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J. Scott Davis
Federal Reserve Bank of Dallas

Kevin X.D. Huang
Vanderbilt University

Zheng Liu
Federal Reserve Bank of San Francisco

Mark M. Spiegel
Federal Reserve Bank of San Francisco

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OPTIMAL FOREIGN RESERVE INTERVENTION AND FINANCIAL DEVELOPMENT

J. SCOTT DAVIS, KEVIN X.D. HUANG, ZHENG LIU, AND MARK M. SPIEGEL

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 development adjust little. Domestic interest rate responses are not systematically related to financial development. A model with borrowing constraints and foreign-currency debt rationalizes these findings: the associated pecuniary externality is maximized at intermediate levels of financial development. Calibrated to match the observed leverage and currency composition, the model reproduces the empirical U-shaped relationship under optimal FX reserve policy, and this relation is robust under a range of conventional interest-rate policy regimes.

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Davis: Federal Reserve Bank of Dallas; email: scott.davis@dal.frb.org. Huang: Vanderbilt University; email: kevin.huang@vanderbilt.edu. Liu: Federal Reserve Bank of San Francisco; email: Zheng.Liu@sf.frb.org. Spiegel: Federal Reserve Bank of San Francisco; email: Mark.Spiegel@sf.frb.org.
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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."

In this paper, we study the use of foreign exchange (FX) interventions—a form of capital account management—for macroeconomic stabilization in response to global financial shocks. We show empirically how the use of FX intervention varies with a country's level of financial development. We also 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 find that, following an increase in short-term U.S. interest rates, central banks in small open economies raise domestic interest rates and reduce holdings of FX reserves. These findings suggest that central banks use both interest rates and FX reserves to manage global financial shocks. More importantly, we find that the relative importance of the two policy instruments— FX reserves and the domestic interest rate—depends on a country's level of financial development. There is a 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. In comparison, interest-rate adjustments are not systematically related to financial development.

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 has access to two policy instruments: the domestic interest rate and FX reserves. In the baseline model, we assume that the central bank chooses the FX reserves optimally to maximize social welfare, while setting the interest rate policy following a Taylor rule augmented with real exchange rate targeting.

The borrowing constraints, with a share of the debt denominated in foreign currency units, introduce a key source of frictions in our model. As in the standard model with collateral constraints, entrepreneurs in our model do not internalize the effects of their collective borrowing on the value of collateral assets, giving rise to a pecuniary externality that leads to excessive borrowing *ex ante* and excessive volatility *ex post* (Lorenzoni, 2008; Dávila and

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).

Korinek, 2017). In addition, our model features another source of frictions through changes in private capital flows and the exchange rate. An exogenous increase in the foreign interest rate leads to private capital outflows, reducing the available funds for financing domestic investment. The increased foreign interest rate also leads to domestic currency depreciation through the uncovered interest rate parity (UIP) condition, raising the entrepreneurs' foreign-currency debt repayment burdens and further tightening the borrowing constraints.

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 enforcements, or the "original sin" (Eichengreen et al., 2005). 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. Countries with intermediate levels of financial development have both relatively high levels of debt and a relatively large of share foreign currency debt. 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 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. Furthermore, our baseline model predicts that interest-rate adjustments are not systematically related to financial development, also in line with the data.

The U-shaped relationship between FX reserve adjustments and financial development is robust to alternative assumptions about how the central bank sets the other policy instrument (i.e., the domestic interest rate). In the baseline model, the central bank chooses the FX reserves to maximize welfare and sets the nominal interest rate following a version of the Taylor rule. Under the Taylor rule, the central bank adjusts the nominal interest rate to respond to deviations of inflation from the target, fluctuations in the output gap, and deviations of the real exchange rate from its steady-state level.[1] Under this constrained optimal policy, we find that an increase in the foreign interest rate leads to a rise in the domestic interest rate and a decline in FX reserves, as we observe in the data. The U-shaped relationship between reserve use and financial development, however, does not depend on the form of interest-rate policy. The relation holds when the domestic interest rate is set to maximize social welfare, to target the price level, or to target the nominal exchange rate. Thus, regardless of how the central bank is using its domestic interest rate instrument, the

[1]The inclusion of the real exchange rate in the Taylor rule reflects the "fear of floating" argument, as documented by Calvo and Reinhart (2002).

central bank finds it welfare maximizing to use FX reserves to manage the externality arising from the presence of foreign currency debt on the borrowing constraint.

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 focus 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 minimalistic 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)).

Our model predicts that the central bank in an economy with an intermediate level of financial development has the greatest incentive to utilize foreign exchange intervention as a stabilization tool in response to global financial shocks. This provides a theoretical explanation for our empirical finding that shows a U-shaped relation 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.

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 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). Like 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, it is an intermediate level of financial development by bringing with it the largest degree of externality that gives rise to the greatest stabilization value of foreign exchange intervention.

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

In this section, we present cross-country evidence on the adjustments of FX reserves and domestic interest rates in responses to changes in global financial conditions induced by a change in short-term U.S. Treasury yields.

II.1. **Panel evidence.**

Under open capital accounts, central banks have two primary tools for adjusting to changes in global financial conditions, which we measure empirically by changes in short-term U.S. Treasury yields. They can adjust domestic interest rates through domestic monetary or exchange rate policies, or, in environments where domestic assets are imperfect substitutes for foreign assets, they can manipulate domestic conditions through intervention in the form of purchases or sales of foreign securities, resulting in reserve holding accumulation or depletion.

We examine how flows of national reserves, as measured by the International Monetary Fund (IMF) Balance Of Payments (BOP) data set, and domestic interest rates, obtained from IMF International Financial Statistics (IFS), respond to changes in 1-year U.S. Treasury yields. We estimate the same empirical specification for responses in both instruments

$$Y_{i,t} = c + \beta_1 \Delta US1T_t + \gamma X_{i,t} + \phi_i + \epsilon_{i,t}, \tag{1}$$

where the dependent variable $Y_{i,t}$ is either the change in log of reserve holdings of country i from year $t-1$ to year t ($\Delta RES_{i,t}$) or the change in log of domestic one-year interest rates from $t-1$ through t ($\Delta DINT_{i,t}$). The independent variable of interest is the change in one-year U.S. Treasury yields from $t-1$ to t ($\Delta US1T_t$). In the regression, we include country fixed effects (ϕ_i) to capture time-invariant differences across countries.[2] The regression also conditions on time-varying country characteristics ($X_{i,t}$), which include population ($POP_{i,t}$), GDP per capita ($PCGDP_{i,t}$), capital account openness, as measured by the Chinn-Ito data set ($CAOPEN_{i,t}$), the current account balance ($CURR_{i,t}$), and the current stock of reserves ($RES_{i,t}$). 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 $CAI_{i,t}$ and $CAO_{i,t}$, respectively.

Our full sample is an unbalanced quarterly panel of 144 countries, from 2001:Q1 through 2024:Q2. We estimate the empirical specification (1) using ordinary least squares, with standard errors clustered by country.[3] We winsorize variables at the $(2.5\%, 97.5\%)$ levels.[4]

Table 1 shows the estimation results from the panel data regressions. Models 1 through 3 are our specification for the responses of reserve holdings to the U.S. interest rate shock. Model 1 runs the univariate regression for our full sample. We obtain a negative and statistically significant coefficient estimate at a 99% confidence level, indicating that central banks reduce their FX reserve holdings following an increase in the U.S. interest rate. The point estimate, combined with the standard deviations of ΔRES and $\Delta US1T$ in our sample, implies that a one standard deviation increase in the one-year U.S. Treasury yields are associated on average with a modest reduction in the FX reserve holdings of about 0.05 standard deviation.[5]

Model 2 adds our conditioning variables. $\Delta US1T$ continues to enter negatively and with statistical significance at a 95% confidence level. The point estimate of the coefficient on

[2] In particular, these time-invariant differences can include exchange rate regimes, which we explicitly condition for in the cross-section regressions in the following sub-section with the qualitative variable from Shambaugh (2004), $USPEG$.

[3] We drop the Democratic Republic of the Congo from our sample, as its experience over this period leaves it as a large outlier in our reserve response ratio measure. However, our results are robust (and indeed strengthened) if we leave Congo in our sample. We also drop Tunisia for lack of usable observations, Timor for missing financial development index values, and the United States as it serves as our base country for global interest rates.

[4] As their distributions do not exhibit substantial outliers, we do not winsorize the movements in the US interest rate. Summary statistics are shown in appendix Table A1.

[5] The standard deviation of $\Delta US1T$ in our sample is equal to 0.36, while the standard deviation of ΔRES is 13.31.

Table 1. Responses to US interest rate shocks

	1	2	3	4	5	6
Dep.Var :	ΔRES	ΔRES	ΔRES	$\Delta DINT$	$\Delta DINT$	$\Delta DINT$
Δ US1T	-1.67***	-1.20***	-1.08**	0.06***	0.04***	0.04***
	(0.35)	(0.40)	(0.50)	(0.01)	(0.01)	(0.01)
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)
CAOPEN		-0.71			-0.00	
		(1.78)			(0.02)	
CAI			1.45			-0.03
			(2.23)			(0.04)
CAO			-0.03			-0.02
			(1.89)			(0.04)
CURR		0.31***	0.40***		-0.00***	-0.00***
		(0.07)	(0.15)		(0.00)	(0.00)
RES		0.34***	0.31***		-0.00	0.00
		(0.03)	(0.03)		(0.00)	(0.00)
CONS	3.40***	2.16	2.07	-0.01***	-0.01	-0.01
	(0.01)	(2.27)	(2.88)	(0.00)	(0.02)	(0.02)
N	11349	9625	5956	10869	9230	5627
Country FE	Y	Y	Y	Y	Y	Y

Note: Dependent variables are ΔRES, the change in reserve holdings from period $t-1$ to t as a share of GDP, and $\Delta DOMINT$, the change in domestic interest rates from period $t-1$ to t. See text for variable definitions. Estimation by OLS with standard errors clustered by country in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

$\Delta US1T$ is slightly reduced compared to that in Model 1, implying that a one standard deviation increase in the change in one year treasury rates is now associated with a 0.03 standard deviation reduction in FX reserves on average.

Model 3 reports results with the one-sided capital control measures from Fernández et al. (2016), with CAI and CAO substituted for $CAOPEN$ to indicate restrictions on inflows and outflows respectively. As these measures are not available for as many countries, our sample size is reduced. Still, our variable of interest $\Delta US1T$ continues to enter significantly negative at a 95% confidence level.

Columns 4 through 6 report the responses of the change in domestic interest rate $\Delta DINT_{i,t}$ to a U.S. interest rate shock, in the specification with a univariate regression or with different sets of country-level control variables. All three models have statistically significant coefficient estimates for the average response to changes in our variable of interest, $\Delta US1T$, at 99% confidence levels. Our point estimate for our univariate specification (Column 4), combined with the standard deviation of $\Delta US1T$ in our sample, implies that a one standard deviation increase in the change in one year U.S. Treasury yields are associated on average with a 0.09 standard deviation increase in the change in domestic interest rates. When we add different sets of country-level conditional variables (Models 5 and 6), the estimated coefficient on $\Delta US1T$ is slightly smaller than in the univariate case (0.04 vs. 0.06), but it remains statistically significant at the 99% confidence level.

Overall, our panel results suggest that countries on average respond to increases in global interest rates by reducing their FX reserve holdings and raising domestic interest rates. These responses are both consistent with stabilization of the local currency.

II.2. **The role of financial development.** We now examine how the use of the two policy instruments—FX reserves and domestic interest rates—following a shock to the US interest rate vary with the country's level of financial development.

We begin by estimating the country-specific responses of FX reserves and of domestic interest rates to an increase in the U.S. interest rate, based on individual time-series regressions. In particular, for each country i, we estimate the following specification for FX reserve adjustments to changes in the U.S. interest rate

$$\Delta RES_{it} = c_i + \beta_{R,i} \Delta US1T_t + e_{it}, \tag{2}$$

where the parameter $\beta_{R,i}$ captures the responses of country i's FX reserves to the U.S. interest rate shock. We estimate a similar specification for interest-rate adjustments for each country, which is given by

$$\Delta DOMINT_{it} = c_i + \beta_{I,i} \Delta US1T_t + u_{it} \tag{3}$$

where the coefficient $\beta_{I,i}$ captures the response of country i's domestic interest rate to changes in the U.S. interest rate.

We then examine how the responses of FX reserves and domestic interest rates vary with the level of financial development across countries. For this purpose, we estimate cross-sectional specifications using ordinary least squares with heteroskedasticity consistent standard errors. 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.[6]

We estimate the specification for FX reserve adjustments

$$\hat{\beta}_{R,i} = c + \beta_R FD_i + \delta_R FD_i^2 + \gamma_R X_i + \varepsilon_i, \tag{4}$$

[6]The full list of countries excluded from our sample, and their financial development scores, can be found in Appendix Table A2. These countries are primarily small or Sub-Saharan, but a small number of Central American and Eastern European countries are also excluded.

where $\hat{\beta}_{R,i}$ is the estimated responses of country i's FX reserves to the U.S. interest rate shock in the specification (2). 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. Since our cross-sectional sample does not allow for country fixed effects, we add $USPEG_i$ as an additional control, which is a qualitative variable indicating exchange rate pegging to the dollar based on Shambaugh (2004) that takes value 1 if the country was pegged to the dollar in 2004 and 0 otherwise.

Note that our estimate of individual country reserve response ($\hat{\beta}_{R,i}$) is likely to be measured with error. But since it is the dependent variable, our specification (4) should still yield consistent estimates of β_R and δ_R, the coefficients of interest.[7]

Similarly, to gauge how the responses of domestic interest rates depend on financial development, we estimate

$$\hat{\beta}_{I,i} = c + \beta_I FD_i + \delta_I FD_i^2 + \gamma_I X_i + \upsilon_i \tag{5}$$

where $\hat{\beta}_{I,i}$ is the estimated responses of country i's interest rate to the U.S. interest rate shock in the specification (3). Again, the key independent variables of interest are the country's level of financial development (FD_i) and the squared financial development (FD_i^2). We include the same set of control variables (X_i). The term υ_i denotes the regression residual. The key parameter of interest is β_I.

Table 2 shows the estimation results. In the simple regression without any conditioning variables (Column (1)), 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). The estimated coefficients on the linear and the squared terms are statistically significant at the 99% and 95% confidence level, 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 including country-specific conditional variables, with alternative measures of capital controls (see Columns (2) and (3)). For example, consider our base specification with conditioning variables included (Model 2, shown in Column (2)). The point estimates of the coefficients for FD and FD^2 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

[7]Summary statistics for the new variables in our cross-section sample, as well as data sources, are also shown in appendix Table A1.

Table 2. Relations of adjustments in FX reserves and domestic interest rates with 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***	0.30	0.17	0.33
	(14.19)	(14.19)	(14.09)	(0.33)	(0.38)	(0.48)
FD^2	34.91**	34.75***	38.16***	-0.08	-0.07	-0.25
	(13.44)	(11.69)	(11.77)	(0.31)	(0.34)	(0.42)
CAOPEN		-3.57			0.04	
		(2.66)			(0.06)	
CAI			-1.42			-0.04
			(3.86)			(0.11)
CAO			4.15			-0.04
			(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**		0.05	0.07
		(1.80)	(1.83)		(0.04)	(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***	-0.05	-0.06	-0.05
	(3.07)	(3.42)	(3.34)	(0.08)	(0.11)	(0.12)
Obs	85	67	59	85	67	59

Note: 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. FD^2 represents the square of financial development index FD. See the text for other variable definitions. Estimation by OLS with heteroscedasticity-robust standard errors.

0.5 threshold for FD, with 36 countries below the threshold, and 31 countries above the threshold. Intuitively, once countries reach a threshold level of financial development, their reliance on reserve adjustment to counter global interest rate shocks diminishes.

In contrast, the responses of domestic interest rate to U.S. interest rate shocks are not systematically related to financial development across all our empirical specifications, as shown in Columns (4)-(6) in the table.

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 also buy and sell foreign bonds.

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 a cost of buying and selling foreign bonds, the central bank would be able to conduct sterilized intervention to affect the economy's total foreign borrowing and equilibrium allocations.

III.1. **Households.** The representative household chooses consumption, $C_{h,t}$, labor effort, $H_{h,t}$, and stocks of domestic and foreign currency denominated bonds, $B_{h,t}$ and F_t, to maximize expected lifetime utility given by:

$$\max E_0 \sum_{t=0}^{\infty} \beta_h^t \left(\ln \left(C_{h,t}\right) + \phi_m \ln \left(\frac{M_t}{P_t} \right) - \psi \frac{H_{h,t}^{1+\eta}}{1+\eta} \right) \tag{6}$$

subject to their sequence of budget constraints:

$$\begin{aligned} & P_t C_{h,t} + M_t + B_{h,t} + S_t F_t + P_t \chi \Omega \left(\frac{S_t \hat{F}_t}{P_t} \right) \\ & = W_t H_{h,t} + M_{t-1} + \left(1 + i_{t-1}\right) B_{h,t-1} + \left(1 + i_{t-1}^*\right) S_t F_{t-1} + \Pi_t + \Pi_t^{cb} \end{aligned} \tag{7}$$

where $B_{h,t}$ is the household's stock of domestic currency denominated bonds, F_t is their stock of foreign currency denominated bonds, S_t is the nominal exchange rate (in units of the home currency per units of the foreign currency), P_t is the consumer price level, W_t is the nominal wage rate, i_t is the nominal interest rate on home currency denominated bonds, i_t^* is the nominal interest rate on foreign currency denominated bonds, Π_t represents the profits of domestic firms, and Π_t^{cb} represents the central bank profits. Both firm and central bank profits are returned lump sum to the household. β_h is the household's discount factor. $\chi \Omega \left(\frac{S_t \hat{F}_t}{P_t} \right)$ is an adjustment cost and 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 $\Omega\left(\cdot\right)$ is differentiable and strictly convex and satisfies $\Omega\left(0\right) = \Omega_F\left(0\right) = 0$, where Ω_F denotes the first derivative of $\Omega(\cdot)$ with respect to F, as in Schmitt-Grohé and Uribe (2003). Yakhin (2022) shows that to a first-order approximation, this adjustment cost is isomorphic to microfounded models of imperfect bond substitution in Gabaix and Maggiori (2015) and Fanelli and Straub (2021).

The functional form of the foreign currency denominated bond adjustment cost function is given by:

$$\Omega\left(\hat{x}_t\right) = \frac{1}{2}\left(\frac{S_t}{P_t}\right)^2 \left(x_t - x_{ss}\right)^2, \tag{8}$$

for $x_t = F_t$.

$\lambda_{h,t}$ is the marginal utility of household income in period t, the first-order conditions of the household's problem with respect to M_t, $B_{h,t}$ and F_t are:

$$\frac{\phi_m}{M_t} = \lambda_{h,t} - \beta_h \mathrm{E}_t\left(\lambda_{h,t+1}\right) \tag{9}$$

$$\lambda_{h,t} = \beta_h\left(1 + i_t\right)\mathrm{E}_t\left(\lambda_{h,t+1}\right) \tag{10}$$

$$\left(1 + \chi\Omega_{Ft}\right) S_t \lambda_{h,t} = \beta_h\left(1 + i_t^*\right)\mathrm{E}_t\left(\lambda_{h,t+1} S_{t+1}\right) \tag{11}$$

The substitution of equation (10) into equation (11) gives:

$$\frac{\left(1 + i_t\right)}{\left(1 + i_t^*\right)} = \frac{\mathrm{E}_t\left(\lambda_{h,t+1} S_{t+1}\right)}{\left(1 + \chi\Omega_{Ft}\right) S_t \mathrm{E}_t\left(\lambda_{h,t+1}\right)} \tag{12}$$

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

The household's first-order-condition with respect to consumption is

$$P_t \lambda_{h,t} = C_{h,t}^{-1}$$

The household's first-order-condition with respect to labor effort is

$$\psi H_{h,t}^{\eta} = W_t \lambda_{h,t}$$

Substituting the household's first order condition with respect to consumption and domestic bonds into the household's first-order condition with respect to money balances yields the household's demand for money:

$$\frac{M_t}{P_t} = \phi_m C_{h,t} \frac{1 + i_t}{i_t} \tag{13}$$

III.2. **Entrepreneurs.** The representative entrepreneur maximizes:

$$\max E_0 \sum_{t=0}^{\infty} \beta_e^t \left(\log(C_{e,t}) - \psi \frac{H_{e,t}^{1+\eta}}{1+\eta} \right) \tag{14}$$

where $C_{e,t}$ is entrepreneur consumption, and $H_{e,t}$ is their labor effort.

The entrepreneur's budget constraint is given by:

$$\begin{aligned} &P_t C_{e,t} + ((1-\gamma_f) + \gamma_f S_t) B_{et} + P_t I_t \\ &= W_t H_{e,t} + R_t K_{t-1} + \left((1-\gamma_f)(1+i_{t-1}) + \gamma_f \left(1+i^*_{t-1}\right) S_t\right) B_{e,t-1}, \end{aligned} \tag{15}$$

where 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 depreciates at a constant rate δ. New investment adds to the capital stock, subject to adjustment costs. The capital stock follows the law of motion

$$K_t = (1-\delta) K_{t-1} + \left(1 - \frac{\kappa}{2} \left(\frac{I_t}{I_{t-1}} - 1\right)^2\right) I_t \tag{16}$$

where $\kappa > 0$ denotes the scale of the investment adjustment costs.

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

$$-\left((1-\gamma_f)(1+i_t) + \gamma_f \left((1+i^*_t) E_t (S_{t+1})\right)\right) B_{e,t} \leq \theta E_t \left(P^k_{t+1} K_t\right) \tag{17}$$

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

The entrepreneur's optimal bond holdings decision implies that

$$((1-\gamma_f) + \gamma_f S_t) \lambda_{e,t} = \beta_e \left((1-\gamma_f)(1+i_t) + \gamma_f (1+i^*_t) E_t (S_{t+1})\right) (E_t \lambda_{e,t+1} + \mu_t), \tag{18}$$

where $\lambda_{e,t}$ denotes the Lagrangian multiplier on the budget constraint (15) (i.e. the entrepreneur's marginal utility of income), μ_t denotes that on the collateral constraint (17), and ω_t denotes that on the capital accumulation rule (18).

The entrepreneur's first-order-condition with respect to consumption is

$$P_t \lambda_{e,t} = C_{e,t}^{-1}$$

[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.

The entrepreneur's first-order-condition with respect to labor effort is

$$\psi H_{e,t}^{\eta} = W_t \lambda_{e,t}$$

The entrepreneur's first-order-condition with respect to investment is

$$P_t \lambda_{e,t} = \omega_t \left(1 - \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right) - \omega_t \kappa \left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}} + E_t\left(\beta_e \omega_{t+1}\kappa\left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right)$$

The entrepreneur's first-order-condition with respect to the capital stock is

$$\omega_t = E_t\left(\beta_e R_{t+1}\lambda_{e,t+1} + \beta_e(1-\delta)\omega_{t+1} + \theta\mu_t P_{t+1}^k\right)$$

If the price of existing capital is $P_t^k = \frac{\omega_t}{\lambda_{e,t}}$, then the first order condition with respect to the capital stock can be written as

$$P_t^k = E_t\left(\beta_e \frac{\lambda_{e,t+1}}{\lambda_{e,t}} R_{t+1} + \beta_e \frac{\lambda_{e,t+1}}{\lambda_{e,t}}(1-\delta)P_{t+1}^k + \theta \frac{\mu_t}{\lambda_{e,t}} P_{t+1}^k\right)$$

And the first-order-condition with respect to investment can be written as

$$P_t = P_t^k\left(1 - \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 - \kappa\left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right) + E_t\left(\beta_e \frac{\lambda_{e,t+1}}{\lambda_{e,t}} P_{t+1}^k \kappa\left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right)$$

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

$$Y_t = \left((1-\lambda)^{\frac{1}{\rho}}\left(Y_t^H\right)^{\frac{\rho-1}{\rho}} + \lambda^{\frac{1}{\rho}}\left(Y_t^F\right)^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}} \tag{19}$$

The demand for aggregate home and foreign goods is given by

$$\begin{aligned} Y_t^H &= (1-\lambda)\left(\frac{P_t^H}{P_t}\right)^{-\rho} Y_t \\ Y_t^F &= \lambda\left(\frac{S_t P_t^F}{P_t}\right)^{-\rho} Y_t \end{aligned} \tag{20}$$

In this small open economy the foreign price is normalized to one, and imports are supplied elastically at this price, $Y_t^F = \lambda\left(\frac{S_t}{P_t}\right)^{-\rho} Y_t$.

Likewise, the demand in the foreign economy for exports from the home country is given by:

$$Y_t^X = \left(\frac{P_t^H}{S_t}\right)^{-\rho} Y^X$$

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

The home good is a Dixit-Stiglitz aggregation of goods from a continuum of firms. Similarly the same firms produce output for the export market

$$\begin{aligned} Y_t^H &= \left(\int_0^1 Y_t^H(i)^{\frac{\sigma-1}{\sigma}} di\right)^{\frac{\sigma}{\sigma-1}} \\ Y_t^X &= \left(\int_0^1 Y_t^X(i)^{\frac{\sigma-1}{\sigma}} di\right)^{\frac{\sigma}{\sigma-1}} \end{aligned}$$

where ρ is the elasticity of substitution between home and foreign goods, and σ is the elasticity of substitution between goods from different firms within the same country.

And the demands for the output from intermediate good firm i are

$$\begin{aligned} Y_t^H(i) &= \left(\frac{P_t^H(i)}{P_t^H}\right)^{-\sigma} Y_t^H \\ Y_t^X(i) &= \left(\frac{P_t^H(i)}{P_t^H}\right)^{-\sigma} Y_t^X \end{aligned} \tag{21}$$

$P_t^H(i)$ is the price set by the home country intermediate good firm i (in home currency).

Thus the various price indices are given by:

$$\begin{aligned} P_t^H &= \left(\int_0^n P_t^H(i)^{1-\sigma} di\right)^{\frac{1}{1-\sigma}} \\ P_t &= \left[(1-\lambda)\left(P_t^H\right)^{1-\rho} + \lambda (S_t)^{1-\rho}\right]^{\frac{1}{1-\rho}} \end{aligned} \tag{22}$$

III.4. **Intermediate Goods Firms.** Firm i produces $Y_t^H(i)$ for the domestic and $Y_t^X(i)$ for the export market. The firm's total output is produced by hiring $N_t(i)$ of homogeneous labor service from domestic households and entrepreneurs at nominal wage W_t, and renting $k_t(i)$ units of capital. Market clearing in the two input markets requires that the total demand for labor by firms is equal to the supply of labor from households and entrepreneurs: $\int_0^1 N_t(i)\, di = H_{h,t} + H_{e,t}$ and the total capital employed by firms is equal to the predetermined stock of entrepreneur capital $\int_0^1 k_t(i)\, di = K_{t-1}$. Aggregate firm profits, which are returned lump-sum to households, are given by: $\Pi_t = \int_0^1 \Pi_t(i)\, di$.

The firm's output is simply a Cobb-Douglas combination of capital and labor inputs:

$$Y_t^H(i) + Y_t^X(i) = A_t (N_t(i))^{\alpha} (k_t(i))^{1-\alpha} \tag{23}$$

The firm's demand for labor and capital inputs are given by:

$$\begin{aligned} N_t(i) &= \alpha \frac{MC_t}{W_t} \left(Y_t^H(i) + Y_t^X(i) \right) \\ k_t(i) &= (1-\alpha) \frac{MC_t}{R_t} \left(Y_t^H(i) + Y_t^X(i) \right) \end{aligned} \tag{24}$$

where the firm's marginal cost is $MC_t = \frac{1}{A_t} \left(\frac{W_t}{\alpha} \right)^{\alpha} \left(\frac{R_t}{1-\alpha} \right)^{1-\alpha}$.

Following Rotemberg, firms face a quadratic price adjustment cost $\frac{\Omega_p}{2} \left(\frac{P_t^H(i)}{\pi P_{t-1}^H(i)} - 1 \right)^2 P_t C_{h,t}$, where π is the steady state gross inflation rate. Thus firm profits are given by $\Pi_t(i) = \left(P_t^H(i) - MC_t \right) \left(Y_t^H(i) + Y_t^X(i) \right) - \frac{\Omega_p}{2} \left(\frac{P_t^H(i)}{\pi P_{t-1}^H(i)} - 1 \right)^2 P_t C_{h,t}$. The firm will set prices to maximize:

$$P_t^H(i) = \arg\max_{P_t^H(i)} E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \lambda_{h,t+\tau} \left(\left(P_t^H(i) - MC_t \right) \left(Y_t^H(i) + Y_t^X(i) \right) - \frac{\Omega_p}{2} \left(\frac{P_t^H(i)}{\pi P_{t-1}^H(i)} - 1 \right)^2 P_t C_{h,t} \right) \tag{25}$$

The firm's optimal price is (using that $P_t \lambda_{h,t} = C_{h,t}^{-1}$)

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

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.

The nominal interest rate is set with a Taylor rule:

$$i_t - \bar{i} = \theta_i \left(i_{t-1} - \bar{i} \right) + (1-\theta_i) \theta_p (\pi_t - \pi) + (1-\theta_i) \theta_Y \left(\frac{Y_t}{\bar{Y}} - 1 \right) + (1-\theta_i) \theta_s \left(\frac{S_t}{P_t} - 1 \right) \tag{26}$$

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 (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).

As shown by the household's money demand equation in equation 13, 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:

$$M_t = B_t^{cb} + S_t F_t^{cb} \tag{27}$$

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

$$
\begin{aligned}
&(M_t - M_{t-1}) - \left(B_t^{cb} - (1 + i_{t-1}) B_{t-1}^{cb}\right) - \left(S_t F_t^{cb} - \left(1 + i_{t-1}^*\right) S_t F_{t-1}^{cb}\right) \\
&= i_{t-1} B_{t-1}^{cb} + (S_t - S_{t-1}) F_{t-1}^{cb} + i_{t-1}^* S_t F_{t-1}^{cb}
\end{aligned}
\tag{28}
$$

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:

$$
\Pi_t^{cb} = i_{t-1} B_{t-1}^{cb} + (S_t - S_{t-1}) F_{t-1}^{cb} + i_{t-1}^* S_t F_{t-1}^{cb} - P_t \chi^{cb} \Omega\left(\frac{B_t^{cb}}{B_t^{cb} + S_t F_t^{cb}}\right) \tag{29}
$$

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.

III.6. **Bond Market Clearing Conditions.** Home currency denominated bonds are held exclusively by home country households, entrepreneurs, and the central bank.

Thus the market clearing condition for home currency denominated bonds is:

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

III.7. **The balance of payments identity.** Central bank profits in equation (29), the central bank's balance sheet in equation (27), and the home currency bond market clearing condition in equation (30) can be substituted into the sum of the household's budget constraint in equation (7) and entrepreneur's budget constraint in (15) to yield the budget constraint for the small open economy:

$$\begin{aligned}
&P_tC_{h,t} + P_tC_{e,t} + P_tI_t - W_tH_{h,t} - W_tH_{e,t} - R_tK_{t-1} \\
&- \Pi_t + S_t\left(F_t + F_t^{cb}\right) - \left(1 + \Phi_{t-1}i^*_{t-1}\right)S_t\left(F_{t-1} + F_{t-1}^{cb}\right) \\
&= -P_t\chi\Omega\left(\frac{S_t\hat{F}_t}{P_t}\right) - P_t\chi^{cb}\Omega\left(\frac{S_t\hat{F}_t^{cb}}{P_t}\right)
\end{aligned} \tag{31}$$

The first line in this economy-wide budget constraint, $P_tC_{h,t} + P_tC_{e,t} + P_tI_t - W_tH_{h,t} - W_tH_{e,t} - R_tK_{t-1}$ represents net imports of the home country, or the negative of the trade balance and thus this economy-wide budget constraint can be rewritten as the fundamental balance of payments identity, where the current account equals the capital account plus the net change in central bank foreign exchange reserves, $CA_t = KA_t + \Delta R_t$.

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):

$$\begin{aligned}
CA_t = {}& W_tH_{h,t} + W_tH_{e,t} + R_tK_{t-1} + \Pi_t - P_tC_t - P_tC_{e,t} - P_tI_t \\
&+ \Phi_{t-1}i^*_{t-1}S_tF_{t-1} + \Phi_{t-1}i^*_{t-1}S_tF^{cb}_{t-1} - P_t\chi\Omega\left(\frac{S_t\hat{F}_t}{P_t}\right) - P_t\chi^{cb}\Omega\left(\frac{S_t\hat{F}_t^{cb}}{P_t}\right)
\end{aligned} \tag{32}$$

Noticing that everything in this expression for the current account except for the term P_tI_t is national savings, so the current account can also be written as savings minus investment.

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

$$KA_t = S_tF_t - S_tF_{t-1} \tag{33}$$

And finally the change in the central bank's stock of foreign currency denominated bonds is given by:

$$\Delta R_t = S_tF_t^{cb} - S_tF_{t-1}^{cb} \tag{34}$$

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 first three Taylor rule parameters are all set to values commonly found in the literature. The Taylor rule weight on the real exchange rate is set to the value estimated in Ghosh et al. (2016).

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 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 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.

$$cred_i = 0.022 + 1.55 FD_i - 0.003 FD_i^2 \tag{35}$$

$$fc_i = 1.03 - 0.03 FD_i - 0.66 FD_i^2 \tag{36}$$

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.

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
θ_i	0.9	Taylor rule weight on lagged interest rate
θ_p	1.5	Taylor rule weight on inflation
θ_Y	0.5/4	Taylor rule weight on output
θ_s	0.4	Taylor rule weight on real exchange rate
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

V. Model implications

This section looks at the quantitative results from the model. First we look at impulse responses to a shock to the foreign interest rate to see how allowing the central bank to adjust their stock of foreign reserves affects the variables in the model. We show how the central bank's use of reserves depends on parameters like θ and γ_f, the total amount of debt in the entrepreneur's borrowing constraint and the currency denomination of that debt.

We then turn to moments from the model in order to draw connections between the quantitative results from the model and the empirical results presented earlier in Section II. Our aim is to see how the central bank adjusts their policy tools in response to fluctuations in the foreign interest rate. We specifically look at how the model implies a U-shaped pattern to reserve sales as a function of financial development, where countries in the intermediate range of financial development are the most active in selling reserves following a foreign interest rate shock while those with high or low levels of financial development are less active in selling reserves.

V.1. **Impulse Responses.** Impulse responses to a 1% shock to the foreign interest rate are presented in Figure 2.

The blue line in each graph presents the response from the benchmark version of the model with the parameters listed in Table 3. Recall that in the benchmark parameterization, the loan-to-value parameter θ and the share of debt denominated in a foreign currency, γ_f were both set to match the data for a country with a financial development index, $FD = 0.5$. For comparison the red line in the graphs in the figure are the responses where θ and γ_f were both set to match the data for a country with a financial development index, $FD = 0$ ($\theta = 0.02$ and $\gamma_f = 1$), and the green line in the graphs in the figure are the responses where θ and γ_f were both set to match the data for a country with a financial development index, $FD = 1$ ($\theta = 0.75$ and $\gamma_f = 0.33$).

Of the three calibrations, the model calibrated for $FD = 0.5$ sees the greatest fall in output and investment and the greatest tightening of the borrowing constraint following a foreign interest rate shock. Here the externality on the borrowing constraint is the greatest. The total amount of debt, represented by θ is higher than in the calibration for $FD = 0$, and the vast majority of that debt is denominated in the foreign currency. While θ is higher still in the calibration for $FD = 1$, most of that debt is denominated in the domestic currency. So the tightening of the borrowing constraint due following the foreign interest rate shock and subsequent exchange rate depreciation is greatest in the calibration with $FD = 0.5$.

In terms of the policy response, in all 3 lines the central bank raises the policy interest rate by about 30-40 basis points after the shock to the foreign interest rate, and there is not

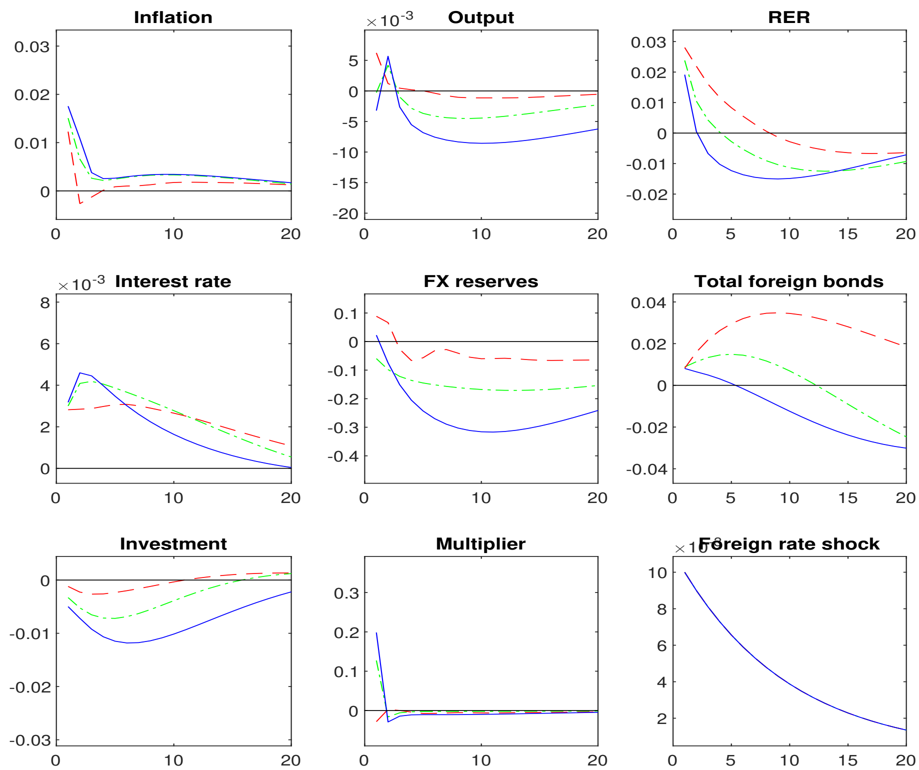

FIGURE 2. Impulse responses following a positive 1% foreign interest rate shock.

Notes: Between the red, blue, and green lines the θ and γ_f vary to reflect different levels of the financial development index. In the blue line, $\theta = 0.44$ and $\gamma_f = 0.85$, the calibrated value when $FD = 0.5$. In the red line $\theta = 0.02$ and $\gamma_f = 1$, the calibrated value when $FD = 0$. In the green line $\theta = 0.75$ and $\gamma_f = 0.33$, the calibrated value when $FD = 1$. All other parameters are set to the benchmark values in Table 3.

much of a difference in the response of the policy interest rate between the three calibrations. This is in contrast to the response of the central bank's stock of foreign exchange reserves. Following the shock to the foreign interest rate the central bank reduces its stock of foreign exchange reserves in all three calibrations, but it reduces them the most when θ and γ_f are set to match the data for a country with $FD = 0.5$. The strong reserve response means that the model calibrated to match $FD = 0.5$ sees the the smallest increase in the economy's total amount of foreign bonds (i.e. smallest increase in the current account) and smallest exchange rate depreciation.

The impulse responses in Figure 2 vary both θ and γ_f in line with changes in FD. To better understand the role of each of these two parameters, Figure 3 just changes one parameter at

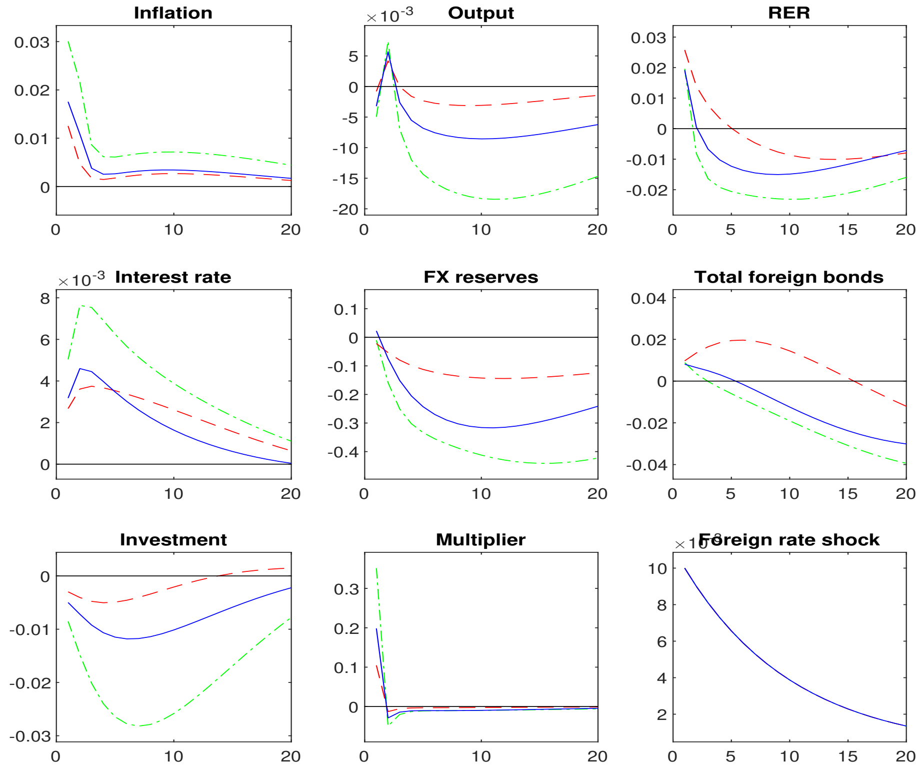

FIGURE 3. Impulse responses following a positive 1% foreign interest rate shock.

Notes: Between the red, blue, and green lines the θ and γ_f vary to reflect changes in the loan-to-value ratio or changes in the currency composition of debt. In the blue line, $\theta = 0.44$ and $\gamma_f = 0.85$, the calibrated value when $FD = 0.5$. In the red line $\theta = 0.44$ and $\gamma_f = 0.33$. In the green line $\theta = 0.75$ and $\gamma_f = 0.85$. All other parameters are set to the benchmark values in Table 3.

a time. The blue line in the figure is the same as the blue line in Figure 2, the benchmark parametrization with the values of $\theta = 0.44$ and $\gamma_f = 0.85$ when $FD = 0.5$. The red line in the figure lowers γ_f to 0.33, the calibrated value when $FD = 1$, holding all else constant. The green line in the figure raises θ to 0.75, the calibrated value when $FD = 1$, holding all else constant.

Thus the blue line plots the impulse response from the benchmark parameterization when $FD = 0.5$. The red line shows the responses from the same model and calibration, except the share of foreign currency debt has been lowered to the calibrated level for a country with $FD = 1$. The green line shows the same model and calibration, except the loan-to-value ratio has been raised to the calibrated level when $FD = 1$.

Between the blue and green impulse responses in the Figure, the only change is the increased loan-to-value ratio. This change on its own would lead to a greater fall in investment and output and a greater increase in the multiplier on the borrowing constraint. But here the central bank is most active in using policy to counter the effect of the foreign interest rate shock and resulting currency depreciation. The central bank raises the policy interest rate by 60-80 basis points and reduces the stock of foreign reserves more than under the benchmark parametrization.

By contrast between the blue and red impulse responses in the Figure, the only change is the lower foreign currency share of debt in the red impulse responses. The response of the policy interest rate is about the same in both sets of impulse responses, but the central bank is much less active in their use of foreign exchange reserves when they have a low foreign currency debt share.

V.2. **Moments.** Figure 4 reports how the central bank's two policy variables respond to fluctuations in the foreign interest rate as a function of the level of financial development. Recall from the calibration section that as we vary the level of FD from 0 to 1 we vary the two parameters θ and γ_f. In the left-hand panel in the figure we vary θ across the range of values it takes as FD varies from 0 to 1, while holding γ_f constant at its benchmark value. In the middle panel we vary γ_f across the range of values it takes as FD varies from 0 to 1, while holding θ constant at its benchmark value. In the right-hand panel we allow both θ and γ_f to vary as FD varies from 0 to 1.

The top set of graphs in the figure plot $\beta_R = \frac{Cov\left(f^{cb}, i^*\right)}{16var(i^*)}$ from the model. This measures the covariance between central bank foreign bonds and the foreign interest rate, normalized by the variance of the nominal interest rate. This is meant to correspond to the response of reserves to changes in the U.S. interest rate in the first three columns of the empirical results in Table 1.[9]

The bottom set of graphs in the figure plot $\beta_i = \frac{Cov(i,i^*)}{var(i^*)}$ from the model. This measures the covariance between the domestic interest rate and the foreign interest rate normalized by

[9]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 model 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

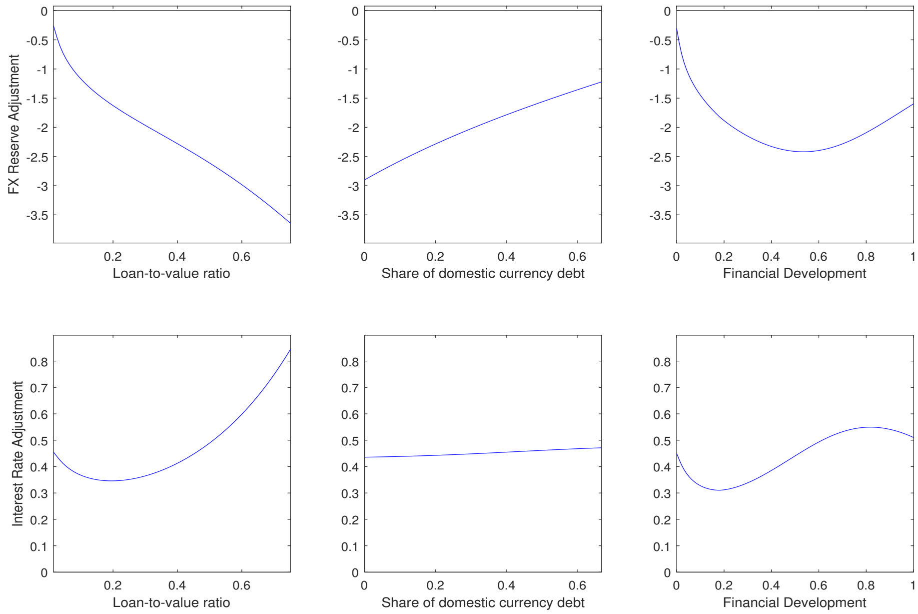

FIGURE 4. Covariance between the foreign interest rate and either central bank foreign reserves or the domestic interest rate.

Notes: 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 is the share of entrepreneur debt that is denominated in foreign currency. The right panel varies both θ and γ_f as a function of financial development, as described in the text.

the variance of the foreign interest rate, and is meant to correspond to the response of the domestic interest rate to changes in the U.S. interest rate in the last 3 columns of Table 1.[10]

First, the moments β_R in the top panel are negative, and the moments β_i in the bottom panel are positive. This corresponds to the empirical results in Table 1, and indicates that in response to an increase in the foreign interest rate, the central bank raises the interest rate and reduces the stock of reserves.

In the left-hand panel, as θ increases, holding all else constant, the central bank is much more active in using reserves as a policy instrument where they reduce reserves to support the value of the currency when the foreign interest rate increases. The response of their other policy instrument, the domestic interest rate, is not monotonic and decreases for low values of θ, but for higher values of θ the response of the interest rate is increasing in θ.

[10]Note that in this case, considering annualized as opposed to quarterly interest rates will raise both the numerator and denominator by a factor of 16

In the middle panel, moving from left to right involves an increase in $1 - \gamma_f$, and thus a decrease in the foreign currency share of debt. The top panel shows that a decreasing foreign currency share means the central bank is less active in the use of foreign exchange reserves. The bottom panel shows that the central bank's interest rate response barely changes as the foreign currency share of debt decreases.

The right-hand panel puts the increase in θ and the decrease in γ_f together to show how the use of the two policy instruments changes as FD increases. For the use of foreign exchange reserves in the top panel, the response of reserve holdings is U-shaped, with the most active use of foreign exchange reserves occurring when $FD \approx 0.55$ and less active use of foreign exchange reserves for low or high levels of FD. For the domestic interest rate, there is no clear relationship between the use of the instrument and FD. These predictions of our model are in line with the empirical evidence presented in Table 2.

V.3. **Alternative Monetary Policies.** The results presented thus far have been from a model where the central bank sets the domestic interest rate using a Taylor rule described in equation 26. This was to match the positive average response of the domestic policy interest rate to an increase in the foreign interest rate that we see in the data. A vast theoretical and empirical literature describes how and why emerging market central banks may have a "fear of floating," and move their policy interest rate in line with the Fed more than would be expected from optimal monetary policy.

So while in the main body of the paper, we attempt to match empirical observations of the interest rate by giving the central bank a Taylor rule, in this section we repeat the experiment under alternative policies for the domestic interest rate, including Ramsey optimal policy, fixed consumer price level, and a fixed nominal exchange rate.

Figure 5 plots the β_R and β_i statistics from the last subsection as FD varies from 0 to 1 under four different rules for the nominal interest rate. The blue solid line simply repeats the Taylor rule case from Figure 4. In the red dashed line the Taylor rule for the domestic interest rate has been replaced by Ramsey optimal policy, where the central bank sets the domestic interest rate to maximize the sum of household and entrepreneur welfare. In the magenta dotted line the Taylor rule has been replaced with a rule that the central bank sets the domestic interest rate in order to hold the domestic consumer price level fixed. In the green dashed-dot line the Taylor rule has been replaced by a rule that the central bank sets the domestic interest rate to keep the nominal exchange rate fixed.

The left-hand graph in the figure plots the FX Reserve Response. Under different interest rate rules there is a level shift in FX Reserve Response. The most negative FX reserve response is for the nominal exchange rate targeting monetary regime; this is consistent with

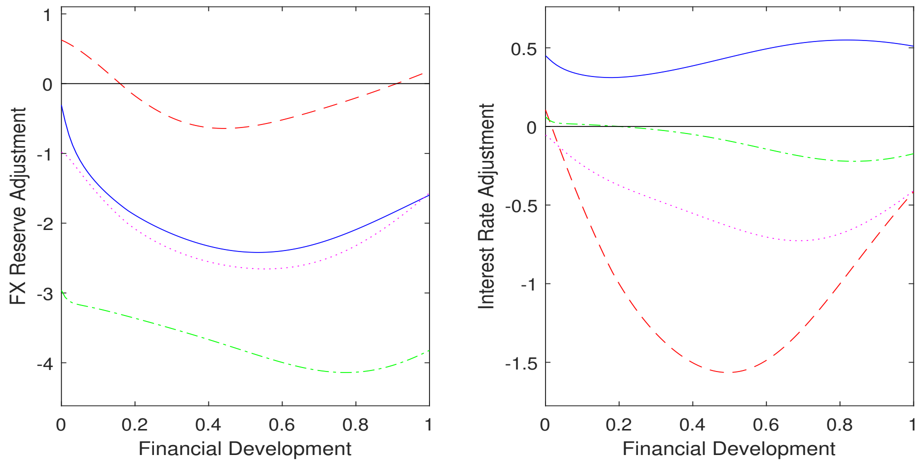

FIGURE 5. Covariance between the foreign interest rate and either central bank foreign reserves or the domestic interest rate under alternative monetary regimes.

Notes: 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 is the share of entrepreneur debt that is denominated in foreign currency. The right panel varies both θ and γ_f as a function of financial development, as described in the text. The stock of reserves is chosen with Ramsey policy. In the blue line the domestic interest rate is chosen with a Taylor rule, in the red line the interest rate is chosen with Ramsey policy, in the green line the interest rate is chosen to hold the nominal exchange rate constant, and in the purple line the nominal exchange rate is chosen to hold the price level constant.

the empirical results in Table 2 where the reserve response is more negative for a country with a pegged currency. The least negative FX reserve response if for the Ramsey optimal interest rate regime. But the U-shaped relationship between the FX reserve responses and financial development holds under each interest rate rule.

The right-hand chart in the figure plots the interest rate response. Here again we see a significant level difference between the different interest rate rules. Under the Taylor rule the response is positive, echoing what we see in the data. But under the other rules it is close to zero or negative. This counterfactual result is why we introduce the Taylor rule with an exchange rate term in the main section of the model to capture a "fear of floating".[11]

[11]In the model with a fixed nominal exchange rate the interest rate response is negative for all but the lowest levels of financial development. This indicates that the central bank cuts the domestic interest rate in response to an increase in the foreign interest rate. This itself highlights the role of the central bank sale of foreign exchange reserves. In a model where the central bank cannot change the stock of foreign exchange

As discussed earlier, under the Taylor rule there is no clear relationship between the interest rate response and financial development. But under the other interest rate rules, and especially Ramsey optimal policy, there is also a strong U-shaped relationship between the change in the domestic interest rates and financial development. The fact that we see this relationship in the model under Ramsey policy, but we do not see this relationship in the data is another reason to indicate that the Taylor rule for the interest rate is a more accurate description of how these central banks set the domestic interest rate following foreign interest rate shocks.

VI. Conclusion

We have documented empirical evidence that central banks have been using 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. The use of the conventional interest-rate policy, in contrast, does not vary systematically with 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 world interest rate shock. An increase in the foreign interest rate leads to private capital outflows, reducing the loanable funds to finance domestic investment. The increased foreign interest rate also leads to a 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

reserves and has just one instrument, the UIP condition ensures that to maintain a fixed nominal exchange rate, the central bank must match all changes in the foreign interest rate one-for-one.

and the average leverage are exogenously fixed. In reality, however, leverage may depend on a country's financial development, and the share of foreign currency debt may be related to the lack of policy creditability. In our view, generalizing our model in these directions should be an important and promising avenue for future research.

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

Table A1. Summary statistics

	1	2	3	4	5	6
$Dep.Var:$	Obs.	Mean	Std. Dev.	Min	Max	Sample
ΔRES	8045	3.799922	13.30835	-26.77368	43.04608	panel
$\Delta DOMINT$	8045	-.0205934	.2285643	-.7978357	.6211737	panel
$\Delta US1T$	8045	-.0492455	.3566296	-1.53	.5999999	panel
POP	8045	32149.98	51388.96	107.279	210707	panel
PCGDP	8045	12554.64	16612.54	362.8999	69110.84	panel
CAOPEN	8045	.5695631	.370395	0	1	panel
CAI	5079	.3412045	.3194671	0	1	panel
CAO	5079	.3917313	.389896	0	1	panel
β_R	101	-1.306805	5.401373	-11.90215	11.96957	cross-section
β_I	101	.0565667	.1154422	-.1597053	.4102789	cross-section
FD	101	.3733556	.240296	.0884792	.8703811	cross-section
USPEG	101	.1782178	.3846047	0	1	cross-section
CURR	101	-2.23745	6.283476	-17.37501	18.86187	cross-section
RES	101	18.67564	15.86979	1.120377	73.26882	cross-section

Note: Summary statistics for panel (Table 1) and cross-section (Table 2) specifications, as indicated in Column 6. Data winsorized at 2.5-97.5 percent levels, except for $USPEG$ dummy and constructed β_R and β_I variables. See text for variable definitions and calculations of β_R and β_I.

Table A2. List of countries in the sample

Country	FD Score
Albania	0.177
Algeria	0.136
Angola	0.137
Armenia, Rep. of	0.189
Belarus, Rep. of	0.147
Bhutan	0.188
Dominican Rep.	0.167
Ecuador	0.161
El Salvador	0.153
Eswatini, Kingdom of	0.160
Ethiopia, The Federal Dem. Rep. of	0.112
Fiji, Rep. of	0.191
Gambia, The	0.093
Ghana	0.162
Guinea	0.089
Guyana	0.149
Haiti	0.091
Honduras	0.195
Kyrgyz Rep.	0.103
Lao People's Dem. Rep.	0.124
Lesotho, Kingdom of	0.139
Liberia	0.088
Madagascar, Rep. of	0.096
Mauritania, Islamic Rep. of	0.105
Mozambique, Rep. of	0.121
Myanmar	0.105
Nepal	0.145
Nicaragua	0.125
Papua New Guinea	0.180
Paraguay	0.125
Rwanda	0.144
Samoa	0.185
Solomon Islands	0.093
Suriname	0.189
São Tomé and Príncipe, Dem. Rep. of	0.128
Tajikistan, Rep. of	0.084
Tanzania, United Rep. of	0.097
Uganda	0.089
Vanuatu	0.197
Yemen, Rep. of	0.113
Zambia	0.183

Note: Countries excluded from cross-section sample due to FD scores below 0.2.

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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\pi_t : i_t - \bar{i} = \theta_i \left(i_{t-1} - \bar{i} \right) + (1 - \theta_i) \theta_p (\pi_t - \pi) + (1 - \theta_i) \theta_Y \left(\frac{Y_t}{\bar{Y}} - 1 \right) + (1 - \theta_i) \theta_s \left(\frac{S_t}{P_t} - 1 \right) \tag{A.23}$$

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

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

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

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

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

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

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

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

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

$$\mu_t : - \left((1 - \gamma_f) (1 + i_t) + \gamma_f \left((1 + i_t^*) E_t (S_{t+1}) \right) \right) B_{e,t} \leq \theta E_t \left(P_{t+1}^k K_t \right) \tag{A.32}$$