External debt currency denomination and the currency composition of foreign exchange reserves

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Abstract: This paper studies the effects of external debt currency denomination on the currency composition of foreign exchange reserves (FXR). We construct a theoretical model in which central banks consider the buffer-stock role of FXR when managing their currency composition of FXR. The model predicts that countries depending more on dollar-denominated debt tend to hold more dollar FXR, especially when macroprudential policies are less strict. Supportive empirical evidence is obtained by analyzing the country-level data of FXR currency composition in 51 countries from 1999 to 2019. Importantly, we leverage an exogenous shock—the central bank swap lines established during the 2008 global financial crisis—to isolate and quantify the effect of dollar-denominated external debt on dollar FXR. Finally, we find that the dollar FXR share is less responsive to the dollar-denominated debt share in the presence of macroprudential policies.

Keywords: Currency composition; Foreign exchange reserves; External debt; Buffer stock; Swap line
JEL codes: F31, F33, F34, F42

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1 Introduction

Emerging market economies increasingly rely on the international debt market to raise capital for economic growth (Caballero et al., 2019). Owing to the "original sin" (Eichengreen et al., 2000; Hausmann and Panizza, 2003), the lion's shares of capital raised in international financial markets are foreign currency-denominated liabilities. They expose emerging markets to external financial shocks (e.g., sudden stops) and are likely to lead to exchange rate volatility and financial instability, particularly when foreign currency-denominated liabilities exceed local currency debts.[1] One way to safeguard against the possible repercussions of high shares of foreign currency liabilities is to hold high levels of foreign exchange reserves (FXR) and align the currency composition of FXR with the foreign currency denomination composition of external debt to avoid currency liquidity mismatch during financial crises.

Previous literature, including a well-known series of studies that use confidential data of FXR currency composition from the International Monetary Fund (IMF), provides evidence on the alignment of the currency composition in FXR with foreign currency-denominated debt currency composition. For example, Dooley et al. (1989) examine how the currency composition of international reserves respond to external debt service currency composition against the background of the debt crisis of the 1980s and find that the reserve currency composition is positively related to the currency denomination of external debt. In a follow-up study, Eichengreen and Mathieson (2000) confirm this positive association using updated reserve currency composition data. Both studies interpret this result from the perspective that the positive association lowers the transaction cost when central banks rebalance their portfolios[2] or intervene in the foreign exchange market to maintain exchange rate stability.

The previous research provides groundbreaking theoretical insights on the nexus of external debt currency denomination and the FXR currency composition. However, as both the global debt market and the behavior of holding FXR have changed drastically since 2000, it is

[1] There is extensive literature on foreign currency-denominated debt and the associated financial instability. See, for example, Schneider and Tornell (2004), Augiar (2005), Frankel (2005), Gopinath and Stein (2018), and Bocola and Lorenzoni (2020).

[2] Most recent studies on the rebalance of FXR currency portfolio include Arslanalp et al. (2022) and Chinn et al. (2022).

imperative to closely scrutinize how the effects of currency denomination of external debt on central banks' FXR currency composition may change in the rapidly evolving global financial landscape[3] and how central banks coordinate their management of FXR currency composition with traditional macroprudential policies to maintain financial stability. In this study, we aim to address these questions by proposing a theoretical model and an empirical strategy to examine the effect of foreign currency denomination in external debt on the currency composition of FXR.

Departing from the typical mean-variance portfolio choice model[4] in the reserve currency composition literature, we focus on the buffer-stock role of international reserves (Frenkel, 1974; Aizenman and Jinjarak, 2020). We develop a theoretical model that relates the central bank's precautionary motives to hold the optimal currency composition in FXR to domestic borrowers' endogenous currency denomination in external debts. Our model is built on the framework of Gopinath and Stein (2018), where the central bank acts as "the lender of last resort" to bail out domestic borrowers in the event of a financial crisis. We allow external debts to constitute both dollar- and euro-denominated debt instruments. The objective of the central bank is to hold the optimal share of dollar FXR *ex ante* to minimize total costs. The closed-form solution of the model predicts that the optimal share of the dollar FXR is an increasing function of the dollar-denominated debt share, and the marginal effect of the dollar debt share depends negatively on the strength of *ex ante* macroprudential policies.

We empirically test the model predictions using the country-level data for the currency composition of FXR from Ito and McCauley (2020), which cover 51 countries (including advanced and developing economies) over 1999–2019. The dataset includes the shares of four major reserve currencies (US dollar, euro, sterling pound, and Japanese yen). As the US dollar is the dominant currency in both FXR and external debt, we focus on how the share of US dollar-denominated external debt influences the US dollar share in a country's FXR. In an OLS regression controlling for country and year fixed effects, we obtain supportive evidence for the theory that the US dollar FXR share responds positively to the US dollar-denominated external

[3] For the recent literature on the evolving global financial landscape and central banks' behavior of holding FXR, see Avdjiev et al. (2017), Gourinchas et al. (2019), and Arslanalp et al. (2022).

[4] See, for example, Dooley et al. (1989), Papaioannou et al. (2006), Lu and Wang (2019), Aizenman et al. (2020), and Ito and McCauley (2020).

debt share. Specifically, central banks raise approximately 0.237% of the dollar FXR relative to other currencies FXR in response to a one percent increase in the relative ratio of the dollar debt to all foreign currency debt.

A concern is that the estimated response of the US dollar FXR shares to the dollar-denominated external debt is a simple statistical association rather than the causal effect of the dollar-denominated external debt share on the dollar FXR share due to endogeneity issues. To quantify the effect of dollar-denominated debt share, we estimate a random treatment model (Imbens and Angrist, 1994)[5] by using the establishment of central bank swap lines during the 2008 global financial crisis (GFC) as the random treatment. Applying swap lines established during the 2008 GFC[6] as the random treatment is because they can be considered as "quasi-natural experiments" for three reasons.[7] First, the occurrence of the 2008 GFC is equivalent to a "natural" financial disaster for countries other than the United States. Second, the unexpected development of the 2008 GFC randomly induced periphery countries to establish swap lines during the GFC periods in the expectation of the unexpected. Third, and more importantly, the U.S. Federal Reserve (Fed) extended swap lines to periphery countries during the 2008 GFC to contain the risk of global shortage in US dollar liquidity rather than helping individual countries (Goldberg et al., 2010; Bahaj and Reis, 2021).

Ad hoc dollar swap lines during the 2008 GFC that provided emergency dollar liquidity were found to reduce the pressure of a peripheral country's central bank to sell US dollar FXR to buffer the strong credit retrenchment of US dollar liabilities during the 2008 GFC (Obstfeld et al., 2009; Aizenman and Pasricha 2010; Miranda-Agrippino and Rey, 2020). Therefore, the swap lines during the 2008 GFC had a "treatment effect" that reduced the responsiveness of the dollar

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[5] Imbens and Angrist (1994) define the treatment effects in terms of potential outcomes or counterfactuals. In their framework, let $Y_i(0)$ be the potential outcome without the treatment; $Y_i(1)$ is the potential outcome with the treatment. Furthermore, the expected treatment effect is measured as $Y_i(1)$-$Y_i(0)$ with the conditional independence assumption. See also Meyer (1995).

[6] The US Federal Reserve Bank (Fed) extended *ad hoc* dollar swap lines during the 2008 GFC (typically maturing in 1 week or 1 month) to periphery country central banks to provide liquidity to alleviate the global dollar liquidity shortage. In addition to the Fed, four other major central banks—the European Central Bank, Bank of England, Bank of Japan, and Swiss National Bank—auctioned US dollar swap lines during the 2008 GFC.

[7] Fuchs-Schündeln and Hassan (2016) provide a comprehensive survey of studies using exogenous policy changes as quasi-natural experiments in macroeconomics and provide suggestions for applying a natural experiment approach.

FXR to dollar-denominated external debt. Using a difference-in-differences (DID) approach to compare the responsiveness of the dollar FXR share during the period of treatment with and without the treatment, we can isolate and quantify the causal effect of the dollar-denominated debt share on dollar FXR shares. Our results suggest that a one percent increase in external debt dollar share causes central banks to hold on average 0.223 percent more dollar FXR share. The effect is reduced to 0.013 after receiving swap lines during the 2008 GFC.

To address the concern that the swap lines established during the 2008 GFC acted through an unobserved confounder related to both the dollar-denominated debt share and dollar FXR share, we perform a falsification test. We compare the estimated treatment effects in the treatment group (countries receiving the treatment of swap lines established during the 2008 GFC) and the control group (countries receiving no treatment). Had the treatment effect worked through an unobserved confounder, exerting a swap line treatment would trigger the confounder in the treatment group, but not in the control group, resulting in the estimated association between the dollar-denominated debt and dollar FXR being different for the treatment and control groups. However, the result of a DID regression suggests a similar association between the dollar-denominated debt and dollar FXR share in the treatment and control group. This rules out the possibility that the treatment effect of swap lines established during the 2008 GFC works through an unobserved confounder.

Finally, as macroprudential policies insulate external shocks and lower the probability of a financial crisis in peripheral countries (Pasricha et al., 2018; Obstfeld et al., 2019; Ma, 2020), we test how the effect of dollar debt shares on dollar reserve shares changes in the presence of macroprudential policies. We use capital controls as proxies for the macroprudential policy and find that higher levels of capital controls reduce the effect of dollar-denominated debt share on the dollar FXR share. The results imply that FXR currency composition management is a part of overall international reserve management and is coordinated with traditional macroprudential policies to maintain financial stability.

Our study is related to four strands of literature. First, it is closely related to studies that model the endogenous currency choices in international debt and FXR (e.g., Gopinath and Stein, 2018, 2021). We follow Gopinath and Stein (2018) but depart from their framework by introducing two core currencies to explicitly study the optimal dollar share of FXR and show how it is affected by the dollar share in external debt. In addition, unlike the typical mean-variance portfolio choice model (Papaioannou et al., 2006; Lu and Wang, 2019), we model the buffer-stock role of FXR to study how central banks manage their FXR currency composition in response to the endogenous currency denomination of external debt.

Second, this paper complements the empirical literature that examines the nexus between the currency composition of central banks' FXR holdings and external debt currency denomination (e.g., Dooley et al., 1989; Eichengreen and Mathieson, 2000; Aizenman et al., 2020; Ito and McCauley, 2020).[8] We add value to this literature by empirically isolating the causal link between the dollar-denominated debt and the dollar FXR using newly available country-specific FXR currency composition data compiled by Ito and McCauley (2020). Notably, we propose to use the establishment of swap lines during the 2008 GFC as the random treatments (e.g., a quasi-natural experiment) to extract a part of the causal effect of the dollar-denominated debt during the 2008 GFC, thereby verifying that the dollar FXR share is affected by the dollar-denominated debt share.

Third, this paper is related to the growing literature on macroprudential policies, for example, FXR management accumulation (Aizenman and Lee, 2007; Obstfeld et al., 2010; Aizenman et al., 2020), capital control policies (Ostry et al., 2012; Pasricha et al., 2018; Devereux and Yu, 2019), and foreign currency debt/loans management (Huang et al., 2018; Ogrokhina and Rodriguez, 2018; Du and Schreger, 2022). Deviating from the literature, we let the FXR currency composition management policy interact with traditional macroprudential policies (e.g., capital controls) and find they are coordinated. Specifically, we find that capital controls reduce the intensity of managing the FXR currency composition in response to the changes in external debt currency composition.

Fourth, our study complements the burgeoning literature on the interactions and synergies among the international use of a currency in different roles—as a medium of exchange, unit of account, and store of value (Goldberg and Tille, 2008; Chung, 2016; Farhi and Maggiori, 2018; Liu et al., 2019; Gopinath and Stein, 2021; Jiao et al., 2021; and a summary by Gourinchas et al.,

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[8] While most of the literature finds that external debt currency denomination is positively associated with the currency composition of FXR, a notable exception is Bocola and Lorenzoni (2020). These authors document a negative link between the dollar FXR and the dollar external debt in a sample of emerging markets. They argue that higher dollar FXR makes central banks better prepared to provide ex post support to borrowers, reducing their ex ante incentives to borrow foreign currency-denominated debt.

2019). We contribute to the literature by examining the nexus of currency denomination in external debt (unit of account) and currency composition in the FXR (store of value).

The remainder of the paper is organized as follows. Section 2 presents a simple model to demonstrate the mechanism through which foreign currency debt affects the central bank's optimal currency composition in the FXR. Section 3 describes the data and provides descriptive analyses of the dollar FXR share and dollar debt share. Section 4 specifies a baseline regression and difference-in-differences models using swap lines established during the 2008 GFC as quasi-natural experiment treatments. It also presents a multiplicative regression model controlling for possible macroprudential policies coordination and performs robustness checks. Section 5 concludes.

2 The model

In this section, we develop a theoretical framework in which a central bank chooses an optimal currency composition in international reserves based on an endogenously determined currency denomination in external debt. We follow the framework of Gopinath and Stein (2018) but customize their model in two ways. First, we allow the central bank to choose between two core currencies (US dollar or euro) in their reserve holdings. Second, we let the central bank coordinate macroprudential policies when managing how the currency composition of the FXR responds to the private sector's debt currency denomination. Detailed model derivations are presented in Appendix A.

There are two core countries, the US and the Eurozone, and a continuum of peripheral countries, whose agents—households, banks, and central banks—make decisions on two dates, denoted as 0 and 1. There are three types of assets: (i) risk-free home currency deposits, D_h; (ii) risk-free deposits in dollars, $D_\$$; and (iii) risk-free deposits in euros, $D_€$. The exchange rate of the home currency against the dollar (euro) is $e_{\$0}$ ($e_{€0}$) at time 0 and is normalized to 1 for ease of notation. The exchange rate is measured in units of the home country's currency per dollar (euro), where a higher value indicates a weaker home currency. The exchange rate $e_{\$1}$ ($e_{€1}$) at time 1 is a random variable. Following Gopinath and Stein (2018), we assume that the exchange rate of both currencies at time 1 is $1+z$ with probability $p=0.5$ (home currency depreciation) and $1-z$ with probability $1-p=0.5$ (home currency appreciation). Thus, z captures exchange rate volatility.[9]

Furthermore, we assume that the correlation between the two core currency exchange rates is $\rho \in (-1,1)$. Therefore, the probability of appreciation (depreciation) of both currencies against the home currency is $(1+\rho)/4$; the probability of one core currency appreciating and the other core currency depreciating against the home currency is $(1-\rho)/4$. Additionally, there is a probability q of a crisis when the local currency depreciates with respect to the dollar.[10] When a crisis occurs, the euro can either appreciate or depreciate against the home currency, and the conditional probability of the euro appreciation is denoted by $a=(\rho+1)/2$. For instance, when the correlation ρ is close to 1, the euro is more likely to behave like the dollar during the crisis.

2.1 Households

Households consume quantities of home goods C_0 and C_1 at times 0 and 1, respectively, and save in the form of $D_\$$, $D_€$, or D_h at time 0. Following Gopinath and Stein (2018), we assume that households derive utility from consumption goods and by holding safe deposits. Households maximize their utility as follows:

$$\max_{D_h, D_\$, D_€} C_0 + \beta \mathrm{E}_0(C_1) + \theta\alpha_\$ log(D_\$) + \theta\alpha_€ log(D_€) + \delta(1-\alpha_\$-\alpha_€)D_h \qquad (1)$$

We use Q_h to denote the price of a deposit that pays off a certain one unit in the local currency at time 0, $Q_h = 1/(1+r_h)$. Similarly, $Q_\$ = 1/(1+r_\$)$ and $Q_€ = 1/(1+r_€)$. $\alpha_\$$ ($\alpha_€$) is a proxy for the fraction of consumption goods invoiced in dollars (euro). The first-order conditions are as follows: $Q_h = \beta + \delta(1-\alpha_\$-\alpha_€)$; $Q_€ = \beta + \frac{\theta\alpha_€}{D_€}$; $Q_\$ = \beta + \frac{\theta\alpha_\$}{D_\$}$. Note that Q_h is determined by

[9] For simplicity, we assume that the volatility of the dollar exchange rate and euro exchange rate against the home currency is the same in the baseline model. The key theoretical predictions do not change if we assume different volatility for the dollar and euro.

[10] According to the literature, the dollar exchange rate is a risk parameter; therefore, depreciation against the dollar is usually associated with higher risk of sudden stop and capital flight (see Aizenman and Lee, 2007; Avdjiev et al., 2019).

local factors; in particular, $\alpha_\$$, $\alpha_€$. $Q_\$$, and $Q_€$ are determined by the international capital markets and thus, are exogenous to the periphery economy.[11] Owing to the exorbitant privilege of the dollar, we assume that the dollar offers the lowest return compared to other currencies, and therefore, $Q_\$ > Q_€$. For ease of notation, we define $S_\$$ ($S_€$) as the spread between $Q_\$$ ($Q_€$) and Q_h; that is, $S_\$ = \frac{Q_\$}{Q_h} - 1 = \frac{Q_\$}{\beta + \delta(1-\alpha_\$ - \alpha_€)} - 1$ and $S_€ = \frac{Q_€}{Q_h} - 1 = \frac{Q_€}{\beta + \delta(1-\alpha_\$ - \alpha_€)} - 1$.

2.2 Banks

The second group of local agents are banks/firms, simply called "banks." They receive funding from households and invest in N projects.[12] In a non-crisis state, the project pays off γN, where $\gamma > 1$. Banks face a currency mismatch and thus, bear an exchange rate risk. When the local currency depreciates against the dollar, each bank has an independent probability m of failing, and its payoff from the projects is zero. Banks can default on their debts if they fail, but the central bank can bail out the bank. Banks choose to issue dollar deposits $B_\$$, euro deposits $B_€$, or home currency deposits B_h, subject to balance sheet constraints:

$$N = Q_h B_h + Q_\$ B_\$ + Q_€ B_€ \tag{2}$$

Banks seek to maximize their expected profits. The expected revenue of the banks is $(1 - pqm)\gamma N$. The expected costs of the banks have five components: (1) repayment in the case of depreciation of both the dollar and euro against home currency c_1: $[(1+\rho)/4][B_h + (1-z)(B_\$ + B_€)]$; (2) repayment in the case of depreciation (appreciation) of the dollar (euro) against the home currency c_2: $[(1-\rho)/4][B_h + (1-z)B_\$ + (1+z)B_€]$; (3) repayment in the case of depreciation of the euro and appreciation of the dollar against the home currency, but the bank itself does not fail c_3: $[p(1-q) + pq(1-m)](1-a)[B_h + (1+z)B_\$ + (1-z)B_€]$; (4) repayment in the case of appreciation of both the dollar and euro against the

[11] When the imported goods are sufficiently large, it is reasonable to assume that $Q_\$$ and $Q_€$ are constant. See the full-fledged model in Gopinath and Stein (2021) for a detailed discussion of $Q_\$$ and $Q_€$.

[12] They are more accurately thought of as an agglomeration of local firms and financial intermediation, because these local firms get funding from the financial market, either through bank loans or debt instruments held by mutual funds.

home currency, but the bank itself does not fail c_4: $[p(1-q)+pq(1-m)]a[B_h + (1+z)(B_\$ + B_€\ \ )]$; and (5) currency mismatch, which we assume is costly in the state of local currency depreciation against the dollar (which occurs with probability p) and is given by $c_5 = \phi B_\$^2 / 2 + \phi B_€^2 / 2$. Therefore, the banks solve the expected profit maximization problem as follows:

$$\max_{B_h, B_\$, B_€} (1-pqm)\gamma N - \{c_1 + c_2 + c_3 + c_4 + pc_5\} \tag{3}$$

The first-order conditions yield an interior optimum for a bank's dollar-denominated debt instruments, $B_\$$ and

$$B_\$ = \frac{1}{\phi p}\{(1-pqm)S_\$ + pqmz\} \tag{4}$$

$$B_€ = \frac{1}{\phi p}\{(1-pqm)S_€ + \rho pqmz\} \tag{5}$$

Compared to the bank's optimal borrowing in dollars $B_\$$, the bank chooses a smaller amount of $B_€$ when $Q_\$$ is greater than $Q_€$, indicating that euro funding is more expensive than dollar funding. When the exchange rate volatility z is higher, banks tend to issue more dollar (euro)-denominated debt instruments, but $B_\$$ increases more than $B_€$ as $\rho < 1$. B_h is determined by the bank's financing constraint (2). The market-clearing conditions are $D_\$ = B_\$ + X_\$$ for the dollar deposits, $D_€ = B_€ + X_€$ for the euro deposits, and $D_h = B_h$ for the home currency deposits. $X_\$$ ($X_€$) is an exogenous net quantity of the dollar (euro)-denominated safe claims.

2.3 The central bank

The central bank acts as the lender of last resort, as in Aizenman and Lee (2007), Obstfeld et al. (2010), and Bocola and Lorenzoni (2020). Specifically, the central bank bails out banks that fail in the crisis state. It can either hold reserves *ex ante* at time 0 and sell reserves *ex post* to bail out (the buffer-stock role of international reserves) or impose a tax on the household to finance the bailout *ex post* at time 1 if it holds less than sufficient reserves. The central bank aims to choose the optimal currency composition of its reserve holdings to minimize bailout costs.[13] Specifically, the central bank's total reserve holdings at time 0 are denoted as $R = R_\$ + R_€$, where $R_\$$ ($R_€$) is the dollar (euro) reserve. The key trade-off facing the central bank is that it tends to hold more dollar reserves, because these would appreciate against the home currency in a crisis state. However, the euro reserves would appreciate against the home currency only with some probability. Nevertheless, holding dollar reserves earns a lower interest rate than holding euro reserves. The central bank's balance sheet at time 0 is as follows:

$$Q_\$ R_\$ + Q_€ R_€ = Q_h B_h^c \tag{6}$$

Here, B_h^c is the central bank's bill on the liability side.[14] At time 1, the central bank liquidates its dollar and euro reserves, and uses the proceeds plus any further taxes to pay off the local currency central bank bill. The expected shortfall of holding reserves (C) is the interest rate differential between the home and reserve currencies, given by $C = S_\$ R_\$ + S_€ R_€$. The central bank must raise funds by taxing households to bail out banks if it holds less than sufficient reserves at the time when a crisis materializes with the probability of pq. Two scenarios could occur: (1) when the euro appreciates, which occurs with probability $a = (\rho + 1)/2$, the central bank levies the amount of tax T_1; (2) when the euro depreciates, which occurs with probability $1 - a$, the central bank taxes households the amount of T_2. Following Gopinath and Stein (2018), we assume that the central bank's raising of the tax in the crisis state is costly and that deadweight costs are a convex function of T_1 and T_2. Against this backdrop, the central bank chooses the optimal foreign reserves—$R_\$$ and $R_€$—to minimize total costs as follows:

$$C + pqa\frac{\gamma}{2}T_1^2 + pq(1-a)\frac{\gamma}{2}T_2^2 \tag{7}$$

[13] Gopinath and Stein (2018) assume that the central bank holds only dollar reserves and study the optimal level of the dollar reserve holdings. We take the lead from their seminal work to examine the optimal currency composition of the central bank's reserve holdings. Therefore, we depart from their assumption of only dollar reserve holdings by introducing another core currency for the central bank's choice, for example, the euro.

[14] The central bank bill B_h^c is held by banks that obtain the funding from households. Therefore, $Q_h B_h^c$ appears both as assets and liabilities of banks. In equation (2), there is no $Q_h B_h^c$, because it cancels out on both sides of the balance sheet. In other words, B_h can be thought of as net home currency deposits issued by the bank.

The optimal dollar reserves $R_{\$}$ that yield from first-order conditions are

$$R_{\$} = \frac{2m\left((z - S_{\$})B_{\$} - S_{€}B_{€} + \frac{N}{Q_h} \right) - T_1 - T_2}{2z} \tag{8}$$

where $T_1 = \frac{S_{\$} + S_{€}}{2pqa\gamma z}$; $T_2 = \frac{S_{\$} - S_{€}}{2pq(1-a)\gamma z}$. Note that $B_{\$}$ and $B_{€}$ are pinned down in equations (4) and (5); therefore, equations (8) is the solution for the optimal dollar reserves $R_{\$}$. Similarly, the optimal euro reserves are $R_{€} = \frac{2mzB_{€} - T_1 + T_2}{2z}$. When z is sufficiently large, $R_{\$}$ tends to increase (decrease) when $B_{\$}$ ($B_{€}$) increases.[15] The optimal euro reserves $R_{€}$ are an increasing function of $B_{€}$. In the extreme case, when z is positive infinity, we can obtain $R_{\$} = m\ B_{\$}$ and $R_{€} = m\ B_{€}$. Intuitively and interestingly, if the exchange rate correlation between the dollar and euro, ρ, increases toward 1, the euro behaves more like the dollar during the crisis and performs an insurance role as effectively as the dollar, the central bank tends to hold more euro reserves.

Additionally, the model allows us to analyze how the dollar share in the FXR varies with the dollar share in foreign debt. Denote the dollar share in FXR as $Share_{\$}^{R} = R_{\$} / (R_{\$} + R_{€})$ and the dollar-denominated foreign debt share as $Share_{\$}^{B} = B_{\$} / (B_{\$} + B_{€})$. We can solve the first derivative, $\frac{\partial Share_{\$}^{R}}{\partial Share_{\$}^{B}}$, the sign of which indicates how the dollar share in the FXR responds to the dollar share in foreign debt. As shown in Appendix A, the sign of $\frac{\partial Share_{\$}^{R}}{\partial Share_{\$}^{B}}$ is positive conditional on a sufficiently high likelihood of a crisis with exchange rate volatility.

Proposition 1. When exchange rate volatility z is high, the optimal share of the dollar in the central bank's reserve holdings, $Share_{\$}^{R}$, increases with the increase in the share of dollar-denominated debt, $Share_{\$}^{B}$.

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[15] Of course, $B_{\$}$ and $R_{\$}$ can be driven by other common factors not captured by this simple model, such as exchange rate regime or exchange rate co-movements. We control these factors in our empirical investigation.

Next, we extend the model to examine how the relationship between the dollar debt share and reserve dollar share changes in the presence of macroprudential policies. We introduce Chilean-style capital control to represent macroprudential policies. To reduce the likelihood of a sudden stop, the central bank levies ex ante capital-inflow tax on the foreign currency-denominated debt issued by banks. Specifically, the tax rate for $B_{\$}$ ($B_{€}$) is τ.[16] The probability of $m(\tau)$ is a decreasing function of τ, indicating that more macroprudential policies reduce the probability of bank crises. By solving the model, we obtain

$$R_{\$} = \frac{2m(\tau)\left((z - S_{\$} + \tau(1+S_{\$}))B_{\$} - (S_{€} - \tau(1+S_{€}))B_{€} + \frac{N}{Q_h} \right) - T_1 - T_2}{2z} \tag{9}$$

We are interested in the sign of $\frac{\partial^2 (R_{\$} / R_{€})}{\partial (B_{\$} / B_{€}) \partial \tau}$, which depends on the dominating effect of two opposite effects that the tax on foreign debt, τ, imposes on the marginal effect of the dollar-denominated foreign debt share on the dollar reserve share. On the one hand, imposing a macroprudential tax, τ, on foreign debt makes dollars more expensive to borrow, thereby reducing the interest rate spreads, which measures the carry cost for central banks to hold dollar reserves. The reduced carry cost constraint makes the dollar reserve share more responsive to borrowing dollar-denominated foreign debt. On the other hand, macroprudential policies reduce the probability of a bank crisis— $m(\tau)$. The reduced likelihood of a bank crisis decreases the need for the central bank to manage its FXR currency composition by adjusting its dollar reserve share in response to the changes in the dollar-denominated foreign debt. The observed effect of the macroprudential policy is the net of these two effects. In Appendix B, we show that under certain conditions (e.g., the marginal effect of τ on bank crisis likelihood m is sufficiently large, when macroprudential policies are effective), $\frac{\partial^2 (R_{\$} / R_{€})}{\partial (B_{\$} / B_{€}) \partial \tau} < 0$. The optimal share of the dollar

[16] The tax collected by the government is rebated to the household and affects net tax T, but does not affect the household's first-order condition.

reserve is less sensitive to changes in the dollar-denominated foreign debt share when macroprudential policies become more effective.

Proposition 2. The optimal share of the dollar in the central bank's reserve holdings, $Share_{\$}$, becomes less responsive to the dollar-denominated debt share, $Share_{\$}^{B}$, as ex ante macroprudential policies become tighter.

3 Data and descriptive analyses

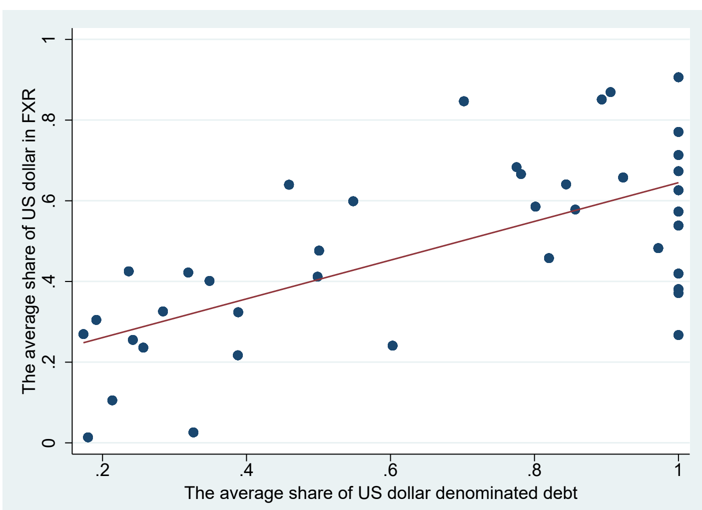
Country-specific data on the FXR currency composition are scarce, because central banks regard currency composition as confidential information. Consequently, most existing works study FXR currency composition based on aggregated FXR currency composition data, which are available from the IMF's Currency Composition of Official Foreign Exchange Reserve.[17] The aggregate data are informative; however, they tend to obscure country-idiosyncratic factors that determine the currency composition of the FXR. Several recent studies, for instance, those of Gopinath and Stein (2018), Iancu et al. (2020), and Ito and McCauley (2020), have collected country-level currency composition data with various sample sizes from the IMF and central banks' annual reports, financial statements, and other information sources to make the data available to the public.[18] Among these three datasets, Ito and McCauley (2020) offer the most coverage by country and period. Therefore, we rely on their dataset. Owing to the unavailability of Latin American economies' data and dropping China and Chinese Taipei data, which have only one observation, we obtain data for 51 economies from 1999 to 2019, including both advanced and developing economies (see Appendix C for country samples). Their data offer shares of four major reserve currencies (US dollar, euro, sterling pound, and Japanese yen). In this study, we focus on the US dollar share in total FXR and use the euro share in FXR to check the robustness of our results.

[17] As an exception, Dooley et al. (1989) and Eichengreen and Mathieson (2000) use non-disclosed country-level data of FXR currency composition data from the IMF.

[18] Specifically, Gopinath and Stein (2018) collect FXR currency composition data of 15 countries in 2015, 2016, or 2017. Iancu et al.'s (2020) data comprise 42 economies from 1999 to 2018 and contain the currency share of four major reserve currencies, namely, the US dollar, euro, sterling pound, and yen. Ito and McCauley (2020) construct a dataset of 75 economies covering the period 1999 to 2020 with four major reserve currencies' shares; however, data of Latin American economies are not available from the authors owing to non-disclosure agreements. All three datasets include both advanced and developing countries.

The data on the currency denomination of international debt are obtained from the International Debt Securities Statistics of the Bank for International Settlements (BIS), which publishes country-specific time-series data for the US dollar, euro, and other aggregated currencies' denominated international debt securities issued outside the issuing country by governments, financial intermediaries, and non-financial firms. We extract the US dollar-denominated debt data of 51 countries from 1999 to 2019 to compile our estimation sample for the share of US dollar-denominated debt. To obtain first-hand information about the nexus between the share of the US dollar-denominated debt and the US dollar share in total FXR, we plot the average US dollar share in FXR and the average share of US dollar-denominated debt for each sample country in Figure 1. Consistent with the findings of previous studies, the figure shows a clear positive association between these two shares (the slope of the linear prediction line is 0.48 with an R^2 value of 0.45).[19] Previous studies suggest that this positive association is due to an increase in the number of dollar-funded banks in a country, which induces the central bank, as the lender of last resort, to hold more dollar reserves for precautionary purposes (Obstfeld et al., 2010; Gopinath and Stein, 2018; Bocola and Lorenzoni, 2020).

Figure 1: The US dollar FXR share and the share of US dollar-denominated external debt

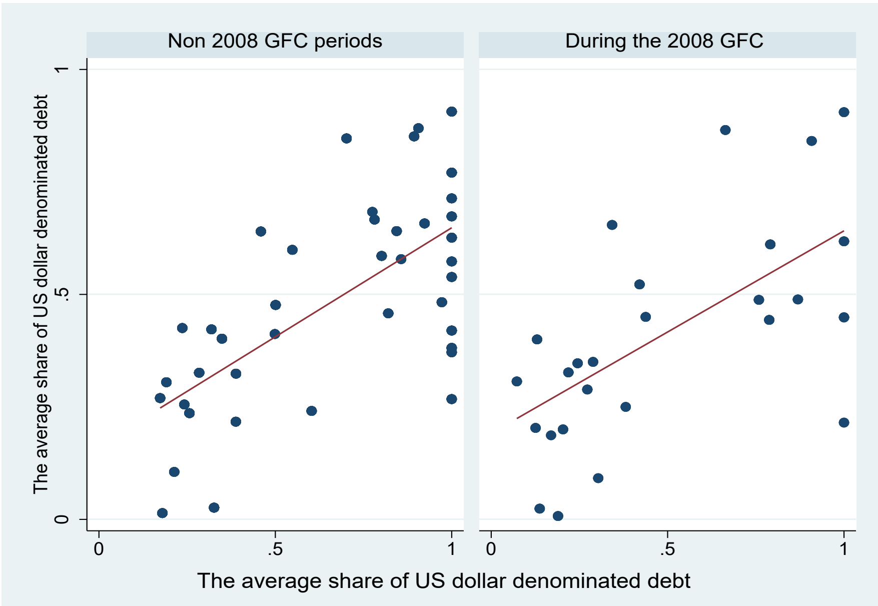


Note: Each dot represents a country. The line plots the linear prediction with slope = 0.48 and R^2 = 0.45.

[19] Gopinath and Stein (2018) plot a similar positive association between the dollar share in FXR and trade invoicing with data of 15 countries.

The 2008 GFC wreaked havoc on the global financial market and triggered a strong retrenchment of capital flows from peripheral countries to the US (Miranda-Agrippino and Rey, 2020). Investors rushed to acquire US dollar assets and stopped issuing US dollar-denominated liabilities (sudden stops). Consequently, the US dollar-denominated debt share in our 51 sample countries reduced from an average of 52% in tranquil times to 43% during the 2008 GFC. To stabilize the financial market, central banks sold US dollar FXR to provide dollar liquidity and intervene in the foreign exchange market (Jeanne, 2016; Aizenman et al., 2021). As a result, the dollar reserve share reduced from an average of 56% in tranquil times to 51% in the 2008 GFC. As the rate of decrease in the dollar FXR share is lower than the rate of dollar debt retrenchment, one would expect the association between the dollar FXR and dollar debt share to be weaker. However, the positive association between the dollar shares in the FXR and dollar debt share remained consistent, even in the 2008 GFC. As shown in Figure 2, where the left panel plots the sample data during tranquil times, and the right panel plots the 2008 GFC data, the positive associations between the dollar FXR and dollar debt shares are not statistically different during the 2008 GFC and tranquil periods. The slope of the linear prediction line is 0.43 and 0.47 during the 2008 GFC and tranquil times, respectively. The Chow test results suggest that they are not statistically different.

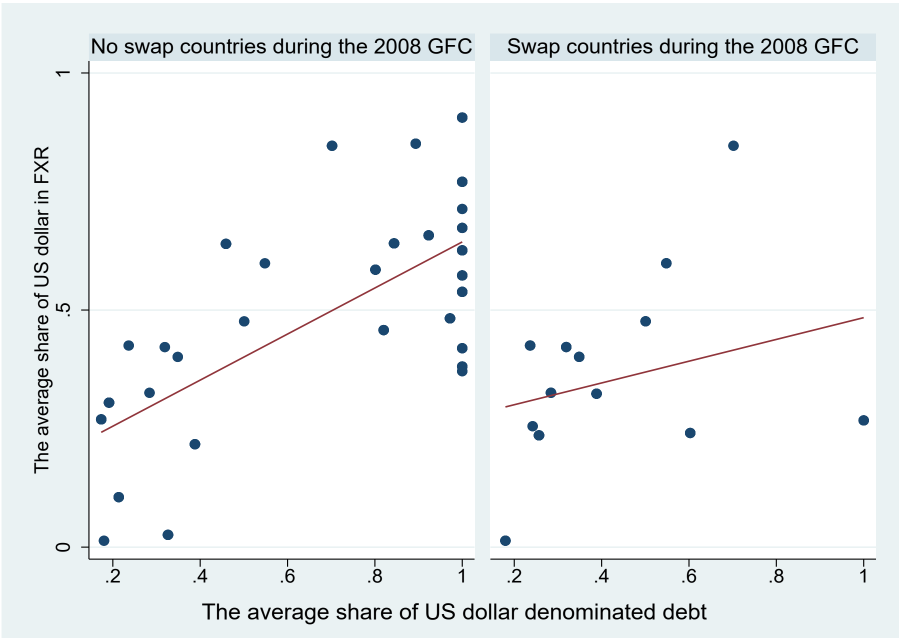
Figure 2: The association between the dollar FXR share and the share of dollar-denominated debt in the 2008 GFC and non-GFC periods



Note: Each dot represents a country. The lines plot linear predictions with slope = 0.47 and 0.43 in the left and right panel, respectively. R^2 = 0.48 in the left panel and 0.57 in the right panel.

Meanwhile, during the 2008 GFC, the Fed extended *ad hoc* US dollar swap lines to selected countries to alleviate the risk of global dollar fund shortages. Swap lines provide US dollar liquidity to peripheral countries' central banks, which are subsequently lent out to financial institutions within their jurisdiction to buffer the dollar asset retrenchment. As such, the recipient central banks act as "the lender of last resort" to bear the credit risk associated with their domestic financial market (Bahaj and Reis, 2021). The dollar liquidity supplied by swap lines subsidizes the buffer-stock role of the FXR and reduces the central banks' reliance on using the FXR as the buffer stock (Aizenman et al., 2011). Thus, central bank swap lines may weaken the linkage between the dollar reserve share and dollar-denominated debt share. We demonstrate this by plotting the association between the dollar reserve share and dollar-denominated debt share for countries that have swap lines and non-swap countries during the 2008 GFC in Figure 3. The left panel plots the data of countries with no swap lines, while the right panel plots the data of countries with swap lines. The slope of the linear prediction line in swap countries is flatter than that in non-swap countries (0.23 vs. 0.48), suggesting that the degree of association is weaker in the presence of swap lines during the 2008 GFC.

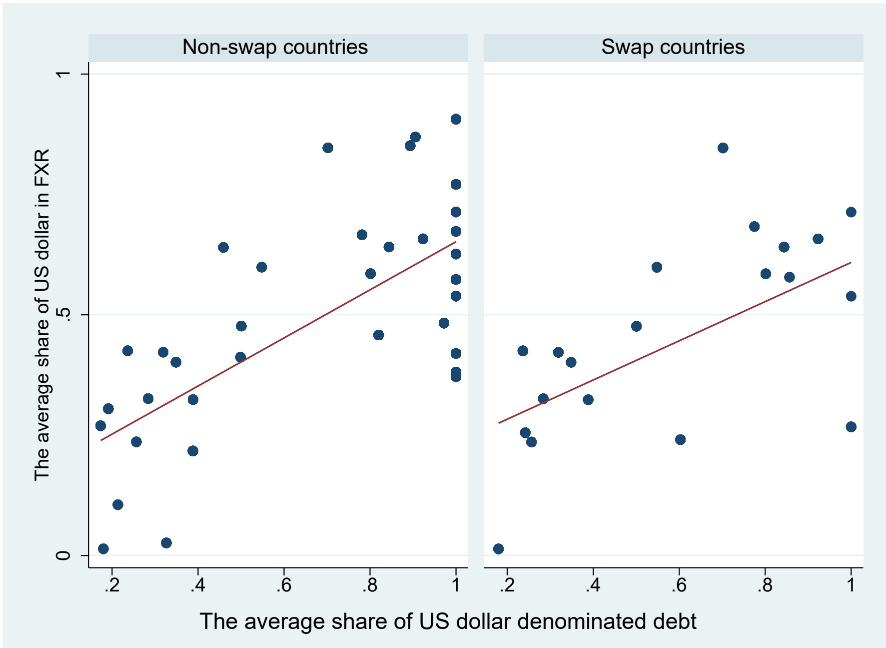
Figure 3: The association between the dollar share in FXR and international debt in non-swap versus swap countries during the 2008 GFC



Note: Each dot represents a country. The lines plot linear predictions; R^2 = 0.45 in the left panel and 0.09 in the right panel.

Despite being prominent during the 2008 GFC, the liquidity substitution effect of swap lines was not effective during the non-2008 crisis times. Figure 4 plots the data for swap and non-swap countries during the tranquil periods. The slopes of the linear predictions are 0.66 and 0.67, respectively. Indeed, *ad hoc* dollar swap lines are typically short-term contracts that provide temporary emergency dollar funds. In the absence of a major crisis, such as the 2008 GFC, the liquidity substitution role may be less effective in influencing the relationship between the dollar debt and dollar FXR.

Figure 4: The association between the dollar share in FXR and international debt in non-swap versus swap countries during the 2008 GFC



Note: Each dot represents a country. The lines plot linear predictions; R^2 = 0.48 in the left panel and 0.57 in the right panel.

These preliminary data analyses, although intuitive, are solely based on the (unconditional) correlation between the data of the dollar FXR share and share of dollar-denominated debt without causal inference and other factors that could possibly affect both the dollar shares in the FXR and debt simultaneously. This issue is addressed using our identification strategy in the next section.

4 Empirical methodology and results

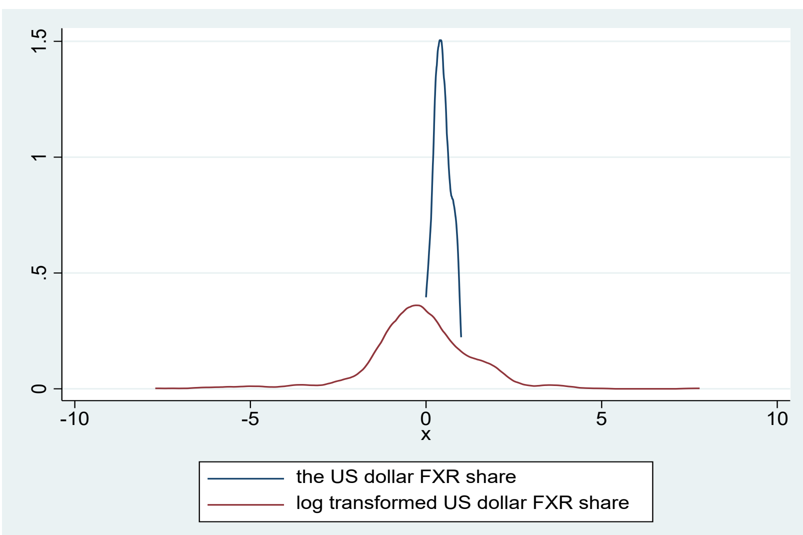
4.1 The base regression model

The baseline model follows the specification of a typical reserve currency composition regression (Dooley et al., 1989; Eichengreen et al., 2016). However, we focus on how the dollar share in the FXR aligns with the share of dollar-denominated debt to reduce currency mismatch when facing financial shocks. The baseline model is specified as follows:

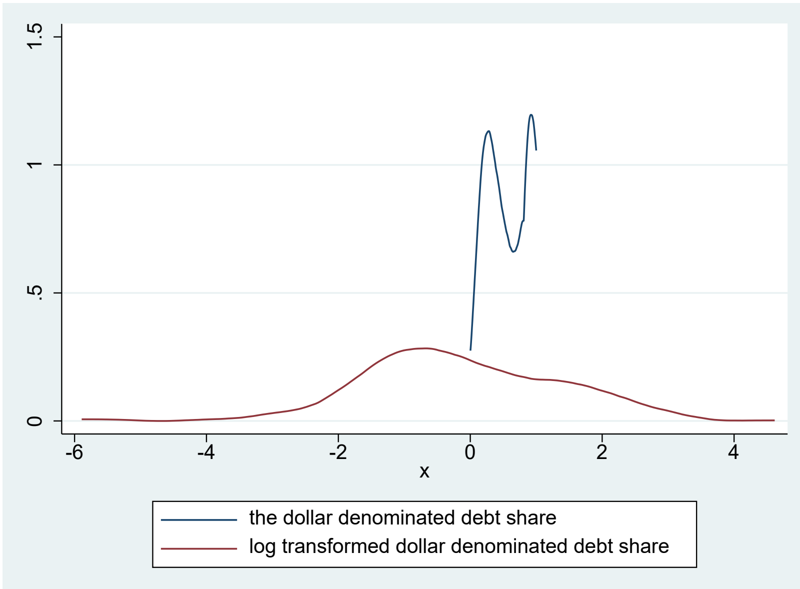
$$FXR\_usd_{it} = \alpha + \beta Debt\_usd_{it} + X'_{it}\Gamma + W'_{t}\Phi + \eta_i + \theta_t + \varepsilon_{it} \qquad (10)$$

where the dependent variable FXR_usd_{it} is the logarithm-transformed US dollar share in the FXR, and the variable of interest $Debt\_usd_{it}$ is the logarithm-transformed dollar-denominated debt share.[20] Using the logarithm transformation addresses two issues associated with currency share data when running linear regressions: 1) log transformation eliminates the non-linearity associated with currency share data (Chinn and Frankel, 2008); and 2) as currency share data are bounded between 0 and 1, a Tobit regression is necessary if one runs a regression with currency share as the dependent variable. However, Tobit regression requires data with a normal distribution (Amemiya, 1973), and currency share data are not normally distributed between 0 and 1 (see the blue curve in Figure 5). Nevertheless, the logarithm transformation breaks the [0 1] boundary and makes the share data more likely to be independent and identically distributed for both the US dollar share in the FXR and dollar-denominated debt share (Figure 5).

Figure 5: The kernel density plot for the dollar FXR share and the dollar-denominated debt share and their log-transformed data distribution



[20] The log transformation takes the form of $ln\left(\frac{the\ US\ dollar\ share\ in\ FXR}{1-the\ US\ dollar\ share\ in\ FXR}\right)$, which essentially equals $ln\left(\frac{US\ dollar\ reserves}{other\ currency\ reserves}\right)$, the log ratio of dollar reserves to all other currency reserves.



X_{it}' includes four commonly identified factors that determine the dollar FXR share as the control variables. First, trade currency invoicing matters: Both the dollar import invoicing (Gopinath and Stein, 2018) and dollar export invoicing (Ito and McCauley, 2020) are found tobe positively associated with the dollar share in the FXR. Owing to the paucity of import and export invoicing data, we use trade volume data (assuming that a country's trade with the US is invoiced in US dollars). To account for the trade invoicing effect and trade-related risk, we include the import propensity, which is measured by the difference between a country's share of imports from the US in its total imports and the country's export share to the US in its total exports (*Import propensity*). This propensity controls the need for the US dollar FXR to safeguard the US imports payment in case of external shock, such as a current account crisis (Frenkel, 1974; Frenkel and Jovanovic, 1981).[21] Second, a country that pegs its currency to the US dollar or has a less flexible exchange rate regime is found to hold more US dollars in its FXR (Eichengreen and Mathieson, 2000; Aizenman et al., 2020). Therefore, we control for the effect of pegging on the US dollar as an anchor (*US dollar anchor*) and the flexibility of the exchange rate (*exchange rate regime*). Data for both the US dollar anchor and exchange rate regimes are

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[21] Previous literature uses different trade-related variables. For example, Eichengreen and Mathieson (2000) use the trade share (imports and exports) with the US in a country's total trade; Gopinath and Stein (2018) use US dollar shares in import invoicing; and Ito and McCauley (2020) use US dollars in exports invoicing.

from Ilzetzki et al. (2019). Finally, as a low inflation rate indicates an effective monetary policy, *inflation* is included to control for the effect of macroeconomic and monetary policy effectiveness.[22]

In addition to the country-specific factors, previous studies identify two main features of the US economy that support the US dollar as an international reserve currency: the share of US GDP in world GDP and US macroeconomic policy credibility (Chinn and Frankel, 2008; Eichengreen et al., 2016). Thus, we include the US GDP share in the global economy and the relative inflation rate between the US and euro areas as a proxy for the US macro-policy credibility in W_t' of equation (10). The country fixed effect and year effect are introduced into the regression as η_i and θ_t, respectively. Similar to some previous studies that use country-level FXR data,[23] we do not add a lagged dependent variable in our regression to investigate the inertia of the FXR currency composition owing to the lack of an appropriate regression model to generate unbiased and consistent estimators in a dynamic panel data regression.[24]

We estimate equation (10) using OLS regression with 51 cross-country time-series data from 1999 to 2019 and report the results in Table 1. To show the direct correlation between the share of dollar-denominated debt and dollar FXR share, we first estimate the coefficient of *Debt_usd* in a simple regression without controlling for any other relevant variables. Column (1) shows that a one percent increase in the ratio of US dollar-denominated debt to all other foreign currency debt is associated with a 0.127% increase in the US dollar FXR relative to all other foreign currency reserves.

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[22] Ogrokhina and Rodriguez (2018) find that developing countries using inflation target as an effective monetary policy framework reduce their reliance on foreign currency-denominated international debt.

[23] See, for example, Dooley et al. (1989), Lu and Wang (2019), and Ito and McCauley (2020).

[24] Adding the lagged dependent variable in panel data makes dynamic panel data, introducing dynamic panel bias, as the exogeneity of the independent variables no longer holds. Additionally, the asymptotic properties of dynamic panel data estimators critically depend on the manner in which samples become large (Anderson and Hsiao, 1982). The estimators are inconsistent if the number of panel N is large and time T is fixed (the situation for most macro data). The Arellano and Bond (1991) dynamic panel data GMM estimator overcomes this issue but is limited for data that have small T and large N. Furthermore, a dynamic panel GMM approach using lagged endogenous variables as instruments is problematic if the error terms or omitted variables are serially correlated. Although we do not use lagged dependent variables, we follow Ito and McCauley (2019) and use 3-year moving average of dollar FXR share and dollar denomination debt share to account for the possible inertia effect. The results are similar to those reported in Table 1.

Table 1: The association between the currency composition of external debt and the international reserve currency composition

	(1)	(2)	(3)	(4)	(5)	(6)
Debt_usd	0.127***	0.152***	0.162***	0.237***	0.170***	0.234***
	(0.038)	(0.053)	(0.062)	(0.074)	(0.054)	(0.061)
Import propensity			0.760	1.614	0.626	1.589
			(1.119)	(1.203)	(1.329)	(1.453)
US dollar anchor			-0.498	-0.574	-0.258	-0.272
			(0.502)	(0.486)	(0.403)	(0.420)
Exchange regime			0.014	0.015	0.037	0.043
			(0.019)	(0.022)	(0.023)	(0.026)
Inflation			0.023**	0.017	0.013	0.007
			(0.010)	(0.013)	(0.008)	(0.011)
US GDP share			0.029*		0.032**	
			(0.017)		(0.016)	
US relative inflation			-0.022		-0.006	
			(0.021)		(0.021)	
Constant	0.303***	0.292***	-0.392	0.319	-0.717	0.058
	(0.087)	(0.039)	(0.454)	(0.306)	(0.436)	(0.310)
Country fixed effects	N	Y	Y	Y	Y	Y
Year fixed effects	N	Y	N	Y	N	Y
Observations	628	628	459	459	480	480
Adjusted R^2	0.022	0.797	0.837	0.837	0.834	0.835

Note: This table shows the regression results for equation (10). The dependent variable is the log-transformed US dollar share in foreign exchange reserves. Debt_usd is the log-transformed dollar-denominated debt share. Columns (1) to (4) show the results with all independent variables in contemporaneous form; columns (5) and (6) use lagged 1-year independent variables. Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

We then gradually include other factors to estimate the marginal effect of *Debt_usd* on the share of dollar FXR. In column (2) of Table 1, we include both the country and year fixed effects. Furthermore, in column (3), we include all control variables in X_{it} and W_{it} and the country fixed effect but no year effect; in column (4), we add the year effect with respect to column (3).[25] All these models estimate positive and statistically significant coefficients on *Debt_usd*, suggesting a positive marginal effect of the dollar debt shares on the dollar FXR share. Central banks raise approximately 0.237% of the dollar FXR relative to other currencies'

[25] Notice that adding the year effect reduces the US GDP share and US relative inflation owing to multicollinearity.

FXR in response to a one percent change in the relative ratio of the dollar debt to other foreign currency debt (column (4)). The positive effect of the dollar debt shares may stem from the central banks' role as lenders of last resort by using FXR as a buffer during a crisis to stabilize the financial market. In other words, central banks choose the dollar FXR share to respond positively to the share of dollar debt *ex ante* to minimize intervention costs (Gopinath and Stein, 2018).

Regarding the control variables in X_{it} and W_{it}, we estimate that *inflation* and the *US GDP share* in the global economy are positively and significantly associated with a country's holdings of dollars in its FXR. The positive estimation for *inflation* is in line with the finding of Ogrokhina and Rodriguez (2018) that inflation targets reduce the share of dollar-denominated international debt. An effective inflation target policy that keeps inflation low and stable represents an effective monetary policy. However, a high inflation rate, particularly in a non-inflation target country or a country that claims an inflation target but does not hold it effectively, may reflect a less effective monetary policy. This may lead to higher borrowing in dollar-denominated debt and more holding of dollars in the FXR.[26] As we do not estimate the US relative inflation significantly, our results may suggest that it is a country's own monetary policy effectiveness rather than that of the US that matters for the behavior of central banks in holding dollar shares in their FXR.[27] Contrary to some previous studies, we find no significant association between *import propensity*, *US dollar anchor*, and *exchange rate regime* with the dollar share in FXR. However, all of them become significant, and the sign is consistent with the findings of previous studies if we drop the country and year effects from the regression.[28] This indicates that trade and exchange rate policies may be closely associated with country- and time-specific latent variables that explain the dollar share in FXR.

To alleviate possible endogeneity issues, we lag all independent variables by 1 year to make them predetermined variables. The estimated coefficients for the lagged *Debt_usd* in

[26] We estimate how inflation targeting affects the dollar share in the FXR by adding a dummy variable to proxy inflation targeting countries. The coefficient is negative but not significant.

[27] Similar findings are obtained by Eichengreen et al. (2016). In policies in reserve-currency economies, for instance, inflation as a measure of policy credibility weakly affects the currency composition of FXR.

[28] Without controlling for the country and time fixed effect, the estimated coefficient for import propensity, USD anchor, and exchange rate are 5.207, 1.639, and -0.130, respectively. All of them are significant at a 1% p-value.

columns (5) and (6) are similar to those when using the contemporaneous term in columns (3) and (4). The other variables are estimated similarly, except that inflation becomes statistically insignificant.

4.2 Isolating and quantifying the causal effect

4.2.1 Using the establishment of swap lines in the 2008 GFC as an exogenous shock

The estimated results in Subsection 4.1 suggest that the dollar FXR share is positively associated with the shares of dollar-denominated debt. However, these associations might not be due to the causal effect, but the unsolved endogeneity issue. In this subsection, we aim to isolate and quantify the possible causal effect by using the establishment of central bank swap lines with the Fed and four other major central banks—the European Central Bank (ECB), Bank of England (BoE), Bank of Japan (BoJ), and Swiss National Bank (SNB)—during the 2008 GFC as a random treatment that affects the effect of the dollar-denominated debt share on the dollar FXR share.

It is important that treatment shocks are random when using the treatment model in macroeconomics research (Fuchs-Schündeln and Hassan, 2016). We argue that the establishment of swap lines with the Fed during the 2008 GFC is random, as it can be considered a "quasi-natural experiment" for three reasons. First, to countries other than the US, the occurrence of the 2008 GFC was as random as a natural disaster. Second, the establishment of swap lines was induced by the unexpected development of the 2008 GFC. Therefore, it appears to have occurred randomly as the 2008 GFC unexpectedly unfolded. In fact, at the beginning of the crisis (December 2007), the Fed established *ad hoc* swap lines with only two central banks—the ECB and SNB (20 billion and 4 billion US dollars, respectively)—to ease dollar funding pressures. More swap lines were extended to these two central banks later in March 2008 when JPMorgan acquired the failing Bear Stearns. As the crisis unexpectedly worsened, especially with the collapse of Lehman Brothers, which triggered the full-blown GFC, the Fed swap lines expanded drastically to 10 major industrial country central banks with a total of approximately 620 billion US dollars. Moreover, the Fed went beyond industrial countries and extended swap lines to four emerging market central banks (Brazil, Mexico, Korea, and Singapore) for up to 30 billion US dollars each in October 2008. From December 2007 to December 2009, the Fed extended more than 10 trillion US dollar swap lines totally to provide emergency dollar liquidity for 14 central banks. Third, the Fed's supply of US dollar swap lines during the 2008 financial crisis was to address the risk of global dollar shortage rather than to deal with individual country conditions (Goldberg et al., 2010; Bahaj and Reis, 2021). Thus, it can be considered an exogenous shock to economic conditions in individual country level.

These randomly established swap lines during the GFC had a treatment effect that weakened the sensitivity of the dollar FXR response to the changes in the dollar-denominated external debt[29]. In fact, upon receiving the dollar swap line, the recipient central banks lent the dollars to financial institutions in their jurisdiction so that they could buffer the vacuum left by the dollar assets retrenchment (i.e., sudden stops) during the 2008 GFC (Goldberg et al., 2010; Bahaj and Reis, 2021). Without the swap lines for dollar liquidity, central banks would have to sell more dollar FXR to buffer and contain the adverse effects of a financial crisis. Thus, the establishment of central bank swap lines subsidizes the buffer-stock role of FXR and makes it less necessary for central banks to sell more US dollar FXR to intervene in dollar debt sudden stops. In other words, swap lines during the 2008 GFC substitute the buffer-stock role of FXR on external debt (Obstfeld et al., 2009; Aizenman and Pasricha, 2010) and weaken the causal link between the dollar debt share and dollar FXR share.

Thus, the realization of the treatment effect requires the existence of a causal link between the dollar-denominated debt and dollar FXR. Had no causal effect existed between the dollar debt share and dollar FXR share, the swap line treatment would not change the association before and after the treatment. A significant treatment effect, meanwhile, would provide evidence of the causal effect of dollar-denominated debt, at least during the 2008 GFC. Further, the treatment effect can be isolated and estimated by comparing the magnitude of the association between the dollar's external debt share and dollar FXR share with and without the swap line treatment during the 2008 GFC.

For convenience, we label countries that established swap lines during the 2008 GFC as the "treatment group." Other countries that did not receive swap lines during the crisis are categorized as the "control group." We estimate the treatment effect of swap lines during the

[29] For papers related to macroeconomic policies exerting impacts on the relation between two economic factors, see for example Angeletos and La'O (2020). These authors analyze the optimal monetary policy that targets the negative relation between the nominal price level and real economic activity in the environment of informational frictions.

2008 GFC using a difference-in-differences (DID) regression.[30] The different marginal associations (potential outcomes) with and without the swap line treatment during the 2008 GFC periods in the treatment group countries (Imbens and Angrist, 1994) suggest the existence of a causal effect of dollar-denominated debt share on dollar FXR share. The DID regression is specified as follows:

$$FXR\_usd_{it} = \alpha + \beta_1 Debt\_usd_{it} + \beta_2 Swap\_trt_{it} + \beta_3 Swap\_trt_{it} \times Debt\_usd_{it} + X_{it}'\Gamma + W_t'\Phi + \eta_i + \theta_t + \varepsilon_{it} \quad (11)$$

where $Swap\_trt_{it}$ is a binary variable that measures the swap treatment. $Swap\_trt_{it}$ equals 1 when the central bank of country *i* established swap line(s) in year *t* during the 2008 GFC with any of the five major central banks (the Fed, ECB, BoE, BoJ, and SNB). Otherwise, it equals 0. We define the duration of the 2008 GFC from 2007 to 2009.[31] β_1 is the total association between the dollar-denominated debt share and dollar FXR share without random treatment. A significant estimate for β_3 suggests that the swap lines established during the 2008 GFC have a significant treatment effect on the dollar debt share's causal effect. The quantity of β_3 is the isolated causal effect reduced by the imposition of random swap lines during the 2008 GFC.

We run regression (11) with the countries in the treatment group to estimate the treatment effect. The results are reported in columns (1) and (2) of Table 2. Column (2) shows that,[32] without the swap line treatment, the share of dollar debt is positively associated with the dollar FXR share; a one percent increase in the dollar share is associated with 0.282% more US dollar FXR share. The magnitude of treatment effect, β_3, is estimated to be -0.205, significant at the 5% level. As discussed earlier, the treatment effect of swap lines during the 2008 GFC weakens the effect of the dollar-denominated debt share on the dollar FXR share. The significantly

[30] We have the option to run two regressions with treatment and non-treatment samples and compare the results. However, as the treatment sample is too small to run the regression, we use a DID regression, which serves the same purpose as two regressions.

[31] The NBER dated the 2008 GFC from December 2007 to June 2009.

[32] In column (1) of Table 2, in which we do not control the year effect, β_1 is positively estimated but slightly less than 10% significant. We use the result of column (2), which controls both the country and year effect, to interpret our findings.

estimated β_3 isolates the causal effect that is reduced by the swap lines established during the 2008 GFC. Our results suggest that receiving the treatment of swap lines during the 2008 GFC reduces the existing marginal effect of the dollar-denominated debt share by an average of -0.205. Indeed, with the treatment, the central banks need to sell only approximately 0.077% of dollar shares in the FXR[33] in response to a one percent decrease in the share of dollar debt during the treatment periods.

Table 2: The causal effect analyses using central bank swap lines during the 2008 GFC as quasi-natural experiment treatments

	(1)	(2)	(3)	(4)
Debt_usd	0.164	0.282**	0.203***	0.233***
	(0.102)	(0.119)	(0.076)	(0.088)
Swap_trt	0.221*	0.334	0.208*	0.331**
	(0.131)	(0.229)	(0.125)	(0.155)
Swap_trt ×Debt_usd	-0.215**	-0.205**		
	(0.100)	(0.098)		
Trt_group×Debt_usd			-0.069	-0.003
			(0.124)	(0.131)
Swap_trt ×Trt_group×Debt_usd			-0.231**	-0.232**
			(0.101)	(0.099)
Import propensity	1.494	3.007	1.081	2.054*
	(2.428)	(2.471)	(1.103)	(1.187)
US dollar anchor	-1.224***	-1.525***	-0.511	-0.475
	(0.425)	(0.464)	(0.509)	(0.531)
Exchange regime	-0.032	-0.049**	0.008	-0.000
	(0.021)	(0.024)	(0.020)	(0.022)
Inflation	0.005	-0.003	0.023**	0.026**
	(0.012)	(0.013)	(0.010)	(0.012)
US GDP share	0.010		0.038**	
	(0.021)		(0.016)	
US relative inflation	-0.010		-0.003	
	(0.036)		(0.022)	
Constant	0.979	1.498***	-0.624	0.351
	(0.615)	(0.274)	(0.457)	(0.309)

[33] The marginal effect of $\partial FXR\_usd_{it}/Debt\_usd_{it} = \beta_1 + \beta_3 Swap\_trt_{it}$ in the DID regression. For non-swap countries in non-2008 GFC periods (i.e., $Swap\_trt_{it} = 0$), the marginal effect is β_1. For swap countries during the 2008 GFC (i.e., $Swap\_trt_{it} = 1$), the marginal effect of $Debt\_usd_{it}$ is $\beta_1 + \beta_3$, and the corresponding standard errors are calculated by $\hat{\sigma} = \sqrt{var(\hat{\beta}_1) + var(\hat{\beta}_3) + 2cov(\hat{\beta}_1, \hat{\beta}_3)}$.

Country fixed effects	Y	Y	Y	Y
Year fixed effects	N	Y	N	Y
Observations	293	293	449	449
Adjusted R^2	0.809	0.810	0.842	0.842

Note: This table reports the results of equation (11). The dependent variable is the log-transformed US dollar share in foreign exchange reserves. Debt_usd is the log-transformed dollar-denominated debt share. Swap_trt is a binary variable indicating a country having established central bank swap lines with the Fed, European Central Bank (ECB), Bank of England (BoE), Bank of Japan (BoJ), and Swiss National Bank (SNB) during the 2008 global financial crisis (GFC, 2007–2009). Trt_group is a binary variable identifying the treatment group; it equals 1 if a country established central bank swap lines with the Fed, ECB, BoE, BoJ, and SNB during the 2008 GFC. Columns (1) and (2) use country samples of the treatment group that have swap lines with five major central banks (the Fed, ECB, BoE, BoJ, and SNB); columns (3) to (6) include both the treatment and control group samples. Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

4.2.2 The falsification test

In Subsection 4.2.1, we postulate that the establishment of the swap lines during the 2008 GFC affects the causal link between the share of dollar FXR and that of dollar debt. However, it is possible that the establishment of swap lines during the 2008 GFC affects an unobserved confounder of the dollar FXR and dollar-denominated debt. If this is true, the swap line treatment triggers the confounder in the treatment group but not in the control group. Hence, we should observe a different marginal association between the dollar-denominated debt share and the dollar FXR share in the treatment group than in the control group.

In this subsection, we perform a falsification test to eliminate this possibility. To do so, we include the control group samples in regression (11) to compare the marginal effects between the treatment and control groups. Furthermore, we specify an interaction term $Trt\_group_i \times Debt\_usd_{it}$ in the DID regression, where $Trt\_group_i = 1$ indicates a country in the treatment group. A significantly estimated coefficient of $Trt\_group_i \times Debt\_usd_{it}$ suggests that swap lines during the 2008 GFC affect the dollar FXR share through the unobserved confounder. However, as reported in columns (3) and (4) of Table 2, the estimates for $Trt\_group_i \times Debt\_usd_{it}$ are negligible and statistically insignificant, which rules out the possibility that the treatment effect goes through an unobserved confounder.

β_1, the estimated effect of the dollar debt share in the control group, is 0.218% (estimation average from columns (3) and (4) for $Debt\_usd_{it}$). The effect is comparable to that in Table 1. The triple interaction term $Swap\_trt_{it} \times Trt\_group_i \times Debt\_usd_{it}$, which isolates the treatment effect relative to the control group, is estimated to be approximately -0.232, significant at 1%. This suggests that the swap line treatment lowers the marginal effect of the dollar-denominated debt share on the dollar FXR share by approximately 0.232% relative to its marginal effect in the control group. As we found that swap lines during the 2008 GFC do not exert a treatment effect on the causal effect of dollar-denominated debt share through omitted confounders, -0.232 is the quantity of isolated causal effect during the GFC in 2008, thereby verifying the existence of a causal link between the dollar-denominated debt share and dollar FXR share during the 2008 GFC.

To further establish the robustness of our verification results, we use an alternative binary measurement for the swap lines established during the 2008 GFC. We let $Swap\_Fed\_trt_{it}$ equal 1 if country *i* established swap lines with the Fed only in year *t*; and otherwise, 0. The results from the alternative measurement for $Swap\_Fed\_trt_{it}$ reported in Table E1 of Appendix E are comparable to those in Table 2.

4.3 Macroprudential policy coordination

Proposition 2 of our theoretical model in Section 2 postulates that, to minimize the cost of buffering stock during a financial crisis, central banks adjust less of the dollar FXR share in response to the dollar-denominated debt share as macroprudential policies become tighter.

In this subsection, we empirically test this prediction by using capital controls as a representative macroprudential policy.[34] We augment equation (10) with a variable that measures the level of capital controls in peripheral countries and let capital controls interact with $Debt\_usd_{it}$ to capture the marginal effect of $Debt\_usd_{it}$ at different levels of capital controls. Thus, the regression is specified as a multiplicative regression, as follows:

$$FXR\_usd_{it} = \alpha + \beta_1 Debt\_usd_{it} + \beta_2 CC_{it} + \beta_3 CC_{it} \times Debt\_usd_{it} + X_{it}'\Gamma + W_t'\Phi + \eta_i + \theta_t + \varepsilon_{it} \quad (12)$$

where CC_{it} is the level of capital controls. Two measures are used to measure the level of capital controls: the inversed Chinn–Ito capital account openness index (*KA*) and Fernández et al. (2016)

[34] The literature finds that capital controls insulate countries' external shocks and reduce the magnitude of shock spillover. See, for example, the IMF (2010), Rey (2015), Han and Wei (2018), and Obstfeld et al. (2019).

capital control index (*KC*). A negative and significant estimation of the interaction term $CC_{it} \times Debt\_usd_{it}$ suggests that capital controls influence central banks' FXR currency composition management. Columns (1) and (2) of Table 3 report the results using the inverse Chinn–Ito index, and columns (3) and (4) report the results using the Fernández et al. (2016) index.

Table 3: The effect of US dollar share of external debt on the US dollar share of FXR in the presence of capital controls

	(1)	(2)	(3)	(4)
Debt_usd	0.175**	0.209**	0.383*	0.616**
	(0.080)	(0.092)	(0.207)	(0.288)
KA	0.420***	0.465***		
	(0.099)	(0.113)		
KA× Debt_usd	-0.131***	-0.139***		
	(0.034)	(0.036)		
KC			1.581*	1.867**
			(0.901)	(0.812)
KC× Debt_usd			-0.675	-1.004*
			(0.491)	(0.511)
Import propensity	-1.060	-1.182	1.312	1.144
	(1.748)	(1.991)	(1.435)	(2.024)
Exchange regime	0.003	0.009	-0.016	0.004
	(0.041)	(0.050)	(0.075)	(0.108)
Inflation	-0.012	-0.015	-0.029	-0.032
	(0.014)	(0.019)	(0.027)	(0.036)
US GDP share	0.116***		0.157***	
	(0.026)		(0.038)	
US relative inflation	0.008		0.033	
	(0.022)		(0.105)	
Constant	-3.775***	-1.173***	-4.373***	-0.908
	(0.659)	(0.435)	(0.877)	(1.105)
Country fixed effects	Y	Y	Y	Y
Year fixed effects	N	Y	N	Y
Observations	145	145	84	84
Adjusted R^2	0.919	0.916	0.920	0.921

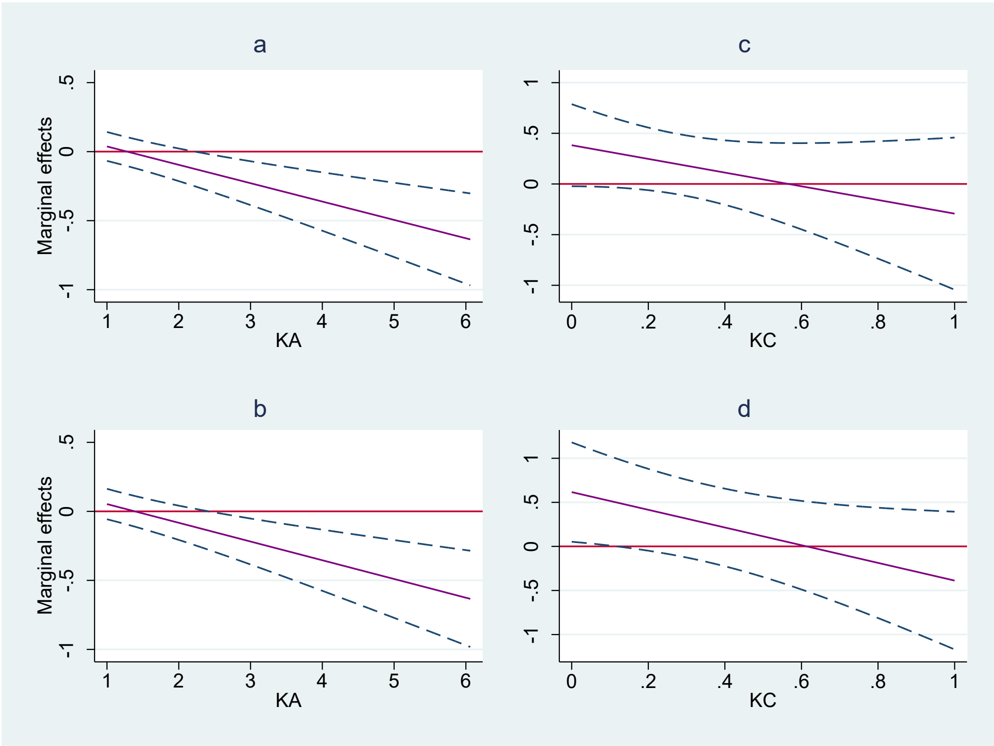
Note: This table shows the results of equation (12). The dependent variable is the log-transformed US dollar share in foreign exchange reserves. Debt_usd is the log-transformed dollar-denominated debt share. KA is the inversed Chinn–Ito capital account openness index and KC is the capital control index in Fernández et al. (2016). Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Before interpreting these results, it is important to note that our data sample size is two-thirds smaller than that in Table 1 owing to a drop in observations for all advanced countries[35] and some developing countries that do not change the level of capital controls in our sample periods. Consistent with Table 1, we find that, in the absence of capital controls, a one percent increase in dollar debt share leads to about 0.192% (the average of columns (1) and (2)) more dollar FXR share. Importantly, our results suggest that the marginal effect depends on the level of capital controls. Specifically, as the level of capital controls increases, the marginal effect of the dollar debt share decreases at a rate of approximately -0.135,[36] suggesting a strong moderation effect of the capital controls. To facilitate the results interpretation, we plot the relationship between the marginal effects of the dollar debt share and level of capital controls in Figure 6. Panels a, b, c, and d, which are plotted based on the results in columns (1) to (4), respectively, demonstrate a clear trend of reduced marginal effect as the level of capital controls increases. In other words, as capital control policy tightens, central banks tend to reduce their responsiveness to adjust their dollar FXR share in response to changes in the dollar debt share. The moderation effect may stem from the role of capital controls to insulate external financial shocks and reduce the likelihood of crises. Therefore, it is less necessary for peripheral countries' central banks to align their dollar FXR share with the dollar debt to reduce the currency mismatch during a crisis as the level of capital controls rises. Our results imply that FXR currency composition management is a part of overall international reserve management and is coordinated with traditional macroprudential policies to maintain financial stability.

[35] According to the Chinn–Ito index, advanced countries are indexed at 1, indicating they are virtually free of restrictions on their capital account. Observations of these countries are consequently dropped from our regressions owing to the multicollinearity with the country fixed effect. As a result, we have the following 19 countries left, most of which have high level of capital controls: South Africa, Israel, Sri Lanka, the Philippines, Kenya, Mozambique, Nigeria, Namibia, Tanzania, Tunisia, Zambia, Azerbaijan, Georgia, Bulgaria, Russia, the Czech Republic, Croatia, North Macedonia, and Romania.

[36] Using the average results of columns (1) and (2) of Table 3, we can evaluate the marginal effect at 0.192–0.135**KA*.

Figure 6: The marginal effects of dollar-denominated debt share and capital controls



Note: This figure plots the marginal effect of the dollar debt share conditional on capital controls. Panels a, b, c, and d are plotted based on the estimation results of columns (1)–(4). KA is the inversed Chinn–Ito capital account openness index and KC is the capital control index in Fernández et al. (2016). Dashed lines plot 95% confidence intervals, which are computed using the delta method.

Despite the significant estimations for the coefficients in Table 3, our results should be interpreted with caution for three reasons. First, we have limited country samples in this section—19 countries using the Chinn–Ito index and 12 countries[37] using the Fernández et al. (2016) index. These countries, mostly developing countries with strict capital controls, behave differently from those presented in Table 1. Second, as shown in panels a and b of Figure 6, the marginal effects of dollar debt share are negative, irrespective of the level of capital controls.[38]

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[37] They are South Africa, Sri Lanka, the Philippines, Ghana, Nigeria, Tunisia, Zambia, Georgia, Bulgaria, Russia, the Czech Republic, and Romania.

[38] In the multiplicative regression, the marginal effect $\partial\, FXR\_usd_{it}/Debt\_usd_{it} = \beta_1 + \beta_3 CC_{it}$, and the corresponding standard errors are calculated by $\hat{\sigma} = \sqrt{var(\hat{\beta}_1) + {CC_{it}}^2 var(\hat{\beta}_3) + 2CC_{it}cov(\hat{\beta}_1, \hat{\beta}_3)}$.

These results contradict those in Table 1. One possible reason is that advanced countries free of capital controls are excluded from the regressions in this subsection. The dollar FXR share of advanced countries responds positively to the change in dollar debt share (we discuss this in the next subsection). Third, although Figure 6 demonstrates that the marginal effect decreases as the level of capital controls increases, the conditional marginal effects are not always significant at the 95% confidence level when we use the Fernández et al. (2016) index to measure capital controls (see panels c and d in Figure 6).

4.4 Additional empirical analyses

In this subsection, we use alternative samples to verify the sensitivity of our results. First, we separate the data into advanced and developing country samples. Subsequently, we use the data on US dollar-denominated international bank loans. Finally, we analyze how the share of euro reserves in the total FXR responds to the changes in the euro-denominated external debt share.

4.4.1 Advanced versus developing countries

Emerging markets and developing countries have been found to hold FXR for precautionary motives to self-insure against a devastating financial crisis.[39] However, advanced countries behave differently from developing countries in holding FXR[40] and tend to use such reserves for exchange rate market intervention (Goldberg et al., 2010). Thus, advanced and developing countries may behave differently in their FXR currency portfolio management, and their dollar FXR shares may respond differently to their dollar debt shares. We test this possibility by running regression (10) on advanced and developing country samples, respectively. Interestingly, as shown in Table 4, the dollar FXR share positively responds to changes in the dollar debt share in both advanced and developing countries, with estimated marginal effects comparable to those in Table 1. This finding is consistent with those of Eichengreen and Mathieson (2000) and Eichengreen et al. (2016), that is, that the main determinants of the FXR currency composition (including the currency composition of external debt) apply to both advanced and developing countries. Nonetheless, the estimated marginal

[39] See, for example, Aizenman and Lee (2007), Cheung and Qian (2009), and Obstfeld et al. (2010).

[40] See, for example, Cheung and Ito (2009), Bussière et al. (2015), and Aizenman et al. (2020).

effect of dollar debt share is higher and more significant in advanced countries than in developing countries. Additionally, a more flexible exchange rate is associated with a higher dollar FXR share in advanced countries, whereas in developing countries, exchange rate flexibility does not affect the dollar FXR share. These results support the view that the purpose of holding FXR in advance countries is to intervene in the foreign exchange market, as identified by Goldberg et al. (2010).

Table 4: The currency composition of external debt and FXR currency composition in developing and advanced economies

	(1)	(2)	(3)	(4)
Debt_usd	0.136**	0.120*	0.171***	0.157***
	(0.058)	(0.063)	(0.053)	(0.055)
Import propensity	1.076	1.053	1.392	1.171
	(1.101)	(1.259)	(1.288)	(1.411)
US dollar anchor	-0.471	-0.479	0.367	0.342
	(0.497)	(0.491)	(0.388)	(0.412)
Exchange regime	0.028	0.025	0.099***	0.099***
	(0.029)	(0.030)	(0.030)	(0.031)
Inflation	0.019**	0.022**	0.007	0.007
	(0.009)	(0.010)	(0.007)	(0.009)
US GDP share	0.081***		0.056***	
	(0.016)		(0.015)	
US relative inflation	0.010		0.035*	
	(0.020)		(0.020)	
Constant	-2.215***	-0.214	-2.661***	-1.209**
	(0.536)	(0.484)	(0.480)	(0.472)
Country fixed effects	Y	Y	Y	Y
Year fixed effects	N	Y	N	Y
Observations	247	247	260	260
Adjusted R^2	0.884	0.880	0.895	0.894

Note: This table shows the results of equation (10) using a sample of developing countries and advanced economies. The dependent variable is the log-transformed US dollar share in foreign exchange reserves. Debt_usd is the log-transformed dollar-denominated debt share. Columns (1) and (2) report the results for developing countries, and columns (3) and (4) report the results for advanced economies. Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

4.4.2 Dollar-denominated bank loans

Foreign currency-denominated international bank loans and foreign currency-denominated external debt have common features during financial crises; for instance, both tend to suddenly stop. Thus, it is likely that the central bank's dollar FXR share responds to the dollar bank loan share in a similar fashion to that of the dollar debt share. We test this postulation in Table 5, where *Debt_usd* is replaced by *Loan_usd*, the log-transformed dollar bank loan share of total international bank loans in a country. Data on foreign currency-denominated bank loans are retrieved from the BIS. The first two columns of Table 5 report the results using dollar loan data, and columns (3) and (4) show the results with the sum of the dollar debt and dollar loan share in the total foreign currency debt and bank loans. The share data are log-transformed before running the regressions. As expected, the results of the bank loan data regressions confirm that the dollar FXR share positively responds to the dollar loan share. However, the marginal effect of the dollar loan share is higher than that of the dollar debt share (e.g., average 0.296 vs. 0.169 in Table 1). This is reasonable, because bank loans, which are more volatile and prone to sudden stop, require the central bank to be more vigilant in insuring against currency mismatches. Using the aggregated data of dollar debt and loan share yields similar results (columns (3) and (4)). Compared to the results in Table 1, the *US dollar anchor* variable turns significant and negative, which contradicts the usual finding that a country that anchors its currency to the US dollar tends to hold more US dollar FXR. Nevertheless, if we drop the country fixed effect, we estimate *US dollar anchor* to be significantly positive. Thus, as presented in Table 1, this is an attribute of the high correlation between *US dollar anchor* and the country fixed effect.

Table 5: The effect of US dollar bank loan share on the currency composition of FXR

	(1)	(2)	(3)	(4)
Loan_usd	0.285***	0.307***	0.337***	0.442***
	(0.062)	(0.064)	(0.071)	(0.084)
Import propensity	1.725	2.024	0.307	1.219
	(1.503)	(1.463)	(1.077)	(1.142)
US dollar anchor	-1.403***	-1.577***	-0.801*	-1.052**
	(0.322)	(0.352)	(0.420)	(0.416)
Exchange regime	-0.006	-0.005	-0.003	-0.007
	(0.018)	(0.019)	(0.018)	(0.020)
Inflation	-0.003	-0.010	0.018**	0.009
	(0.008)	(0.010)	(0.009)	(0.012)
US GDP share	0.025*		0.018	
	(0.015)		(0.016)	

US relative inflation	-0.019		-0.038*	
	(0.021)		(0.021)	
Constant	0.600	1.296***	0.300	0.888***
	(0.413)	(0.296)	(0.444)	(0.277)
Country fixed effects	Y	Y	Y	Y
Year fixed effects	N	Y	N	Y
Observations	565	565	459	459
Adjusted R^2	0.802	0.801	0.841	0.843

Note: This table shows the results of equation (10) using the share of US dollar-denominated bank loans as the independent variable (Loan_usd). The dependent variable is the log-transformed US dollar share in foreign exchange reserves. Columns (1) and (2) use the share of US dollar loans; columns (3) and (4) use the total share of US dollar loans and bonds in total foreign currency-denominated loans and bonds. Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

4.4.3 Euro share in FXR

The euro has been the second largest reserve currency since its inception in 1999. Do our results also apply to the euro as a reserve currency? We check the robustness of our results using the share of euro FXR-related variables in Table 6. In this case, our dependent variable is the log-transformed euro FXR share; the key independent variable is *Debt_euro*, the log-transformed euro-denominated debt share. Control variables include the euro import propensity, euro anchor, exchange rate regime, inflation rate, Eurozone GDP share in the world economy, and relative inflation between the US and Eurozone. We drop all Eurozone countries from the regression, as the euro is their domestic currency. As in Table 1, we report the results in Table 6 using contemporaneous independent variables in columns (1) and (2) and the results with 1-year lagged independent variables in columns (3) and (4). Overall, Table 6 yields results similar to those in Table 1, suggesting that central banks adjust their euro FXR share in response to the changes in the euro debt share, similar to the US dollar FXR response to dollar debt. The estimated marginal effect of the euro debt share is slightly higher than that of the dollar share (averagely 0.21 vs. 0.20 in columns (1) and (2)). Most control variables are statistically insignificant, except *inflation*, which is negatively correlated with the euro FXR share.

Table 6: The effect of euro debt share on the euro FXR share

	(1)	(2)	(3)	(4)
Debt_euro	0.225***	0.196**	0.192**	0.178**

	(0.080)	(0.091)	(0.075)	(0.081)
Import propensity (euro)	0.438	0.015	1.332	1.106
	(1.056)	(1.122)	(1.131)	(1.158)
Euro anchor	0.068	0.060	0.005	-0.007
	(0.152)	(0.157)	(0.161)	(0.154)
Exchange regime	-0.022	-0.019	-0.024	-0.021
	(0.018)	(0.020)	(0.021)	(0.023)
Inflation	-0.017	-0.026*	-0.007	-0.011
	(0.013)	(0.014)	(0.013)	(0.013)
Eurozone GDP share	0.742		2.168	
	(2.119)		(2.074)	
Euro relative inflation	-0.012		0.014	
	(0.045)		(0.045)	
Constant	-0.044	0.078	-0.397	0.020
	(0.421)	(0.206)	(0.391)	(0.235)
Country fixed effects	Y	Y	Y	Y
Year fixed effects	N	Y	N	Y
Observations	264	264	277	277
Adjusted R^2	0.948	0.947	0.953	0.952

Note: This table shows the regression results of equation (10) using the log-transformed euro share in foreign exchange reserves as the dependent variable. Debt_euro is the log-transformed euro-denominated debt share. Columns (1) and (2) report results with contemporaneous independent variables and columns (3) and (4) show results with 1-year lagged independent variables. Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

5 Conclusion

This paper examines the effects of external debt currency denomination on FXR currency composition. A theoretical model that focuses on the buffer-stock role of international reserves is constructed to study how central banks manage the FXR currency composition in response to the currency denomination of external debt. We extend Gopinath and Stein's (2018) framework in two respects. First, we allow firms to borrow dollar-denominated debt and euro-denominated debt, and central banks to choose between dollars and euros in their optimal reserve holdings. Second, we augment the model with an *ex ante* macroprudential policy, represented by capital controls, to reduce the likelihood of financial crises. The theoretical model predicts a positive effect of dollar-denominated external debt on the dollar FXR share. It also suggests that the effects become smaller for countries with tighter macroprudential policies. Using a newly constructed cross-country panel data of the FXR currency composition (Ito and McCauley, 2020), we obtain supportive empirical evidence for these theory predictions.

An important contribution of this study is that it isolates the causal effect of external debt currency composition on foreign reserve currency composition. We use Imbens and Angrist's (1994) treatment effects approach to isolate and quantify the causal effect of dollar debt shares induced by the treatment from the total association between the dollar debt share and dollar FXR share. The US dollar swap lines established during the 2008 GFC are used as quasi-natural experiments. Using a difference-in-differences regression, we find a significant treatment effect that weakens the effect of the dollar-denominated debt share on the dollar FXR share, thereby isolating a causal effect during the 2008 GFC. Falsification tests rule out the possibility that the treatment effect occurs through channels other than the causal link between the dollar-denominated debt share and dollar FXR share.

In a multiplicative regression, we find that tighter macroprudential policies reduce the intensity of FXR currency composition management in response to changes in the debt currency composition. This implies that central banks coordinate their FXR currency composition management with other macroprudential policies to maintain financial stability. Therefore, the FXR currency composition management can be considered a macroprudential policy tool.

Against the background of the 2022 Russia–Ukraine war, our study may offer some insights on countries' US dollar reserve holding behavior. Sanctions imposed by the US and its allies on the Russian economy effectively cut off Russia's access to its FXR[41] and triggered the devaluation of the Russian ruble and "imminent" default on Russian sovereign bonds. The IMF expressed concern that the severe consequences of US sanctions on the Russian economy could drive other countries to hold the US dollar as international reserves. Our study, however, implies that, as countries continue to issue US dollar-denominated debt, the hoarding of US dollar reserves would persist.

As countries accumulate unprecedented levels of international reserves, how central banks manage their stockpiles of reserves has important implications for both individual and global economies. In addition to FXR currency composition management, investment portfolio

[41] See, for example, a news article on the likelihood of Russian debt default from Fortune (https://fortune.com/2022/03/14/russia-sovereign-debt-default-imf-kristalina-georgieva-bonds/).

management has become an increasingly important task for central banks to manage their international reserves. The high social/opportunity cost of holding reserves pushes central banks to diversify from investing in the US treasury security market to high-yield yet risky investments. Seeking yield may compromise the precautionary role of the reserves. Therefore, while this topic is beyond the scope of the current study, future research could focus on the interaction between investment portfolio management and reserve currency portfolio.

Appendices

Appendix A: Model Solutions and Proof of Proposition 1

In this section, we provide more details on the model solutions and proof for Proposition 1. The central bank acts as a lender of last resort to bail out banks that fail in a crisis. When there is a crisis with probability pq , the central bank must raise money to bail out the banks. There are two cases. In the case of euro appreciation, which happens with probability $a = (\rho + 1)/2$, the total amount of tax is

$$T_1 = m\left[B_h + (1+z)(B_\$ + B_€)\right] - z(R_\$ + R_€) \tag{13}$$

In the case of euro depreciation, which occurs with probability $1-a$, the total amount of tax is

$$T_2 = m\left[B_h + (1+z)B_\$ + (1-z)B_€\right] - z(R_\$ - R_€) \tag{14}$$

The central bank chooses the optimal foreign reserves $R_\$$ and $R_€$ to minimize the total costs in equation (7). From the first-order condition of $R_\$$ and $R_€$, we obtain the following:

$$\begin{aligned} R_\$ &: S_\$ + pqa\gamma\left(-zT_1\right) + pq(1-a)\gamma\left(-zT_2\right) = 0 \\ R_€ &: S_€ + pqa\gamma\left(-zT_1\right) + pq(1-a)\gamma\left(zT_2\right) = 0 \end{aligned} \tag{15}$$

$$T_1 = \frac{S_\$ + S_€}{2pqa\gamma z}; \quad T_2 = \frac{S_\$ - S_€}{2pq(1-a)\gamma z}$$

Using (15), we obtain the total reserve holdings R, that is,

$$R = \frac{2m\left(B_h + (1+z)(B_\$ + B_€)\right) - 2T_1}{2z} \tag{16}$$

and the optimal dollar reserves $R_\$$ and euro reserves,

$$\begin{aligned} R_\$ &= \frac{2m\left(B_h + (1+z)B_\$ + B_€\right) - T_1 - T_2}{2z} \\ R_€ &= \frac{2mzB_€ - T_1 + T_2}{2z} \end{aligned} \tag{17}$$

Subsequently, we use (2) to rewrite dollar reserves of (17):

$$R_\$ = \frac{2m\left((z-S_\$)B_\$ - S_€ B_€ + \frac{N}{Q_h}\right) - T_1 - T_2}{2z}$$

This is equation (8) in Section 2. Note that $B_\$$ and $B_€$ are pinned down in equations (4) and (5); therefore, the above function is the solution for optimal reserve holdings. Notably, the dollar share in foreign reserves, $Share_\$^R = R_\$ / (R_\$ + R_€)$, is an increasing function in $R_\$ / R_€$. Similarly, the dollar share in foreign debt, $Share_\$^B = B_\$ / (B_\$ + B_€)$, is an increasing function in $B_\$ / B_€$. Therefore, the sign of $\frac{\partial Share_\$^R}{\partial Share_\$^B}$ is positive if $\frac{\partial (R_\$ / R_€)}{\partial (B_\$ / B_€)}$ is positive. From equations (8) and (17), we obtain

$$\frac{R_\$}{R_€} = \frac{(z - S_\$ + (1+S_\$))\frac{B_\$}{B_€} - (S_€ - (1+S_€)) + \frac{N}{Q_h B_€} - \frac{(T_2 + T_1)}{2mB_€}}{z + \frac{(T_2 - T_1)}{2mB_€}} \quad (18)$$

Consider holding $B_€$ constant; then, there is an increase in $B_\$ / B_€$ due to cheaper funding of the dollar.

$$\frac{\partial (R_\$ / R_€)}{\partial (B_\$ / B_€)} = \frac{(z - S_\$ + (1+S_\$))}{z + \frac{(T_2 - T_1)}{2mB_€}} \quad (19)$$

The sign of $\frac{\partial Share_\$^R}{\partial Share_\$^B}$ is positive if z is sufficiently large. This result proves Proposition 1.

Appendix B: Model Extensions and Proof of Proposition 2

We extend the model to examine how the relationship between the debt dollar share and reserve dollar share is affected by macroprudential policies. We introduce macroprudential policy, or more generally, a financial safety net, by allowing the central bank to impose an *ex ante* tax on the foreign currency-denominated debt issued by banks. Specifically, the tax rate for $B_\$$ ($B_€$) is τ. In the baseline model, we must modify the bank's balance sheet constraint:

$$N = Q_h B_h + (1-\tau) Q_\$ B_\$ + (1-\tau) Q_€ B_€ \quad (20)$$

The first-order condition gives us an interior optimum of the bank's dollar-denominated debt instruments $B_\$$ and

$$B_{\$} = \frac{1}{\phi p}\{(1 - pqm(\tau))[\frac{Q_{\$}(1-\tau)}{Q_h} - 1] + pqm(\tau)z\} \tag{21}$$

$$B_{€} = \frac{1}{\phi p}\{(1 - pqm(\tau))[\frac{Q_{€}(1-\tau)}{Q_h} - 1] + \rho pqm(\tau)z\} \tag{22}$$

The ex ante macroprudential policy τ affects the incentive for banks to issue dollar-dominated debt. Higher τ, indicating stronger capital controls or tighter financial safety nets, would decrease the total dollar deposits $B_{\$}$. The analysis of $B_{€}$ is similar to that of $B_{\$}$. However, note that if $Q_{\$} > Q_{€}$ and $\rho < 1$, the dollar deposits $B_{\$}$ decrease more than the euro deposits $B_{€}$ when τ increases. Therefore, the share of dollar deposits in total foreign currency deposits decreases as macroprudential policy becomes stricter.

Based on the solution procedures in Appendix A, we obtain the optimal dollar reserves:

$$R_{\$} = \frac{2m(\tau)\left((z - S_{\$} + \tau(1+S_{\$}))B_{\$} - (S_{€} - \tau(1+S_{€}))B_{€} + \frac{N}{Q_h}\right) - T_1 - T_2}{2z} \tag{23}$$

Notably, the ratio between $R_{\$}$ and $R_{€}$: $R_{\$} / R_{€}$ is an increasing function in $B_{\$}$ and a decreasing function in $B_{€}$.

$$\frac{R_{\$}}{R_{€}} = \frac{(z - S_{\$} + \tau(1+S_{\$}))\frac{B_{\$}}{B_{€}} - (S_{€} - \tau(1+S_{€})) + \frac{N}{Q_h B_{€}} - \frac{(T_2 + T_1)}{2m(\tau)B_{€}}}{z + \frac{(T_2 - T_1)}{2m(\tau)B_{€}}} \tag{24}$$

Thus, the dollar share in total foreign reserves, $Share_{\$}^{R} = R_{\$} / (R_{\$} + R_{€})$, is an increasing function in $B_{\$}$ and a decreasing function in $B_{€}$. As $Share_{\$}^{B}$ is an increasing function in $B_{\$} / B_{€}$, the sign of $\frac{\partial Share_{\$}^{R}}{\partial Share_{\$}^{B}}$ is the same as that of $\frac{\partial(R_{\$} / R_{€})}{\partial(B_{\$} / B_{€})}$, which is as follows:

$$\frac{\partial(R_{\$} / R_{€})}{\partial(B_{\$} / B_{€})} = \frac{(z - S_{\$} + \tau(1+S_{\$}))}{z + \frac{(T_2 - T_1)}{2m(\tau)B_{€}}} \tag{25}$$

Subsequently, we can calculate $\frac{\partial^2 (R_{\$} / R_{€})}{\partial(B_{\$} / B_{€})\partial\tau}$ by taking the derivative of (25) with respect to τ. According to the chain rule, it can be either positive or negative, depending on the first derivative of $m(\tau)$ with respect to $\tau : m^{'}(\tau) \cdot \frac{\partial^2 (R_\$ / R_€)}{\partial(B_\$ / B_€)\partial\tau} < 0$, when the response of m to τ, $m^{'}(\tau)$, is sufficiently large, macroprudential policies are highly effective. This result proves Proposition 2.

Appendix C: Country Samples

Australia, Azerbaijan, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Ghana, Hong Kong SAR, Iceland, India, Israel, Italy, Kazakhstan, Kenya, Kyrgyz Republic, Lithuania, Luxembourg, Moldova, Mozambique, Namibia, Netherlands, New Zealand, Nigeria, North Macedonia, Norway, Papua New Guinea, Philippines, Poland, Romania, Russia, Serbia, South Africa, South Korea, Spain, Sri Lanka, Sweden, Switzerland, Tajikistan, Tanzania, Tunisia, Turkey, Ukraine, United Kingdom, Zambia

Appendix D: Variable Definitions and Data Sources

Variable name	Definition
FXR_usd	The log transformed US dollar share in foreign exchange reserves (FXR), which is calculated as ln[the share of US dollar in the total FXR/(1-the share of US dollar in total FXR)]. Data source: Ito and McCauley (2020)
Debt_usd	The log-transformed US dollar share in international debt securities, which is calculated as ln [the share of US dollar in total foreign currency-denominated international debt/(1-the share of US dollar in total foreign currency-denominated international debt)]. The international debt securities include treasury bills, commercial paper, negotiable certificates of deposit, bonds, debentures, and asset-backed securities, and distinguish between debt securities issued in international markets. Data source: BIS Statistics Warehouse
Import propensity	A measurement of a country’s trade deficit against the US, calculated as its US import share in total imports subtracted by the share of exports to the US in its total exports
US dollar anchor	A dummy variable for countries that anchor their currency exchange rate to the US dollar; Data source: Ilzetzki et al. (2019)
Exchange regime	The index variable for exchange rate flexibility, measured by the fine classification code of Ilzetzki et al. (2019); the higher the index, the more flexible the exchange regime

Inflation	The inflation rate, measured by the annual CPI percentage changes; Data source: World Bank WDI
US GDP share	The share of US GDP in the total GDP of global economy; Data source: World Bank WDI
US relative inflation	The relative inflation of the US, measured by the ratio of US inflation to the average inflation in the euro area; Data source: World Bank WDI
Swap_trt	A binary variable indicating a country having established central bank swap lines with the Fed, ECB, BoE, BoJ, and SNB during the 2008 global financial crisis (2007–2009)—for example, the BoE established swap agreements with the Fed in 2008 and 2009, so we let Swap_trt = 1 for the UK in years 2008 and 2009; in all other years for the UK, Swap_trt = 0
Swap_Fed_trt	A binary variable indicating a country having established central bank swap lines with the Fed only
Trt_group	A binary variable identifying the treatment group of swap; countries that had established central bank swap lines with the Fed, ECB, BoE, BoJ, and SNB during the 2008 global financial crisis are included in the treatment group and marked 1; all others are marked 0
KA	Capital control index. The inversed Chinn–Ito financial openness index (i.e., KA = 1/Chinn–Ito index); a higher KA suggests less capital account openness (or more capital controls); the mean of the index is 3.2, with a standard deviation of 2.2; the lowest index is 1, and the highest index is 6.06 (Chinn and Ito, 2008)
KC	Capital control index. The overall capital control index of Fernández et al. (2016); a higher index indicates more capital controls; the mean of the index is 0.43, with a standard deviation of 0.36; the lowest index is 0, and the highest index is 1
GFC08	A time dummy variable indicating the 2008 global financial crisis; GFC08 = 1 if year == 2007, 2008, and 2009; and 0 otherwise

Appendix E: Additional regression results

Table E1: The causal effect analyses using central bank swap lines during the 2008 GFC as quasi-natural experiment treatments

	(1)	(2)	(3)	(4)
Debt_usd	0.302	0.816**	0.282**	0.525**
	(0.340)	(0.399)	(0.133)	(0.246)
Swap_Fed_trt	0.286	0.656	2.735***	2.394**
	(0.223)	(0.516)	(0.963)	(1.025)
Swap_Fed_trt × Debt_usd	-0.221*	-0.162		
	(0.123)	(0.136)		
Trt_group×Debt_usd			-0.035	0.177
			(0.342)	(0.377)
Swap_Fed_trt ×Trt_group×Debt_usd			-1.301**	-1.179**
			(0.545)	(0.570)
Import propensity	-4.453	1.180	-1.346	2.165
	(4.968)	(5.422)	(4.159)	(4.689)
US dollar anchor			-0.066**	-0.073**
			(0.031)	(0.035)
Exchange regime	-0.072**	-0.084**	0.030	-0.020
	(0.030)	(0.037)	(0.047)	(0.057)
Inflation	0.041	-0.054	0.001	
	(0.076)	(0.111)	(0.028)	
US GDP share	-0.010		-0.008	
	(0.030)		(0.041)	
US relative inflation	-0.032		1.135	1.838***
	(0.050)		(0.930)	(0.455)
Constant	1.671	2.225***	0.282**	0.525**
	(1.077)	(0.534)	(0.133)	(0.246)
Country fixed effects	Y	Y	Y	Y
Year fixed effects	N	Y	N	Y
Observations	189	189	459	459
Adjusted R^2	0.810	0.817	0.843	0.842

Note: This table reports the results of equation (11). The dependent variable is the log-transformed US dollar share in foreign exchange reserves. Debt_usd is the log-transformed dollar-denominated debt share. Swap_Fed_trt is a binary variable indicating a country having established central bank swap lines with the Fed during the 2008 global financial crisis (GFC, 2007–2009). Trt_group is a binary variable identifying the treatment group; it equals 1 if a country established central bank swap lines with the Fed during the 2008 GFC. Columns (1) and (2) use country samples of the treatment group that have swap lines with the Fed. Columns (3) and (4) include both the treatment and control group samples.

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