange rate and international reserves in the era of financial integration," *Journal of International Money and Finance*, 2024, *141*, 103014.

Arango-Lozano, Lucía, Lukas Menkhoff, Daniela Rodríguez-Novoa, and Mauricio Villamizar-Villegas, "The effectiveness of FX interventions: A meta-analysis," *Journal of Financial Stability*, 2020, p. 100794.

Backus, David K and Patrick J Kehoe, "On the denomination of government debt: a critique of the portfolio balance approach," *Journal of Monetary Economics*, 1989, *23* (3), 359–376.

Benes, Jaromir, Andrew Berg, Rafael A Portillo, and David Vavra, "Modeling sterilized interventions and balance sheet effects of monetary policy in a New-Keynesian framework," *Open Economies Review*, 2015, *26* (1), 81–108.

Benigno, Gianluca, Luca Fornaro, and Martin Wolf, "Reserve accumulation, growth and financial crises," *Journal of International Economics*, 2022, *139*, 103660.

Bianchi, Javier and César Sosa-Padilla, "Reserve accumulation, macroeconomic stabilization and sovereign risk," *Review of Economic Studies*, 2024, *91*, 2053–2103.

——— **and Louphou Coulibaly**, "A theory of fear of floating," *Journal of Monetary Economics*, 2026, *157*, 103869.

Boehm, Christoph E, Andrei A Levchenko, and Nitya Pandalai-Nayar, "The long and short (run) of trade elasticities," *American Economic Review*, 2023, *113* (4), 861–905.

Bénétrix, Agustin S., Philip R. Lane, and Jay C. Shambaugh, "International currency exposures, valuation effects and the global financial crisis," *Journal of International Economics*, 2015, *96*, S98–S109.

Calvo, Guillermo A. and Carmen M. Reinhart, "Fear of Floating," *The Quarterly Journal of Economics*, 05 2002, *117* (2), 379–408.

Castillo, Paul, Ruy Lama, and Juan Pablo Medina, "Escaping the Financial Dollarization Trap: The Role of Foreign Exchange Intervention," Technical Report, International

Monetary Fund 2024.

Cavallino, Paolo, "Capital flows and foreign exchange intervention," *American Economic Journal: Macroeconomics*, 2019, *11* (2), 127–170.

Céspedes, Luis Felipe and Roberto Chang, "Optimal foreign reserves and central bank policy under financial stress," *American Economic Journal: Macroeconomics*, 2024, *16* (3), 230–267.

Chang, Chun, Zheng Liu, and Mark M Spiegel, "Capital controls and optimal Chinese monetary policy," *Journal of Monetary Economics*, 2015, *74*, 1–15.

Christiano, Lawrence J, Martin Eichenbaum, and Charles L Evans, "Nominal rigidities and the dynamic effects of a shock to monetary policy," *Journal of political Economy*, 2005, *113* (1), 1–45.

Davis, J Scott, Ippei Fujiwara, Kevin XD Huang, and Jiao Wang, "Foreign exchange reserves as a tool for capital account management," *Journal of Monetary Economics*, 2021, *117*, 473–488.

———, Michael B Devereux, and Changhua Yu, "Sudden stops and optimal foreign exchange intervention," *Journal of International Economics*, 2023, *141*, 103728.

Devereux, Michael B and James Yetman, "Globalisation, pass-through and the optimal policy response to exchange rates," *Journal of International Money and Finance*, 2014, *49*, 104–128.

Devereux, Michael B. and Steve Pak Yeung Wu, "Foreign Reserves Management and Original Sin," November 2023. NBER Working Paper No. 30418.

Driskill, Robert and Stephen McCafferty, "Exchange-rate variability, real and monetary shocks, and the degree of capital mobility under rational expectations," *The Quarterly Journal of Economics*, 1980, *95* (3), 577–586.

Eichengreen, Barry, Ricardo Hausmann, and Ugo Panizza, "The pain of original sin," *Other people's money: Debt denomination and financial instability in emerging market economies*, 2005, pp. 13–47.

Fanelli, Sebastián and Ludwig Straub, "A theory of foreign exchange interventions," *The Review of Economic Studies*, 2021, *88* (6), 2857–2885.

Fernández, Andres, Michael Klein, Alessandro Rebucci, Martin Schindler, and Martín Uribe, "Capital Control Measures: A New Dataset," *IMF Economic Review*, 2016, *64* (3), 548–574.

Gabaix, Xavier and Matteo Maggiori, "International liquidity and exchange rate dynamics," *The Quarterly Journal of Economics*, 2015, *130* (3), 1369–1420.

Ghosh, Atish R, Jonathan D Ostry, and Marcos Chamon, "Two targets, two instruments: Monetary and exchange rate policies in emerging market economies," *Journal of*

International Money and Finance, 2016, *60*, 172–196.

Jeanne, Olivier and Damiano Sandri, "Global financial cycle and liquidity management," *Journal of International Economics*, 2023, *146*, 103736.

Kouri, Pentti JK, "The Exchange Rate and the Balance of Payments in the Short Run and in the Long Run: A Monetary Approach," *The Scandinavian Journal of Economics*, 1976, pp. 280–304.

Liu, Zheng and Mark M. Spiegel, "Optimal Monetary Policy and Capital Account Restrictions in a Small Open Economy," *IMF Economic Review*, Sep 2015, *63* (2), 298–324.

Ma, Chang and Hidehiko Matsumoto, "Foreign Reserves and Capital Controls: A Financial Development Perspective," *Available at SSRN 4698033*, 2024.

Montoro, Carlos, Marco Ortiz et al., "Foreign exchange intervention and monetary policy design: a market microstructure analysis," *Banco Central de Reserva des Perú Working Paper*, 2016, *8.*

Ottonello, Pablo, "Optimal exchange-rate policy under collateral constraints and wage rigidity," *Journal of International Economics*, 2021, *131*, 103478.

Rey, Hélène, "Dilemma not trilemma: the global financial cycle and monetary policy independence," *NBER Working Paper No. 21162*, 2015.

Rotemberg, Julio J., "Monopolistic Price Adjustment and Aggregate Output," *The Review of Economic Studies*, 1982, *49* (4), 517–531.

Schmitt-Grohé, Stephanie and Martın Uribe, "Closing small open economy models," *Journal of international Economics*, 2003, *61* (1), 163–185.

Shambaugh, Jay C, "The Effect of Fixed Exchange Rates on Monetary Policy," *The Quarterly journal of economics*, 2004, *119* (1), 301–352.

Yakhin, Yossi, "Breaking the UIP: A Model-Equivalence Result," *Journal of Money, Credit and Banking*, 2022, *54* (6), 1889–1904.

Online Appendix

In the first section of the appendix we will present the summary statistics for the data and some other details related to the empirical results section. In the second section of the appendix we present the full list of variables and equilibrium conditions for the model.

Appendix A. Summary statistics of the data

Table A1 shows the summary statistics of the variables used in our empirical analysis. Table A2 shows the list of countries included in our sample.

Table A1. Summary statistics

	1	2	3	4	5
	Obs.	Mean	Std. Dev.	Min	Max
$\hat{\beta}_{R,i}$ (OLS)	67	-0.87	5.14	-11.90	11.97
$\hat{\beta}_{I,i}$ (OLS)	67	0.08	0.13	-0.18	0.46
$\hat{\beta}_{R,i}$ (IV)	67	0.99	10.04	-18.46	41.86
$\hat{\beta}_{I,i}$ (IV)	67	0.05	0.14	-0.25	0.37
FD	67	0.49	0.21	0.20	0.87
CAOPEN	67	0.67	0.33	0.00	1.00
POP	67	43896.73	60649.14	107.31	210707.00
PCGDP	67	20537.37	19330.92	1123.83	69110.84
USPEG	67	0.19	0.40	0.00	1.00
CURR	67	-0.64	5.80	-17.38	18.86
RES	67	19.10	17.24	1.12	73.27
CAO	59	0.37	0.36	0.00	1.00
CAI	59	0.32	0.31	0.00	1.00

Note: Summary statistics for base sample using Chinn-Ito index of capital account openness (CAPOPEN), except for CAI and CAO, whose summary statistics are reported for base sample using those capital account openness indicators. $\hat{\beta}_{R,i}$ (OLS) and $\hat{\beta}_{I,i}$ (OLS) represent responsiveness of reserves and domestic interest rates respectively as estimated by OLS (reported in Table 1), while $\hat{\beta}_{R,i}$ (IV) and $\hat{\beta}_{I,i}$ (IV) represent responsiveness of reserves and domestic interest rates respectively as estimated by IV (reported in Table 2). See text for definitions of other conditioning variables.

Table A2. Countries in sample

	1 Base Sample	2 FD
Argentina	Yes	0.296
Aruba, Kingdom of the Netherlands	No	0.255
Australia	Yes	0.870
Azerbaijan, Rep. of	No	0.217
Bahamas, The	Yes	0.428
Bangladesh	Yes	0.214
Belgium	Yes	0.657
Belize	Yes	0.212
Bolivia	Yes	0.232
Bosnia and Herzegovina	No	0.226
Brazil	Yes	0.581
Bulgaria	No	0.352
Cabo Verde	Yes	0.223
Canada	Yes	0.828
Chile	Yes	0.493
China, P.R.: Hong Kong	Yes	0.759
China, P.R.: Mainland	Yes	0.566
Colombia	Yes	0.343
Costa Rica	Yes	0.248
Croatia, Rep. of	No	0.445
Cyprus	Yes	0.579
Czech Rep.	No	0.405
Denmark	Yes	0.695
Egypt, Arab Rep. of	Yes	0.286
Estonia, Rep. of	No	0.298
Finland	Yes	0.592
France	Yes	0.713
Georgia	No	0.201
Germany	Yes	0.749
Greece	Yes	0.561
Guatemala	Yes	0.204
Hungary	Yes	0.479
Iceland	Yes	0.552
India	Yes	0.460
Indonesia	Yes	0.330
Ireland	Yes	0.729
Israel	Yes	0.564
Italy	Yes	0.754
Jamaica	Yes	0.345
Japan	Yes	0.797

Note: List of nations included in 85 country sample. Base sample indicates if country is also included in 67 country sample after adding conditioning variables. FD indicates IMF financial development index score.

Table A3. Countries in sample (cont.)

	1	2
	Base Sample	FD
Jordan	Yes	0.444
Kazakhstan, Rep. of	No	0.286
Korea, Rep. of	Yes	0.820
Kuwait	No	0.451
Lebanon	Yes	0.303
Lithuania	No	0.238
Malaysia	Yes	0.640
Malta	Yes	0.509
Mauritius	Yes	0.400
Mexico	Yes	0.368
Moldova, Rep. of	No	0.223
Mongolia	No	0.278
Morocco	Yes	0.323
Namibia	Yes	0.432
Netherlands, The	Yes	0.814
New Zealand	Yes	0.564
Nigeria	Yes	0.222
Norway	Yes	0.679
Pakistan	Yes	0.259
Panama	Yes	0.388
Peru	Yes	0.305
Philippines	Yes	0.334
Poland, Rep. of	Yes	0.422
Qatar	Yes	0.505
Romania	Yes	0.235
Russian Federation	No	0.508
Saudi Arabia	Yes	0.470
Seychelles	Yes	0.336
Singapore	Yes	0.756
Slovak Rep.	No	0.238
Slovenia, Rep. of	No	0.485
South Africa	Yes	0.509
Spain	Yes	0.846
Sri Lanka	Yes	0.246
Sweden	Yes	0.772
Switzerland	Yes	0.870
Thailand	Yes	0.628
Tonga	Yes	0.218
Trinidad and Tobago	Yes	0.360
Ukraine	No	0.202
United Kingdom	Yes	0.860
Uruguay	Yes	0.217
Uzbekistan, Rep. of	No	0.234
Venezuela, Rep. Bolivariana de	Yes	0.208
Vietnam	Yes	0.370

Appendix B. Summary of equilibrium conditions

Here are the model equations and variables. All prices have been normalized by the home country price level, P_t. All normalized prices are written in lower case. In addition the nominal exchange rate S_t has been normalized to the real exchange rate s_t by dividing by the home price level and multiplying by the foreign price level (which has been normalized to one). The marginal utility of income $\lambda_{h,t}$ has been multiplied by the home price level to convert it to the marginal utility of consumption $\Lambda_{h,t}$. All bonds denominated in the home currency B are divided by the home price level to write these bonds in real terms b. Similarly all foreign currency denominated bonds F have been divided by the foreign price level to write these bonds in real terms f. The firm and central bank profits Π_t and Π_t^{cb} are also normalized by the home price level.

$$C_{h,t} : \Lambda_{h,t} = C_{h,t}^{-1} \tag{A.1}$$

$$C_{e,t} : \Lambda_{e,t} = C_{e,t}^{-1} \tag{A.2}$$

$$M_t : \frac{M_t}{P_t} = \phi_m C_{h,t} \frac{1+i_t}{i_t} \tag{A.3}$$

$$I_t : 1 = p_t^k \left(1 - \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 - \kappa\left(\frac{I_t}{I_{t-1}} - 1\right)\left(\frac{I_t}{I_{t-1}}\right)\right) + E_t\left(p_{t+1}^k \frac{\Lambda_{e,t+1}}{\Lambda_{e,t}} \beta_e \kappa \left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right) \tag{A.4}$$

$$Y_t : Y_t = C_{h,t} + C_{e,t} + I_t + \frac{\Omega_p}{2}\left(\pi_t^H - 1\right)^2 C_{h,t} + \chi\Omega\left(s_t \hat{f}_t\right) + \chi^{cb}\Omega\left(\frac{b_t^{cb}}{b_t^{cb} + s_t f_t^{cb}}\right) \tag{A.5}$$

$$Y_t^H : Y_t^H = (1-\lambda)\left(p_t^H\right)^{-\rho} Y_t \tag{A.6}$$

$$Y_t^F : Y_t^F = \lambda\left(s_t\right)^{-\rho} Y_t \tag{A.7}$$

$$Y_t^X : Y_t^X = \left(\frac{p_t^H}{s_t}\right)^{-\rho} Y^X \tag{A.8}$$

$$H_{h,t} : \psi H_{h,t}^{\eta} = w_t \Lambda_{h,t} \tag{A.9}$$

$$H_{e,t} : \psi H_{e,t}^{\eta} = w_t \Lambda_{e,t} \tag{A.10}$$

$$N_t : N_t = \alpha \frac{mc_t}{w_t} Y_t \tag{A.11}$$

$$B_t^{cb} : M_t = B_t^{cb} + S_t F_t^{cb} \tag{A.12}$$

$$K_t : K_{t-1} = (1-\alpha)\frac{mc_t}{r_t} Y_t \tag{A.13}$$

$$MC_t : mc_t = \left(\frac{w_t}{\alpha}\right)^{\alpha}\left(\frac{r_t}{1-\alpha}\right)^{1-\alpha} \tag{A.14}$$

$$\Pi_t : \Pi_t = \left(p_t^H - mc_t\right) Y_t - \frac{\Omega_p}{2}\left(\pi_t^H - 1\right)^2 C_{h,t} \tag{A.15}$$

$$\Pi_t^{cb} = i_{t-1} B_{t-1}^{cb} + \left(S_t - S_{t-1}\right) F_{t-1}^{cb} + i_{t-1}^* S_t F_{t-1}^{cb} - P_t \chi^{cb}\Omega\left(\frac{b_t^{cb}}{b_t^{cb} + s_t f_t^{cb}}\right) \tag{A.16}$$

$$P_t^H : p_t^H = \frac{\sigma}{\sigma-1} mc_t - \frac{\Omega_p}{\sigma-1} \frac{C_{h,t}}{Y_t^H + Y^X} \left(\left(\pi_t^H - 1 \right) \pi_t^H - E_t \left(\beta \left(\pi_{t+1}^H - 1 \right) \pi_{t+1}^H \right) \right) \tag{A.17}$$

$$\pi_t^H : 1 + \pi_t^H = \frac{p_t^H}{p_{t-1}^H} (1+\pi_t) \tag{A.18}$$

$$W_t : N_t = H_{h,t} + H_{e,t} \tag{A.19}$$

$$R_t : p_t^k = E_t \left(\beta_e \frac{\Lambda_{e,t+1}}{\Lambda_{e,t}} r_{t+1} + \beta_e \frac{\Lambda_{e,t+1}}{\Lambda_{e,t}} (1-\delta) p_{t+1}^k + \theta \frac{\mu_t}{\Lambda_{e,t}} p_t^k \right) \tag{A.20}$$

$$F_t : \frac{(1+i_t)}{(1+i_t^*)} = \frac{\mathrm{E}_t \left(\Lambda_{h,t+1} S_{t+1} \right)}{(1+\chi\Omega_F) S_t \mathrm{E}_t \left(\Lambda_{h,t+1} \right)} \tag{A.21}$$

$$S_t : 1 = \left[(1-\lambda) \left(p_t^H \right)^{1-\rho} + \lambda \left(s_t \right)^{1-\rho} \right]^{\frac{1}{1-\rho}} \tag{A.22}$$

$$\pi_t : policy \tag{A.23}$$

$$F_t^{cb} : policy \tag{A.24}$$

$$B_{h,t} : \Lambda_{h,t} = E_t \left(\beta \Lambda_{h,t+1} \frac{1+i_t}{\pi_{t+1}} \right) \tag{A.25}$$

$$\Lambda_{h,t} : C_{h,t} + m_t + b_{h,t} + s_t f_t + \chi\Omega \left(s_t \hat{f}_t \right) = w_t H_{h,t} + m_{t-1} + \frac{(1+i_{t-1})}{\pi_t} b_{h,t-1} + \frac{\left(1+i_{t-1}^*\right)}{\pi_t} s_t f_{t-1} + \Pi_t + \Pi_t^{cb} \tag{A.26}$$

$$\omega_t : K_t = (1-\delta) K_{t-1} + \left(1 - \frac{\kappa}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right) I_t \tag{A.27}$$

$$P_{t+1}^k : p_t^k = \frac{\Lambda_{e,t}}{\omega_t} \tag{A.28}$$

$$B_{e,t} : \lambda_{e,t} = \beta_e \left((1-\gamma_f)(1+i_t) + \gamma_f (1+i_t^*) E_t \left(\frac{S_{t+1}}{S_t} \right) \right) E_t \lambda_{e,t+1} + \left((1-\gamma_f) + \gamma_f S_t \right) \mu_t \tag{A.29}$$

$$i_t : B_{h,t} + B_t^{cb} + (1-\gamma_f) B_{e,t} = 0 \tag{A.30}$$

$$\Lambda_{e,t} : P_t C_{e,t} + \left((1-\gamma_f) + \gamma_f S_t \right) B_{et} + P_t I_t = \tag{A.31}$$

$$W_t H_{e,t} + R_t K_{t-1} + \left((1-\gamma_f)(1+i_{t-1}) + \gamma_f \left(1 + i_{t-1}^* \right) S_t \right) B_{e,t-1}$$

$$\mu_t : -\left((1-\gamma_f) + \gamma_f S_t \right) B_{e,t} \leq \theta P_t^k K_t \tag{A.32}$$