Central Banks as Dollar Lenders of Last Resort: Implications for Regulation and Reserve Holdings*

Mitali Das, IMF

Gita Gopinath, IMF

Helene Hall, Harvard

Taehoon Kim, IMF

Jeremy C. Stein, Harvard and NBER

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Abstract: This paper explores how non-U.S. central banks behave when firms in their economies engage in currency mismatch, borrowing more heavily in dollars than justified by their operating exposures. We begin by documenting that, in a panel of 56 countries, central bank holdings of dollar reserves are correlated with the dollar-denominated bank borrowing of their non-financial corporate sectors, controlling for a number of known covariates of reserve accumulation. We then build a model in which the central bank can deal with private-sector mismatch, and the associated risk of a domestic financial crisis, in two ways: (i) by imposing ex ante financial regulations such as bank capital requirements; or (ii) by building a stockpile of dollar reserves that allow it to serve as an ex post dollar lender of last resort. The model highlights a novel externality: individual central banks may over-accumulate dollar reserves, relative to what a global planner would choose. This is because, in the presence of imperfect regulation of currency mismatch, individual central banks do not internalize that their hoarding of reserves exacerbates a global scarcity of dollar-denominated safe assets, which lowers dollar interest rates and encourages firms to further increase the currency mismatch of their liabilities. Relative to the decentralized outcome, a global planner may therefore prefer higher capital requirements and reduced holdings of dollar reserves.

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*Authors' email addresses: mdas@imf.org; ggopinath@imf.org; helenehall@fas.harvard.edu; tkim@imf.org; and jeremy_stein@harvard.edu.

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1. Introduction

Central banks around the world hold large balances of foreign currency reserves, with the U.S. dollar accounting for the dominant share of these reserves, at about 59% of the total.[1] In the aggregate, foreign official accounts held $6.2 trillion of dollar securities in April of 2024, with $3.78 trillion of this in the form of U.S. Treasury securities.[2] This makes foreign reserve managers among the most important players in the Treasury market, a fact that is often argued to be a key determinant of the level of U.S. interest rates.[3] The implications of these reserve balances for market outcomes were also dramatically highlighted in the COVID-pandemic-induced "dash for cash" in March of 2020, when heavy foreign central bank selling of Treasuries played a major role in the dislocations seen in that market.[4]

What explains the large appetite of global central banks for foreign currency reserves, and for dollar reserves in particular? In this paper, we focus on one potential motive, arising out of the fact that firms in many countries run a significant currency mismatch in their capital structures, borrowing heavily in dollars even when they have largely domestic operating exposures.[5] We argue that in the face of such mismatch, a central bank will have a natural incentive to stockpile dollars, so that it can more effectively serve as a lender of last resort in a state of the world where the local economy and banking system are under stress and need to be bailed out. We then go on to explore the normative implications of this behavior, showing how the reserve-accumulation decisions of individual central banks can be excessive relative to a global optimum to the extent that they do not internalize the general-equilibrium impact of their choices on the aggregate supply of safe dollar assets and on the dollar interest rate.

We begin by presenting some simple empirical relationships to motivate our subsequent theoretical work. We document that in a panel of 56 countries, central bank holdings of dollar reserves (relative to GDP) are significantly correlated with the dollar-denominated bank borrowing of the non-financial corporate sector (again relative to GDP), controlling for a number of known covariates of reserve accumulation. The interpretation we have in mind is that the latter variable is

[1] Source: IMF COFER data.

[2] Source: Treasury International Capital data.

[3] Early analyses of the impact of foreign demand for U.S. dollar assets and its effect on interest rates include Bernanke (2005), and Caballero, Farhi and Gourinchas (2008).

[4] See, e.g., Vissing-Jorgensen (2021).

[5] This tendency is documented in Du and Schreger (2022).

a rough proxy for the currency mismatch of the corporate sector, which in turn drives the currency exposure of the banking system and ultimately the dollar lender-of-last-resort motive in our theory.

Next, building on the framework in Gopinath and Stein (2018), we develop a model of optimal reserve accumulation for a small open-economy central bank that faces a risk of a banking crisis, a risk which is exacerbated when the non-financial corporate sector runs a currency-mismatched capital structure. Importantly, while reserve holdings can help to mitigate the fallout from a banking crisis ex post, they are not the only policy tool available. We consider the possibility that the central bank can also deploy ex ante financial-regulatory tools, such as bank-capital regulation. The optimal mix of these tools depends on a straightforward tradeoff. On the one hand, when ex ante regulation is too stringent, this reduces the profitability of the local banking sector and hence social welfare; this effect tends to favor reserve accumulation. On the other hand, there is a carrying cost associated with reserve holdings, which is greater when dollar interest rates are lower. When this carrying cost increases, the balance tips back towards using more heavy-handed financial regulation, and less reserve accumulation.

While this small open-economy version of the model helps to make sense of the basic cross-sectional empirical patterns we see in the data, a primary contribution of the paper is in fleshing out the model's normative properties. In particular, suppose we have a global economy in which many central banks act as price-takers in the market for safe dollar assets. If each of these central banks sets their regulatory and reserve-holding policies individually, so as to maximize own-country welfare, how does the outcome compare to one in which a global central planner aims to maximize global welfare?

Here the model highlights a novel externality: individual central banks may tend to over-accumulate dollar reserves, relative to what the global planner would choose. This is because individual central banks do not internalize the fact that their hoarding of reserves exacerbates a global scarcity of dollar-denominated safe assets and puts downward pressure on dollar interest rates. This downward pressure on dollar rates in turn intensifies the tendency of private-sector firms to engage in mismatch, increasing their exposure to a dollar appreciation. Relative to the decentralized outcome, a global planner may therefore prefer a different mix of tools, with stricter financial regulation (i.e., higher bank capital requirements) and reduced holdings of dollar reserves.

However, it should be noted that this externality only arises when financial regulation is imperfect, in the following sense. If regulators can not only set bank capital requirements, but can also directly control the currency mismatch of all non-financial firms in the economy, then there is no longer an externality, and the decisions of individual central banks will align with those of a global planner. Or said differently, a global planner will seek to reduce reserve hoarding only as a second-best way of dealing with currency mismatch—via the influence of dollar interest rates on mismatch incentives—when mismatch cannot be addressed directly via a more surgical form of financial regulation. We believe that this second-best/imperfect-regulation scenario is an accurate description of reality in most countries, but it is important to understand its key role in our model. Indeed, the idea that influencing interest rates can be a second-best mechanism for dealing with financial-stability problems when regulation is imperfect is a familiar theme in other settings.[6]

The literature on central-bank reserve holdings is well-developed, and has identified a number of potential motives, which can be grouped into two broad categories, sometimes referred to as the "mercantilist" and "precautionary" views.[7] According to the mercantilist view, a central bank that seeks to protect its tradable sector—and hence to prevent its exchange rate from appreciating—will tend to accumulate reserves when it is running a trade surplus.[8]

The precautionary view encompasses several mechanisms that can lead a central bank to stockpile reserves as a buffer against the risk of a future adverse shock. One version focuses on the potential for "sudden stops" in emerging markets—i.e., rapid reversals of *external* capital flows—and the role of reserves in mitigating the damage from such episodes.[9] Another instead

[6] Kashyap and Stein (2023) argue that monetary policy should take account of its potential to contribute to overheating in credit markets when macroprudential regulation is imperfect. Greenwood, Hanson and Stein (2015) suggest that the Federal Reserve or the Treasury department should aim to reduce steepness at the front end of the yield curve in light of regulators' inability to perfectly contain excessive short-term funding by financial intermediaries.

[7] This terminology follows Aizenman and Lee (2007).

[8] See Dooley et al (2003), Aizenman and Lee (2010), Benigno and Fornaro (2012), Korinek and Serven (2016), and Benigno, Fornaro, and Wolf (2023).

[9] See Caballero and Panageas (2008), Alfaro and Kanczuk (2009), Durdu, Mendoza and Terrones (2009), Korinek (2011), Jeanne and Ranciere (2011), Bianchi, Hatchondo and Martinez (2018), Cespedes and Chang (2020), Arce, Bengui and Bianchi (2022), and Bianchi and Lorenzoni (2021), among others.

emphasizes the possibility that *domestic* depositors might attempt to flee the banking system by converting their local-currency-denominated deposits into foreign currency.[10]

Our starting premise—that central banks hold dollar reserves to deal with the potential consequences arising from a currency mismatch on the part of their corporate sectors—can also be thought of as fitting within the broad precautionary view. In this regard, we are perhaps closest to recent work by Bocola and Lorenzoni (2020), who emphasize the same currency-mismatch motive. We differ from their paper in highlighting the joint roles of financial regulation and reserve holdings in shoring up financial stability, and in showing how the decisions of individual central banks lead to too little of the former and too much of the latter, relative to what a global planner would choose.[11]

Our normative analysis also connects to the literature on international coordination in financial regulation. For example, we share the conclusion of Clayton and Schaab (2022) that individual countries acting on their own will tend to impose lower capital requirements on their domestic banks than is globally efficient. This externality motivates the need for international cooperation on the regulatory front, of the sort seen in the so-called Basel Process. However, a key distinction is that in our framework, such regulatory cooperation is not sufficient—there also needs to be a separate mechanism to restrain excessive reserve accumulation by central banks.

The remainder of the paper is organized as follows. In Section 2, we present some motivating evidence on the relationship between central bank holdings of dollar reserves and the dollar-denominated bank borrowing of their corporate sectors. In Section 3, we develop a single-country model in which the central bank can deal with the risks created by currency mismatch in one of two ways: by imposing stricter financial regulation, or by accumulating foreign-exchange reserves. In Section 4, we consider a global economy consisting of many such individual countries and explore the externalities that arise when regulatory policy and reserve holdings are determined at the country level, rather than by a global planner. Section 5 discusses some further extensions of our framework, and Section 6 concludes.

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[10] This idea is developed in Obstfeld, Shambaugh and Taylor (2010), who use M2/GDP as a proxy for the vulnerability of the domestic banking sector to such an "internal capital drain".

[11] Fanelli and Straub (2021) also build a model in which individual countries over-accumulate reserves relative to a global planner's optimum. However, the mechanism in their model is quite different, and more "mercantilist" in nature—central bank reserve holdings are driven by a desire to stabilize exchange rate fluctuations.

2. Motivating Evidence

Unlike much of the empirical work on foreign-exchange reserve holdings, our focus is on dollar reserves, as opposed to total reserves. This presents something of a data challenge, as the composition of central-bank reserves by currency is not available for all countries. Thus we begin with a panel of 56 non-U.S. and non-Eurozone countries for which we are able to break out the currency composition of reserve holdings, as well as compile a small set of covariates. We exclude the Eurozone countries because, to the extent that they all benefit from either explicit or implicit ECB support, it does not make sense to relate dollar reserve holdings measured at the individual-country level (e.g., dollar reserves on the books of the Bank of Italy) to country level measures of corporate-sector mismatch. The data on dollar reserve holdings is constructed from the union of data in IMF (2020), Chinn et al (2021), Arslanalp et al. (2023), and, for China, the State Administration of Foreign Exchange (SAFE); Table A1 in Appendix A lists all of our data sources. Our unbalanced panel of 56 countries has 410 observations, covering the period 2013-2020.[12] Of these 56 countries, 13 are classified by the IMF as advanced economies, 32 are classified as emerging economies, and 11 are classified as developing economies. Table A2 gives a full listing of the countries broken down by these categories.

Our basic objective is to relate a country's dollar reserves to a measure of its private sector's foreign currency mismatch. In thinking about how to best proxy for foreign currency mismatch, we are informed by the following observation: as a general matter, and likely in part as the result of regulation, banks tend not to run large outright currency mismatches on their own books; there is an extremely tight correlation between their dollar-denominated assets and liabilities.[13] Rather, currency mismatch shows up to a greater extent on the balance sheets of the non-financial sector. As discussed in Gopinath and Stein (2021) and Gutiérrez, Ivashina and Salomao (2023), one way to think about this is that the exogenous variation in the data comes from the fact that the preference on the part of households for dollar-denominated assets is greater in some countries than others.

[12] This number comes after discarding three countries that appear to have data errors in some years—where the ratio of dollar reserves to total reserves is coded as either negative or as exceeding 100%.

[13] For example, in our 409-observation panel, the correlation between the ratio of dollar-denominated bank assets to GDP and the ratio of dollar-denominated bank liabilities to GDP is 0.961. If we instead look at the 56 observations of country-level averages, the correlation is 0.97. The data on total dollar-denominated bank assets and liabilities is from BIS Table A6.1.

And when a bank finds itself awash in dollar deposits, it seeks to reduce its own currency exposure by cutting the rates on dollar loans, thereby creating an incentive for the non-financial sector to borrow more aggressively in dollars.[14]

With this observation in mind, one simple way to measure mismatch might be to look at the ratio of the dollar-denominated borrowing of the nonfinancial corporate sector to GDP. This would clearly be an imperfect proxy to the extent that it incorporates dollar-denominated borrowing by those firms (e.g., exporters) who may not actually be mismatched. It would in principle be better to capture only dollar-denominated borrowing by purely domestic non-tradable firms; unfortunately, we have been unable to create such a measure.

Moreover, even if we look at the aggregate nonfinancial sector, thereby blurring over this distinction, we face a further limitation: for our sample of 56 countries, we have available from the BIS complete data only on those dollar-denominated bank loans to the corporate sector that come from *cross-border banks*, i.e., banks headquartered outside the country in question. To get total dollar-denominated bank lending to the corporate sector in a given country, we need to add loans from *local banks*, but unfortunately, we only are able to obtain this local-lending data by currency for a smaller subsample of 21 countries, 10 of which are advanced economies and 11 of which are emerging economies.[15]

As an admittedly second-best approach, and one that allows us to work with the larger 56-country sample, we use the cross-border lending data in what follows. In doing so, we draw some comfort from the fact that for the 21 countries where we can construct the preferred total (i.e., cross-border plus local) measure of dollar-denominated lending to the nonfinancial corporate sector, it has a correlation of 0.66 with cross-border dollar lending. If we break the data down further into advanced-economy and emerging-economy subsamples, the correlations are higher, at

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[14] Of course, in this case, while the banking sector may appear to be nominally currency hedged, it still bears a significant economic exposure to the dollar—when the dollar appreciates, more of its currency-mismatched borrowers will tend to default on their loans. However, for the purposes of measuring mismatch in the data, this line of argument suggests that we need to look to the balance sheets of the non-financial sector.

[15] The currency composition of banks' local (as opposed to cross-border) claims is in many cases either not available or is treated as confidential by the BIS. Of the 46 countries that report banks' local dollar claims to the BIS, only 8 are non-euro area countries whose data are non-confidential *and* where we also have the currency breakdown of reserves. For the remaining countries, the breakdown of local claims by currency is made available to the IMF from national monetary authorities.

0.89 and 0.73, respectively. Thus the cross-border lending data may be a tolerably good proxy for total dollar-denominated bank lending.

One reason why this might be the case is that if, say, the U.S.-based subsidiary of a U.K. bank holding company (for example, HSBC Bank USA, which is a subsidiary of U.K.-headquartered HSBC) makes a loan to a U.K. firm, this will be counted in the BIS data as a cross-border loan to the U.K. corporate sector, even though it is in effect a U.K.- headquartered bank holding company lending to a U.K.-domiciled firm. So some of what are categorized by the BIS Locational Banking Statistics as cross-border loans may be more closely connected to the domestic banking sector than the label might otherwise suggest. Nevertheless, the imperfect nature of our approach suggests caution in interpreting the results that follow; we cannot be sure that they would continue to hold with a more complete measure of dollar-denominated lending.[16]

With these caveats in mind, Figure 1 presents a first simple univariate visualization of our basic result. For each of the 56 countries in our baseline sample, we plot on the horizontal axis the time-averaged value of cross-border dollar bank loans to GDP, and on the vertical axis the time-averaged value of dollar reserves to GDP. As can be seen, there is a positive correlation between these two variables. The R-squared of the regression is 0.17, and the coefficient on the dollar bank loan variable is 0.6, with a t-statistic of 3.4, so that a one-percentage point increase in dollar loans to GDP is associated with a 0.6 percentage point increase in dollar reserves to GDP.

However, as Figure 1 also makes clear, this relationship is affected in important ways by three data points—Hong Kong, Mauritius, and Seychelles—which are extreme outliers, with very large values of either dollar bank loans to GDP, or dollar reserves to GDP, or both. In Figure 2, we repeat the plot, this time excluding Hong Kong, Mauritius, and Seychelles. In this case, the R-squared of the regression falls to 0.1, but the slope coefficient rises to 1.5, with a t-statistic of 2.5. In the rest of what follows, we focus on a modified sample that excludes the three outlier countries. To be clear, it is not because we think the data for these countries is mistaken; rather we just are concerned about them having an overly influential impact on the results. Table 1 presents some basic summary statistics for our modified 53-country sample.

[16] Also missing from our measure is dollar-denominated bond-market borrowing, which again we have not been able to assemble for many of the countries in our baseline sample. Though here the theoretical case for including it is arguably murkier, as it is less obvious that the central bank will find itself compelled to bail out bond-market investors as compared to commercial banks.

To get a better sense of where the correlation between dollar borrowing and dollar reserve holdings is coming from, in Figure 3 we repeat the graphical exercise for each of three subsamples separately: advanced, emerging and developing economies. As can be seen, the relationships are significant for both the advanced-economy (coefficient estimate of 3.7, t-statistic of 2.1, R-squared of 0.30) and emerging-economy subsamples (coefficient estimate of 2.2, t-statistic of 2.5, R-squared of 0.17).[17] However, in the developing-economy subsample, there is no significant correlation, and the point estimate goes slightly in the wrong direction. Thus, our story does not seem to apply to the poorest countries. Of course, in a value-weighted sense, these countries loom less large than they do in our equal-weighted regressions, suggesting that we may nevertheless have something to say about the behavior of the most important holders of dollar reserves.

Table 2 explores these relationships in a series of regressions that exploit the full panel structure of our data, rather than just focusing on country averages. In columns (1)-(4), we run univariate panel regressions of dollar reserves to GDP against the ratio of cross-border dollar loans to nonfinancial firms divided by GDP, for the full sample, and the advanced, emerging and developing-economy subsamples, respectively. Consistent with the impressions from Figures 2 and 3, the results for the full sample and the advanced-economy subsample are significant at the 10% level, while that for the emerging-economy subsample is significant at the 5% level.[18] The developing-economy subsample by contrast yields a completely insignificant result.

In columns (5)-(8) we re-run the same regressions, adding several controls familiar from the literature on central-bank reserve holdings: the ratio of M2 to GDP following Obstfeld, Shambaugh and Taylor (2010); a measure of financial openness following Chinn and Ito (2006); bilateral trade with the U.S. scaled by GDP; GDP per capita; and the log of population. Although these controls add substantially to the explanatory power of the regressions, they leave the coefficient estimates close to those in columns (1)-(4).

Finally, in columns (9)-(12), we add country fixed effects (this entails dropping Mexico from the sample, as we only have one observation for Mexico). Because all of the controls in columns (5)-(8) are nearly time-invariant for each country, we omit them in the fixed-effects

[17] It should be noted that the significant result for the advanced-economy subsample disappears if, in addition to Hong Kong, we also remove Switzerland from the sample. However, given the relatively small number of countries in this subsample, it is perhaps not surprising that the two most influential observations carry a lot of the explanatory weight.
[18] Standard errors in these regressions are clustered by country.

regressions; however, this makes no meaningful difference to the results.[19] However, because we are now isolating the time-variation in the data, we add a control for the nominal exchange rate, which turns out to be strongly significant in columns (9)-(11). However, even with this added control, the point estimates on our coefficient of interest are again quite similar and are now significant at the 5% level for the full sample as well as both the advanced and developing-economy subsamples, although we lose significance in the emerging economy subsample. In all three of the significant cases, the country fixed effects lead to R-squared values that are now in the neighborhood of 0.90. This suggests—not surprisingly—that the lion's share of the variation in the data is between, rather than within countries.

In sum, for both advanced and emerging economies—though not for developing economies—there appears to be a meaningful correlation in the data between dollar-denominated borrowing by their nonfinancial corporate sectors, and dollar reserve holdings by their central banks. Of course, such correlations by themselves do not allow us to say anything about causation. So our empirical results should at most be interpreted as suggestive patterns, which we hope provide some broad-brush motivation for the model that we turn to shortly; they are certainly not intended as tight tests of any particular causal theory.

Moreover, even if one accepts these empirical results at face value—i.e. one accepts that countries' dollar-denominated borrowing helps to explain the cross-section of their dollar reserve holdings—it does not follow that this specific motive can account for an economically significant fraction of aggregate dollar reserve holdings. Indeed, the fact that countries like China and Switzerland lie far above the regression lines in Figure 3 suggests that consistent with received wisdom, the lion's share of their dollar reserve holdings are *not* explained by the dollar borrowing of their corporate sectors. And given that we are ultimately interested in the interest-rate externalities associated with the specific mechanism in our model, it would seem important to be able to make the case that this mechanism is in fact quantitatively meaningful.

In an effort to do so, we conduct the following quantitative exercise. First, we begin with each of the 60 advanced-economy and emerging-market countries for which we have data on actual

[19] Another control that is sometimes seen in the literature is an indicator for whether a country anchors its currency to the dollar. However, in our sample this variable has literally no time variation at all. So, it is perfectly subsumed by our country fixed effects.

dollar reserve holdings.[20] Next, using the estimated slope coefficients of 3.428 and 1.737 in columns (6) and (7) of Table 2 respectively, we compute for each country the reduction in the ratio of dollar reserves to GDP that would occur if their dollar-denominated corporate borrowing were zeroed out—this is simply the relevant slope coefficient for the country times their ratio of dollar-denominated corporate borrowing to GDP. Finally, for the most recent year that we have data available for a country, we multiply this value by their GDP. This give us an estimate of the value of their dollar reserves that can be explained by the dollar-denominated borrowing of their corporate sectors.

By construction, for countries like China and Switzerland, this estimate will be well below their actual dollar reserve holdings. In other words, for these countries, we will only attribute a small fraction of their dollar reserve holdings to the mechanism in our model. In particular, for China in 2018 (the last year we have data available), our estimate of the value of dollar reserves explained by their dollar-denominated corporate borrowing is \$90.7 billion, as compared to the actual value of dollar reserves of \$1.8 trillion. So consistent with what we take to be a sensible set of priors, we are giving our theory very little credit for explaining China's reserve holdings.

By contrast, for countries that lie below the regression line, the value from this process may exceed their actual dollar reserve holdings. So in these cases, we simply assume that all of their reserve holdings are explained by our mechanism. Thus, for any given country, the dollar reserves that we attribute to our mechanism is given by the minimum of either: the value imputed by our estimation process; or their actual dollar reserves.

Panel A of Figure 4 illustrates the output from this exercise, plotting for each of the 60 countries the fraction of their total dollar reserve holdings that we attribute to our mechanism. The median value of this fraction across these countries is 0.24, i.e., just under one-quarter of all dollar reserve holdings.

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[20] Recall that of the 56 countries in Figure 1, 13 are advanced economies and 32 are emerging economies. To these 45 we add 3 (Brunei, Serbia, and Taiwan POC) for which we have data on dollar reserves but which were previously excluded from the analysis due to lack of data on some of the covariates in the regressions. We then add back the 12 Eurozone countries for which we have data on dollar reserves. We did not include them in the cross-sectional regressions out of a concern that dollar reserve holdings in these individual countries might not naturally line up with country-level dollar corporate liabilities, given that they all are under the umbrella of a single central bank. This concern does not arise for the purposes of the present exercise, however, since we are now effectively just asking how much of the Eurozone's *aggregate* dollar reserves are explained by its *aggregate* dollar corporate liabilities.

This approach works for the 60 countries where we have data on dollar reserve holdings. However, there are another 69 countries where we do not have the currency breakout of reserve holdings, but we do still have data on their dollar-denominated corporate borrowing. For these countries, we can once again use the regression coefficients in Table 2 to compute an estimate of the value of their dollar reserves that can be explained by the dollar-denominated borrowing of their corporate sectors. Now however, we have to do a cruder truncation, with the attribution to our mechanism being the minimum of either: this estimate; and their actual *total* reserves. The results of this approach are shown in Panel B of Figure 4. In this case, the median value of dollar reserves attributed to our mechanism relative to total reserves (in all currencies) is 0.14. We would expect this number to be lower than the median of 0.24 in Panel A, since now the denominator is total reserves, rather than dollar reserves.[21]

With these results in hand, all that is left is to tally the total dollar of reserves across all countries that we are attributing to our mechanism. For the 60 countries where we can observe dollar reserve holdings, this comes to \$1.1 trillion, while for the remaining 69 countries where we cannot, the sum is \$509 billion. Putting it all together, our estimate for the quantity of dollar reserves due to the motive in our model is \$1.61 trillion.

For our purposes, the key question is whether a number like \$1.61 trillion is large enough to be consistent with economically meaningful consequences for interest rates. One place to turn for a sense of magnitudes is the large empirical literature on the interest-rate impact of the Federal Reserve's Quantitative Easing (QE) and Quantitative Tightening (QT) programs. There are numerous estimates and estimating strategies in this literature, which we will not survey here.[22] But a recent paper by Eren, Schrimpf and Xia (2023)—which concludes that a \$215 billion sale of Treasuries by the Fed would drive Treasury yields up by 10 basis points—provides one example that turns out to be closely in line with the consensus in much of the recent work. If one accepts

[21] As a crude sanity check, the ratio of these two numbers is 0.14/0.24 = 58%. This is very close to the aggregate share of dollar reserves in total reserves, which was 59% as of March 2024, suggesting that our attribution approach is working in a broadly consistent fashion across the two samples.

[22] See however Bernanke (2020) for a recent survey of much of this work.

this conclusion, it would seem that the aggregate dollar reserve holdings associated with our mechanism might indeed have the potential to create meaningful interest-rate spillovers.[23]

3. Optimal Regulation and Reserve Holdings in a Small Open Economy

We begin with a model of central bank regulatory policy and reserve holdings in a single small open economy that takes the dollar interest rate as given. The model, which builds on that in Gopinath and Stein (2018), has three types of agents: households, banks, and the central bank. Importantly, however, the agents we call "banks" should be interpreted as an aggregation of the intermediary sector and the non-financial firms that these intermediaries lend to. And as noted above, when we refer to currency mismatch in the "banking" sector in the model, the real-world counterpart is predominantly mismatch in the capital structure of non-financial firms.

3.1. Households

There are two dates in the model, given by time 0 and time 1. Households have linear utility over consumption at both dates. These households can save in three types of assets at time 0: home-currency-denominated safe assets, D_h, dollar-denominated safe assets, $D_\$$, and home-currency equity K. The representative household consumes only home goods, and has utility given by:

$$U \equiv C_0 + \beta E[C_1] + \underbrace{\theta_d(D_\$ + D_h)}_{\textit{Preference for Safe Assets}} + \underbrace{f(D_\$)}_{\textit{Extra Preference for the Dollar}} \tag{1}$$

where $f'(\cdot) > 0$ and $f''(\cdot) \leq 0$. The budget constraints are:

$$C_0 = Z - Q_\$ D_\$ - Q_h D_h - Q_K K \tag{2}$$

$$C_1 = \tilde{e} D_\$ + D_h + \pi - S_K R_\$ - \Omega(\tau) \tag{3}$$

where Z is the initial household endowment in units of home goods, $Q_\$$ and Q_h are the prices of dollar and home-currency safe assets at time 0 respectively, and Q_K is the time-0 price of a share that delivers an expected payoff of one at time 1. Note that $Q_\$$, Q_h, and Q_K are the reciprocals of

[23] Taken literally, these numbers would imply that if all the dollar reserve holdings associated with our mechanism were to vaporize, Treasury yields would increase by 10*1.61/.215 = 75 basis points. To be clear, this is not the same thing as, e.g., the answer to the question of what the yield differential would be if reserves were chosen in our model by a local vs. a global planner; the magnitude in this case would likely be considerably smaller.

one plus the required returns on dollar safe assets, home-currency safe assets, and home-currency equity, respectively. In addition, $\tilde{e}$ is the time-1 nominal exchange rate, π is the time-1 profit of the banking sector (net of payments to depositors), $S_K R_\$$ is the net transfer to foreigners on the central bank's reserve position, and $\Omega(\tau)$ are deadweight costs of taxation; we show how these latter values are determined below. In period 0, the nominal exchange rate is given by 1.

The time-1 exchange rate, denoted by $\tilde{e}$, takes on the values $(1-z)$ and $(1+z)$, each with probability ½. Our convention is that a higher value of $\tilde{e}$ represents an appreciation of the dollar relative to the home currency. The exchange rate is assumed to be exogenously determined, perhaps as the outcome of financial flows outside the model interacting with limited arbitrage capacity on the part of foreign-exchange traders, as in Gabaix and Maggiori (2015).[24]

We also take households' extra preference for dollar assets, as represented by $f(D_\$)$, to be exogenous, as our interest is in seeing how banks and the central bank respond to the lower interest rate on dollar assets. Given that households consume only home goods, one might rationalize this assumption by arguing that their demand for dollar assets reflects a belief that these assets are "extra safe" and can be counted to pay off in full even in an (unmodelled) severe-disaster state of the world when countries other than the U.S. are unable to bail out their banking sectors.[25]

The first order conditions of the household utility maximization problem yield:

$$Q_K = \beta, \quad Q_h = \beta + \theta_d, \quad Q_\$ = \beta + \theta_d + f'(D_\$) \tag{4}$$

Home-currency assets, D_h and K, are both manufactured locally, as the liabilities of the domestic banking sector. On the other hand, the demand for dollar-denominated assets, $D_\$$, is satisfied both by imported dollar bonds (e.g., U.S. Treasury bonds), $X_\$$, and by domestically-issued dollar-denominated bank liabilities, $B_\$$. A small open economy takes the price of dollar bonds, $Q_\$ > \beta +$

[24] The fact that we take the exchange rate to be exogenous, and in particular unrelated to central-bank reserve holdings, shuts down some potentially important effects in the model, and it might be interesting to relax this assumption. For example, we conjecture that if one allowed dollar reserves to be used to stabilize the exchange rate, and thereby avert some of the consequences to the banking sector of a local-currency depreciation, the motive for dollar reserve holdings that we analyze would be strengthened, as too might be the wedge between the incentives of local and global regulators.
[25] This approach differs from that in Gopinath and Stein (2021), who endogenize the preference for dollar deposits by assuming that households that purchase more dollar-invoiced imported goods will have a stronger preference for dollar assets, since these serve as a hedge for them against changes in exchange rates.

θ_d, as exogenously given. The quantity of dollar savings by households $D_\$$ is then pinned down by the exogenous global price.

3.2. Banks

There is a continuum of banks, with measure equal to one. At time 0, a bank raises funding from households and provides financing for a fixed quantity of projects given by I. To raise funds for these projects, a bank relies on three types of securities: B_h, $B_\$$ and K. Here, B_h denotes deposits denominated in home currency, $B_\$$ denotes deposits denominated in dollars, and K represents outside equity capital. Thus, the bank's balance sheet at time 0 must satisfy:

$$Q_\$ B_\$ + Q_h B_h + Q_K K = I \qquad (5)$$

With probability q, there is a banking crisis at time 1. In a crisis, the revenues of a fraction p of banks fall to zero, while the remainder stay solvent. Those banks whose revenues fall to zero must be bailed out by the government, meaning that the government has to pay off all depositors in full. For the moment, we assume that the probability of a crisis is independent of the exchange rate. We will revisit this assumption below and allow for some correlation between banking crises and exchange rates.

Both in and out of the crisis state, those banks whose revenues do not fall to zero—i.e., banks that are solvent—have sufficient gross revenues from their projects, which we denote by Y, to pay off all depositors, independent of the realization of the exchange rate. However, if a bank is solvent, but the home currency depreciates, which happens with probability $(1 - pq)/2$, the resulting currency mismatch leads to liquidity-constraint costs for the banks and their customers of $\gamma I \left(\frac{B_\$}{I}\right)^2 = \frac{\gamma B_\$^2}{I}$. Concretely, one can think of a currency-mismatched operating firm as having to cut back on positive-NPV investments when its debt-service costs increase due to a depreciation of the home currency relative to the dollar. The logic behind the specific functional form is that such costs scale linearly with project size I but are convex in the degree of capital-structure mismatch—i.e., the proportion of funding coming from dollar deposits, which is given by $\left(\frac{B_\$}{I}\right)$. Thus, the ex-ante expected costs of mismatch (in time-1 units) are given by $\frac{(1-pq)\gamma B_\$^2}{2I}$.

Given its fixed scale, the bank's problem is simply to minimize the sum of its expected funding and mismatch costs. Note that the bank only pays such costs when it is solvent, which happens with probability $(1 - pq)$. Thus the bank's problem is given by:

$$\min_{B_\$, B_h, K} (1 - pq)\, E\left[\left\{\tilde{e} B_\$ + B_h + K + \frac{\gamma B_\$^2}{2I}\right\}\right] \tag{6}$$

The only constraint faced by banks, unless additional capital requirements are imposed by the central bank, is the time-0 balance sheet condition in (5). Therefore, we have that, with no regulations in place, banks adopt the following capital structure in an interior optimum:

$$B_\$^* = \frac{SI}{\gamma}, \quad B_h^* = \frac{I - Q_\$ B_\$^*}{Q_h}, \quad K^* = 0 \tag{7}$$

with $S \equiv \left(\frac{Q_\$}{Q_h} - 1\right)$ denoting the interest-rate spread between domestic-currency and dollar-denominated deposits. Here and in what follows, a single-asterisk superscript (*) refers to a choice made by an unconstrained bank. Intuitively, dollar deposits are attractive to a bank to the extent that they have a lower interest rate than domestic deposits, with this spread given by S. On the other hand, too much dollar borrowing increases mismatch, and the associated liquidity-constraint costs when the dollar appreciates, with the magnitude of this cost parameterized by γ. And absent financial regulation, there is no motive in our simple model for the bank to finance itself with the more expensive equity capital.

3.3. Central Bank

To address the risk of having to bail out the banking sector, the central bank can in principle make use of three policy tools: (i) it can accumulate dollar reserves; (ii) it can regulate the equity capital of the banking sector; and (iii) it can regulate the deposit mix of the banking sector, i.e., the relative proportions of dollar-denominated and home-currency denominated deposits. We discuss each of these tools in turn. Note that there is a natural role for regulation in our setting, because individual banks do not internalize the deadweight fiscal cost that arises when they have to be bailed out.

Dollar Reserve Holdings The central bank purchases dollar-denominated reserves, $R_\$$, paying $Q_\$ R_\$$ at time 0. We assume that in doing so, it holds the overall size of its balance sheet constant, and finances the purchase by selling off other assets (e.g., a portfolio of global stocks) that yield an equity-like rate of return. This implies that the central bank earns an expected negative return (in time-1 units) of $S_K R_\$ \equiv \left(\frac{Q_\$}{\beta} - 1\right) R_\$$ on its reserve holdings, with S_K denoting the spread between the rate of return on equity and the safe dollar interest rate.[26] This negative return amounts to a net transfer to foreigners (e.g. to the U.S. Treasury or other non-domestic issuers of dollar-denominated securities) and so reduces the time-1 consumption of the household sector. We assume that this expected cost associated with the negative carry on reserves does not involve any distortionary taxation.

However, if there is a banking crisis, the central bank has to bail out depositors either by raising taxes on domestic residents, or by using the net profits (or losses) it earns on its reserve holdings. We assume that in the crisis state, fiscal capacity is limited, and the deadweight costs of any incremental taxation are convex and are given by $\psi\tau^2$, where τ is the tax that is raised.

Putting it together, the central bank chooses $R_\$$ to minimize the sum of reserve carrying costs $S_K R_\$$ and deadweight costs of taxation $\Omega(\tau)$:

$$\min_{R_\$} S_K R_\$ + \Omega(\tau) = S_K R_\$ + \frac{\psi q}{2}\left[(pB_h + (1+z)pB_\$ - zR_\$)^2 + (pB_h + (1-z)pB_\$ + zR_\$)^2\right] \quad (8)$$

This leads to the following expression for optimal reserve holdings in an interior solution:

$$R_\$^{**} = pB_\$ - \frac{S_K}{2qz^2\psi} \quad (9)$$

[26] An alternative approach is to assume that the central bank expands its balance sheet by issuing local-currency-denominated money to finance its reserve purchases, in which case the relevant carry cost is reduced, and is given by $SR_\$$ instead of $S_K R_\$$. All of our results carry through in this case, although when we analyze global externalities it is less clean, because various transfer terms between the U.S. and other countries do not cancel out as completely.

Here and in what follows, a double-asterisk superscript (**) refers to a choice made by the central bank. The expression in (9) holds true for any value of $B_\$$. If there is no financial regulation, then $B_\$$ is given by the bank's choice in (7), and reserves satisfy $R_\$^{**} = pB_\$^{*} - \frac{S_K}{2qz^2\psi} = \frac{pSI}{\gamma} - \frac{S_K}{2qz^2\psi}$. If there is regulation, $B_\$^{*}$ may or may not be lower, depending on the form of regulation, as we show below. Either way, the logic behind (9) is intuitive: in the limit where taxation is very expensive (as ψ goes to infinity) the central bank holds sufficient reserves $pB_\$$ to fund a bailout entirely via reserves, without resorting to taxation. As deadweight costs of taxation decline, the central bank relies less on reserves and more on taxation, particularly to the extent that the carrying cost S_K of reserve holdings is significant.

It is worth being clear on the precise mechanism that makes dollar-denominated reserves attractive to the central bank in our model. The motive is one of risk management: dollar-denominated reserves allow the central bank to *transfer wealth across states of the world* and, crucially, to leave itself with more wealth when the dollar has appreciated. This is of value because: (i) the cost of bailing out dollar-denominated deposits is higher in this state; and (ii) there are convex costs of financing the bailout with taxation.[27]

One implication of this observation is that central-bank swap lines cannot serve as a substitute for dollar reserves. A swap line from the Federal Reserve to another country's central bank does not enable a transfer of wealth across states; rather it is an ex post liquidity-provision mechanism that just allows the recipient central bank to borrow dollars on a collateralized basis *against whatever wealth it already has in that state*. Thus swap lines and reserves serve entirely different purposes in our setting.

Capital Requirements If the central bank imposes a capital requirement of K^{**}, this will act as a constraint on the *sum* of home-currency and dollar-denominated borrowing. However, the central bank cannot control these components individually. Moreover, we can see from the bank's first-order condition in (7) that in an interior optimum, its choice of dollar borrowing $B_\$^{*} = \frac{SI}{\gamma}$ is

[27] This logic is exactly parallel to the theory of risk management for non-financial firms developed by Froot, Scharfstein and Stein (1993), who argue that costly external finance makes firms want to transfer wealth to states where internal resources are scarce relative to investment opportunities. Here, convex costs of taxation for the sovereign simply take the place of costly external finance for firms.

independent of the total amount of deposit funding raised. Therefore, it follows that a capital requirement will not change dollar borrowing and can be thought of as equivalent to the regulator simply picking a reduced value of home currency borrowing B_h. It then further follows that a capital requirement will not change the central bank's desired reserve holdings, since from (9) these are only influenced by dollar borrowing and are unrelated to home-currency deposits.

To solve for the central bank's optimal choice of B_h, we need to write down the planner's problem. To do so, note that we can write:

$$C_0 = Z - I - Q_\$(D_\$ - B_\$) - Q_h(D_h - B_h) \tag{10}$$

$$E[C_1] = Y + (D_\$ - B_\$) + (D_h - B_h) - \frac{(1-pq)\gamma B_\$^2}{2I} - S_K R_\$ - \Omega(\tau) \tag{11}$$

Note that (10) follows from (2), combined with the bank's balance-sheet constraint in (5). And (11) reflects the fact that consumption at time 1 is the sum of: (i) the net profits of the banks (gross revenues *Y*, less the repayment of their borrowings, less the liquidity-constraint costs incurred in the event of local-currency depreciation); (ii) the deposit savings that households have accumulated; minus (iii) the carrying costs of central-bank reserve holdings and the deadweight costs of taxation, which are ultimately borne by households.

So overall, social welfare *W* can be written as (neglecting the exogenous terms *Z*, *I* and *Y*):

$$W = -Q_\$(D_\$ - B_\$) - Q_h(D_h - B_h) + \beta\{(D_\$ - B_\$) + (D_h - B_h)\} + \theta_d(D_\$ + D_h) + f(D_\$) - \beta\left\{\frac{(1-pq)\gamma B_\$^2}{2I} + \left(S_K R_\$ + \Omega(\tau)\right)\right\} \tag{12}$$

This can be simplified to:

$$W = B_\$(Q_\$ - \beta) + B_h(Q_h - \beta) + \left(f(D_\$) - D_\$ f'(D_\$)\right) - \beta\left\{\frac{(1-pq)\gamma B_\$^2}{2I} + S_K R_\$ + \Omega(\tau)\right\} \tag{13}$$

The first three terms in (13) have an intuitive interpretation. The first two are the bank's excess profits from borrowing with dollar and home-currency deposits respectively, rather than by issuing equity. The third is related to the utility created for households from their holdings of dollar assets.

Importantly, this third term is exogenous from the perspective of a small-country planner since households' dollar asset holdings are pinned down by the exogenous $Q_\$$ and are thus invariant to any policies that the planner implements. So, in the small-country case, the planner's problem boils down to maximizing local welfare W_L, given by:

$$W_L = B_\$(Q_\$ - \beta) + B_h(Q_h - \beta) - \beta\left\{\frac{(1-pq)\gamma B_\$^2}{2I} + S_K R_\$ + \Omega(\tau)\right\} \quad (14)$$

A local planner who controls only capital requirements effectively picks B_h to maximize this objective function. In this case, the optimal value of B_h in an interior optimum is given by:

$$B_h^{**} = \frac{(Q_h - \beta)}{2\beta\psi q p^2} - B_\$ \, . \quad (15)$$

If the regulator does not control $B_\$$ directly, it continues to be given by the bank's optimum of $B_\$^* = \frac{SI}{\gamma}$. From adding up, this implies that the capital requirement is given by $K^{**} = \frac{I - Q_\$ B_\$^* - Q_h B_h^{**}}{Q_K}$. And from (9), this implies that reserves are unchanged from the unregulated case and are again given by: $R_\$^{**} = pB_\$^* - \frac{S_K}{2qz^2\psi} = \frac{pSI}{\gamma} - \frac{S_K}{2qz^2\psi}$.

Funding Regulation Finally, we consider the case where a planner can also control a bank's funding mix—its proportions of dollar and local-currency deposits—in addition to its capital ratio.[28] We do so in order to draw out the logic of the model more fully, and to provide a benchmark that will be useful when we move to the general-equilibrium version of the model

[28] In our simple setting, where all the relevant parameters are known with certainty, quantity regulation of the sort that we study is isomorphic to Pigouvian taxation—i.e., it is always possible to set a tax rate that implements the desired quantity. Thus when we argue below that quantity regulation of the funding mix may not always be possible, this implicitly amounts to saying that the first-best also cannot be achieved via a tax-based regime.

where dollar interest rates are endogenous. At the same time, we are mindful of the fact that this case almost surely overstates the scope of financial regulation in the real world. As we have emphasized, the empirical reality is that the vast majority of currency mismatch occurs on the balance sheets of non-financial firms, where traditional regulatory bank regulatory tools do not reach. While some countries (e.g., China, Turkey, India, and Indonesia) do attempt to impose restrictions on foreign-currency borrowing by non-financial firms, the view among the IMF country experts that we spoke with is that it is costly and difficult to implement such restrictions.[29] Moreover, the evidence is clear that in many emerging markets there is a substantial amount of dollar borrowing even among firms that have no real-side dollar exposure at all, suggesting that whatever regulation does exist is unable to eliminate currency mismatch.[30]

With that caveat in place, this case is equivalent to the planner picking both $B_\$$ and B_h to maximize W_L as given in (14). The first order condition for $B_\$$ in an interior optimum is:

$$B_\$^{**} = \frac{(Q_\$ - \beta) - 2\psi q \beta p^2 B_h^{**} + 2\psi q \beta p z^2 R_\$^{**}}{\left(\frac{\beta(1-pq)\gamma}{I}\right) + 2\psi q \beta p^2 (1+z^2)} \quad (16)$$

The first-order conditions for B_h and $R_\$$ continue to be given by equations (15) and (9), respectively. These three equations (i.e., (16), (15), and (9)) can then be solved jointly to yield expressions for the three policy variables as functions of the primitive parameters.

3.4. Banking and Currency Crises are Correlated

Thus far, we have been assuming that the probability of a banking crisis is independent of the exchange rate. This is likely to be too simplistic, as banking crises often coincide with large

[29] See Capacioglu and Kara for a discussion of the Turkish experience with regulating currency mismatch in the corporate sector. They note the relative rarity across countries of such a regulatory approach, saying "macroprudential tools directly targeting currency mismatches for non-financial firms are rare." In a similar vein, Acharya, Cecchetti, De Gregorio, Kalemli-Ozcan, Lane, and Panizza (2015) write: "Policymakers have a challenging task controlling these risks [arising from mismatch on the part of non-financial firms] directly, as it is difficult to intervene to reduce the external foreign-currency borrowing by what are generally unregulated institutions."

[30] See, e.g., Chui, Kuruc, and Turner (2016), who write: "Microeconomic data show that it was not only companies providing tradable goods and services but also those producing non-tradable goods which have increased their foreign currency borrowing…many authorities allowed local banks to take dollar deposits from residents. Once banks had dollar deposits, the banks sought dollar assets. Often, they would encourage local customers to borrow in dollars."

depreciations of the local currency (Kaminsky and Reinhart 1998). We can easily extend our framework to capture such a correlation. To do so, assume that there is an increased probability $(q + h)$ of a banking crisis when the exchange rate is $(1 + z)$, i.e., when the local currency depreciates against the dollar. And symmetrically, there is a reduced probability $(q - h)$ of a banking crisis when the exchange rate is $(1 - z)$. All else is the same as before. Here the parameter h is a measure of the strength of the correlation between exchange rates and banking crises; note that this setup nests our previous no-correlation case if $h = 0$. With these assumptions in place, we can re-derive our various results. First, we have that an unregulated bank now sets:

$$B_{\$}^{*} = \frac{I((1-qp)S+hpz)}{(1-p(q+h))\gamma} \tag{17}$$

Relative to the previous solution given in equation (7), the primary change is the addition of the hpz term in the numerator of (17). This is a moral hazard effect—since the bank is more likely to default when the dollar has appreciated, it effectively has a call option on the dollar in the crisis state. So, dollar borrowing is increased in this version of the model. A second mechanical effect of the reformulation is that there are fewer states of the world with no crisis and a stronger dollar, so expected mismatch costs are not as important, which also increases dollar borrowing.

The central bank now sets:

$$R_{\$}^{**} = \frac{ph(B_{\$}+B_h)}{qz} + pB_{\$} - \frac{S_K}{2qz^2\psi} \tag{18}$$

As compared to the no-correlation case in equation (9), central bank reserves are potentially much higher, by an amount $\frac{ph(B_{\$}+B_h)}{qz}$, and are now influenced by both dollar and home-currency bank deposits, though the effect of the former is still stronger. This is because of an additional risk-management motive, beyond the one identified previously. Now, when there is a banking crisis, we know the dollar is more likely to have strengthened than to have weakened. So, holding dollar reserves is a good way to hedge the possibility of having to bail out both dollar and home-currency deposits. In the zero-correlation case, there was no motive to hedge home-currency deposits with dollar reserves, because the central bank was equally likely to have to bail out these home-currency deposits if the dollar strengthened or weakened.

One implication of this observation is that in the case with correlation between banking crises and exchange rates, any kind of financial regulation that reduces bank deposits of either type will be associated with a decline in reserve holdings. Importantly, this was not true in the zero-correlation case, where capital regulation alone had no impact on reserve holdings.

The local planner's objective function is now given by:

$$W_L = B_\$(Q_\$ - \beta) + B_h(Q_h - \beta) - \beta\{\left(1 - p(q+h)\right)\gamma B_\$^2/2I + S_K R_\$ + \Omega(\tau)\} \quad (19)$$

where deadweight costs of taxation can now be written as:

$$\Omega(\tau) = \frac{\psi}{2}\left((q+h)(pB_h + (1+z)pB_\$ - zR_\$)^2 + (q-h)(pB_h + (1-z)pB_\$ + zR_\$)^2\right) \quad (20)$$

If the central bank sets just capital requirements, i.e., it just controls B_h, it sets:

$$B_h^{**} = \frac{(Q_h - \beta)}{2\beta\psi q p^2} - \left(1 + \frac{zh}{q}\right)B_\$ + \frac{zh}{pq}R_\$, \quad (21)$$

with $B_\$$ and $R_\$$ given by equations (17) and (18) respectively.

If in addition, the central bank controls the funding mix, i.e., it also chooses $B_\$$, we have:

$$B_\$^{**} = \frac{(Q_\$ - \beta) - 2(q+zh)\psi\beta p^2 B_h + 2z\left(\frac{h}{q} + z\right)\psi q p \beta R_\$}{\left(\frac{\beta(1-p(q+h))\gamma}{I}\right) + \psi\beta p^2\left((q+h)(1+z)^2 + (q-h)(1-z)^2\right)}, \quad (22)$$

and in this case the full solution is given by equations (18), (21) and (22).

Numerical Example: Set the parameter values as follows: $I = 100$; $\beta = 0.9$; $\theta_d = 0.045$; $p = 0.25$; $z = 0.75$; $q = 0.1$; $h = 0.07$; $\gamma = 0.06$; $\psi = 0.053$; and $Q_\$ = 0.97$. In this case, the solutions to the model are given in Table 3 below.

Table 3: Numerical Example

	No Regulation	Capital Regulation Only	Capital and Funding Regulation
$B_{\$}$	67.744	67.744	14.505
B_h	36.284	26.528	79.766
K	0	10.245	11.724
$R_{\$}$	28.165	25.888	12.578

The parameters in the example are such that absent any regulation (column 1 of the table), banks finance themselves with more dollar-denominated deposits than local currency deposits. In this case, the only policy tool the central bank has available is to accumulate dollar reserves, which take on a value of 28.17, relative to private-sector investment of 100. In column 2, we allow the central bank to impose capital regulation, and it sets a capital requirement of approximately 10.25%. With this capital requirement in place—and given that we have assumed a modest correlation between banking crises and exchange rates—dollar reserve holdings fall to 25.89, even though dollar deposits are unchanged, so that the capital requirement only crowds out local-currency deposits. Finally, in column 3, we further allow the central bank to control the volume of dollar deposits directly. When given this power, it keeps the capital requirement roughly the same as in column 2, but significantly cuts back on dollar deposits relative to local-currency deposits. This in turn allows it to further economize on dollar reserve holdings, which decline to 12.58.

To summarize the analysis to this point: we have developed a relatively bare-bones model of how a small open-economy central bank can attempt to mitigate the costs of banking crises that are associated with currency mismatch on the part of the private sector. The central bank can do so either by accumulating dollar reserves, or by imposing various forms of financial regulation. There is an intuitive tradeoff between these tools: when we give the central bank more scope to deploy regulatory measures, it holds less in the way of reserves.

However, all of this is in a partial equilibrium setting where the small-country central bank takes the interest rate on dollar-denominated assets to be exogenous, and the supply of these assets to be perfectly elastic. We next turn to the question of global externalities, asking whether a planner who internalizes the general-equilibrium effects would strike the balance between regulation and reserve accumulation differently.

4. Global Externalities from Reserve Accumulation

4.1. Basic Setup

We now assume that the global economy consists of a unit measure of identical small countries indexed by $i \in [0,1]$, as well as the United States. We continue to allow for a correlation between banking crises and exchange rates, as in the latter part of the previous section. However, to highlight most starkly the externality of interest, we further assume that: (i) all countries draw the same exchange rate, $\tilde{e}$, against the dollar; and (ii) the occurrence of banking crises is perfectly correlated across countries. These assumptions have the effect of making all risks non-diversifiable, so absent a pecuniary externality with respect to the dollar interest rate, there would be no reason for a global planner to choose a different level of reserve holdings than a local planner. Clearly, if risks are imperfectly correlated across countries, there can be an additional risk-sharing motive for economizing on reserve holdings, but we neutralize this motive for the time being and return to it in the next section.

We focus on symmetric outcomes, so now when we refer to any given endogenous variable (e.g., $B_\$$), this should be interpreted as representing the common value of this variable across countries. We can then write aggregate welfare among the mass of small countries as:

$$W_L = B_\$(Q_\$ - \beta) + B_h(Q_h - \beta) + \big(f(D_\$) - D_\$ f'(D_\$)\big) - \beta\{\big(1 - p(q+h)\big)\gamma B_\$^2/2I + S_K R_\$ + \Omega(\tau)\} \quad (23)$$

However to capture all elements of global welfare, we also have to consider the welfare of the U.S., which issues an exogenous quantity of Treasury securities, $X_\$$, at time 0 at a price of $Q_\$$. Thus the U.S. takes in $Q_\$ X_\$$ at time 0, and pays out $X_\$$ at time 1 to those investors that bought the Treasuries, i.e., to investors in the other small countries. Hence U.S. welfare is given by:

$$W_{US} = X_\$(Q_\$ - \beta) \quad (24)$$

And global welfare is:

$$W_G \equiv W_L + W_{US} = X_\$(Q_\$ - \beta) + B_\$(Q_\$ - \beta) + B_h(Q_h - \beta) + \big(f(D_\$) - D_\$ f'(D_\$)\big) - \beta\{\big(1 - p(q+h)\big)\gamma B_\$^2/2I + S_K R_\$ + \Omega(\tau)\} \quad (25)$$

The global market clearing conditions are given by:

$$B_\$ + X_\$ = R_\$ + D_\$ \quad (26)$$

$$D_{hi} = B_{hi} \quad (27)$$

Equation (26) says that the total supply of dollar assets—which comes from either external sources, or from dollar-denominated deposits in non-U.S. banks—must equal the demand for such assets, which comes from both households and central-bank reserve managers. Equation (27) is an analogous market-clearing condition for local-currency safe assets, but in this case stating that household demand for local-currency safe assets can only be satisfied by local banks. Note that this second market-clearing condition has to hold country-by-country, as opposed to globally.

In what follows, we specialize households' utility function from dollar assets, so that it is quadratic in nature. This will allow us to continue writing down all first-order conditions in closed form. In particular, we assume that:

$$f(D_\$) = \theta_{\$1} D_\$ - \frac{1}{2}\theta_{\$2} D_\$^2 \quad (28)$$

Under this specification, we can express the price of safe dollar assets as:

$$Q_\$ = \beta + \theta_d + \theta_{\$1} - \theta_{\$2} D_\$, \quad (29)$$

where we assume that $\frac{\theta_{\$1}}{\theta_{\$2}}$ is large enough that the dollar interest rate is always lower than the domestic-currency interest rate in equilibrium. It follows that the spreads S and S_K are given by:

$$S = \frac{\theta_{\$1} - \theta_{\$2}(X_\$ + B_\$ - R_\$)}{\beta + \theta_d} \tag{30}$$

$$S_K = \frac{\theta_d + \theta_{\$1} - \theta_{\$2}(X_\$ + B_\$ - R_\$)}{\beta} = \left(1 + \frac{\theta_d}{\beta}\right) S + \frac{\theta_d}{\beta} \tag{31}$$

4.2. Global Equilibrium When Reserves and Capital Are Chosen Locally

We begin by solving for the global equilibrium—now with endogenous values of the interest-rate spread spreads S and S_K—that arises when each country sets reserve holdings and capital requirements locally, ignoring their impact on the aggregate supply of dollar claims and hence on S and S_K. In Appendix B.1, we show that in this case, one can solve out the model in terms of primitive parameters to obtain the following expressions for $B_\$^*$, $R_\$^{**}$, and S^{**}:

$$B_\$^* = a_1 S^{**} + a_2 \tag{32}$$

$$R_\$^{**} = b_1 S^{**} + b_2 \tag{33}$$

$$S^{**} = \frac{\theta_{\$1} - \theta_{\$2}(X_\$ + a_2 - b_2)}{\beta + \theta_d + \theta_{\$2}(a_1 - b_1)} \tag{34}$$

where the constants a_1, a_2, b_1 and b_2, all expressed in terms of primitive parameters, are defined in Appendix B.1, and where S^{**} denotes the equilibrium interest-rate spread that arises under the decentralized equilibrium. And once we have pinned down $B_\$^*$ and $R_\$^{**}$ the equilibrium value of B_h^{**} follows from equation (21).

4.2. Equilibrium With a Global Planner

We now turn to the case where a global planner sets both reserve holdings and capital requirements. The crucial difference in this case is that a global planner recognizes that the choice of $R_\$$ impacts the dollar interest rate, and hence the interest rate spreads S and S_K, as can be seen in equations (30) and (31). To see this explicitly, we can take the global planner's first order condition for $R_\$$. To simplify matters, note that given that: (i) $\beta S_K R_\$ = R_\$(Q_\$ - \beta)$; and (ii) $(B_\$ + X_\$ - R_\$ = D_\$)$, we can re-write global welfare as:

$$W_G = D_\$(Q_\$ - \beta) + B_h(Q_h - \beta) + \left(f(D_\$) - f'(D_\$)\right)$$
$$-\beta\left(\left(1 - p(q+h)\right)\gamma B_\$^2/2I + \Omega(\tau)\right) \tag{35}$$

The first order condition is then given by:

$$\frac{dW_G}{dR_\$} = \frac{d}{dR_\$}\left(D_\$\left(Q_\$ - \beta\right)\right) + \frac{d}{dR_\$}\left(f(D_\$) - D_\$ f'(D_\$)\right) - \beta\frac{d}{dR_\$}\left(\frac{\left(1 - p(q+h)\right)\gamma B_\$^2}{2I}\right)$$
$$-\beta\frac{d}{dR_\$}\Omega(\tau) = 0 \tag{36}$$

where the four individual components of (36) can be expressed as:

$$\frac{d}{dR_\$}\left(D_\$(Q_\$ - \beta)\right) = (\phi - 1)(Q_\$ - \beta) + D_\$\left(\theta_{\$2}(1 - \phi)\right) \tag{37}$$

$$\frac{d}{dR_\$}\left(f(D_\$) - D_\$ f'(D_\$)\right) = -(1-\phi)\theta_{\$2} D_\$ \tag{38}$$

$$\frac{d}{dR_\$}\left(-\frac{\beta\left(1-p(q+h)\right)\gamma B_\$^2}{2I}\right) = -\frac{\phi\beta\left(1-p(q+h)\right)\gamma B_\$}{I} \tag{39}$$

$$\frac{d}{dR_\$}\left(-\beta\Omega(\tau)\right) = -2\psi\beta\left(\phi q p^2 - zhp(1-p\phi)\right)(B_h + B_\$) -$$
$$2\psi\beta\left(\phi zph - qz^2(1-p\phi)\right)(pB_\$ - R_\$) \tag{40}$$

and where:

$$\phi \equiv \frac{dB_\$}{dR_\$} = \frac{\frac{\theta_{\$2} I(1-qp)}{\gamma}}{\left(1-p(q+h)\right)(\beta + \theta_d) + \frac{\theta_{\$2} I(1-qp)}{\gamma}} < 1 \tag{41}$$

To understand why the global planner's solution differs from that with a local planner, note that by netting the second term in (37) against (38)—and thereby eliminating pure transfer effects—we can re-write $\frac{dW_G}{dR_\$}$ as:

$$\frac{dW_G}{dR_\$} = \underbrace{-(Q_\$ - \beta) - \beta \frac{\partial \Omega}{\partial R_\$}}_{\textit{Local Planner's FOC}} + \underbrace{\phi \left((Q_\$ - \beta) \; - \frac{\beta(1-p(q+h))\gamma B_\$}{I} - \beta \; \frac{\partial \Omega}{\partial B_\$} \right)}_{\textit{Wedge Between Global and Local Planner}} \tag{42}$$

Equation (42), which is derived in more detail in Appendix B.2, highlights the core intuition for the results that follow. The first two terms in (42) represent the first-order condition for a local planner, who trades off the fact that more reserves entail a carry cost (the first term), but reduce deadweight costs of taxation (the second term). The remaining terms capture the wedge between the local and the global planner. Crucially, this wedge arises only when $\phi \equiv \frac{dB_\$}{dR_\$} > 0$, i.e., to the extent a change in aggregate central-bank reserve holdings influences dollar interest rates and hence dollar mismatch by banks. In this case, three additional terms come into play.

The first term inside the wedge, $(Q_\$ - \beta)$, is positive, pushing the global planner to actually prefer more reserves than the local planner. This reflects the fact that, via a lower interest rate, more reserves mean more aggregate dollar borrowing in equilibrium, which all else equal increases the supply of safe assets, and thereby increases household utility. A local planner does not take this effect into account since they behave as if the supply of safe assets is infinitely elastic.

The second two terms inside the wedge are negative, leading the global planner to prefer a lower value of reserves than the local planner. These terms capture the idea that an interest-rate-induced change in mismatch matters to the global planner because it in turn has knock-on implications for mismatch-related liquidity costs, as well as for deadweight costs of taxation.

Based on this logic, we have:

Proposition 1: If, when evaluated at the local planner's optimum, it is the case that $\left((Q_\$^{**} - \beta) - \frac{\beta(1-p(q+h))\gamma B_\$^*}{I} - \beta \frac{\partial \Omega}{\partial B_\$} \right) < 0$, then $R_\$^{***} < R_\$^{**}$, i.e. the global planner chooses a lower level of reserves than the local planner.

The proposition follows directly from equation (42). First, by definition, at the local planner's optimum, the first two terms in (42), which represent the local planner's first-order condition, sum to zero. This leaves the three terms that enter the wedge between the global planner's and the local planner's first order conditions. The first term, $(Q_\$ - \beta)$, will lead the global planner to want to increase reserves from its level under the local planner's optimum. By contrast, the latter two terms, $-\frac{\beta(1-p(q+h))\gamma B_\$}{I}$ and $-\beta \frac{\partial \Omega}{\partial B_\$}$, will lead the global planner to want to reduce reserves from this level. These latter two effects will tend to overwhelm the former if: (i) β is large relative to $Q_\$$; or (ii) either mismatch costs or deadweight costs of taxation, as proxied by γ and ψ, respectively, are large enough. If so, then starting at the local planner's optimum it will be the case that $\frac{dW_G}{dR_\$} < 0$, meaning that the global planner will wish to reduce reserves below the local planner's optimum value.

It turns out that there is a very natural way to think about the condition in Proposition 1. In Appendix B.5, we show that it can alternatively be stated as follows:

Proposition 2: Suppose a more-empowered local planner could choose a value of $B_\$$ directly. Define mismatch as socially excessive if, when starting from the local planner's optimum, such an empowered local planner would choose a lower value than the bank's privately optimal value $B_\$^*$. If mismatch is socially excessive in this sense, then $R_\$^{***} < R_\$^{**}$, i.e. a less-empowered global planner who cannot set $B_\$$ directly chooses a lower level of reserves than the local planner.

Proposition 2 reflects the observation that the only reason a global planner differs from a local planner is that the global planner recognizes that $\phi \equiv \frac{dB_\$}{dR_\$} > 0$. Therefore the global planner will want to restrain reserve accumulation if and only if the ultimate goal is to reduce $B_\$$.

Regarding capital regulation, recall that capital regulation is equivalent to picking a value of domestic-currency deposits B_h. It is easy to show that the global planner's first-order condition for this variable is identical to that of an individual central bank as given in (21). Domestic-currency deposits do not affect the externalities we are focused on, since these externalities involve only the quantity and price of dollar-denominated assets. So, holding all else fixed, there is no motive for a global planner's behavior to diverge from that of a local planner. Similarly, given that we are studying the case with only capital regulation, the value of dollar-denominated deposits $B_\$$ continues to be chosen by the banks themselves. So the relevant first-order condition for $B_\$$ is again given by (17). Of course, while the partial-equilibrium first-order conditions are the same, the ultimate general-equilibrium values of B_h and $B_\$$ will differ with a global planner, because they depend on the planner's choice of $R_\$$ and the resulting value of *S*.

Putting it all together, the solutions for the global-planner case, which we denote with triple-asterisk superscripts (***), are obtained by combining (17), (21), and (36), along with the formula for the spread *S* given in (30) and expressing everything in terms of primitive parameters. In Appendix B.6, we derive:

$$B_\$^* = a_1 S^{***} + a_2 \tag{43}$$

$$R_\$^{***} = b_3 S^{***} + b_4 \tag{44}$$

$$S^{***} = \frac{\theta_{\$1} - \theta_{\$2}(X_\$ + a_2 - b_4)}{\beta + \theta_d + \theta_{\$2}(a_1 - b_3)} \tag{45}$$

where a_1, a_2, b_3 and b_4 are given in Appendix B.6. We use these expressions to compute the numerical examples below.

4.3. When Regulators Can Control Mismatch Directly

Next, we consider the scenario where central banks have all three regulatory instruments at their disposal: reserves, capital requirements, and regulation of the dollar funding mix. In other words, we now allow both local central banks, as well as the global planner, to select their preferred values of all of $R_\$$, $B_\$$ and B_h, as opposed to optimizing solely over $R_\$$ and B_h. Here we have the following result, which is proven in Appendix B.5.

Proposition 3: When regulators can directly control dollar mismatch $B_\$$, the outcome is the same under a global planner as under decentralized regulation by individual central banks.

The intuition for this proposition also follows directly from equation (42), and the observation that a wedge between a local planner and a global planner in choosing an optimal level of reserves only arises to the extent that the level of reserves indirectly influences dollar mismatch via its effect on the dollar interest rate—i.e., to the extent that $\phi \equiv \frac{dB_\$}{dR_\$} > 0$. If, by contrast, regulators can set $B_\$$ directly, this effectively makes $\phi = \frac{dB_\$}{dR_\$} = 0$, thereby eliminating the wedge between a local planner and the global planner. In Appendix B.5, we formally demonstrate that in this case, all the first-order conditions characterizing the decisions of individual central banks are identical to those characterizing the decisions of the global planner.

Again, we stress that we do not believe that the case where regulators can control $B_\$$ directly is an accurate description of reality. As a practical matter, it would require an ability to dictate the capital-structure choices of those non-financial firms that engage in mismatched dollar borrowing, something that seems beyond the reach of traditional bank-centric regulatory tools. But this case highlights a key piece of economics, namely that the externality in reserve accumulation that we have been focused on only arises in the presence of imperfect regulation, and as such, relies on a second-best kind of logic. This general insight—that, when regulatory tools are imperfect, policymakers have to consider the indirect impact of interest rates on various financial-stability considerations—applies in other settings as well, including monetary policy and purely domestic bank liquidity regulation (Kashyap and Stein 2023; Greenwood, Hanson and Stein 2015).

Numerical Example (continued): Set the parameter values as follows: $I = 100$; $\beta = 0.9$; $\theta_d = 0.045$; $p = 0.25$; $z = 0.75$; $q = 0.1$; $h = 0.07$; $\gamma = 0.06$; and $\psi = 0.053$. Unlike in the partial-equilibrium case, $Q_\$$ is no longer exogenous. Rather, we have to specify three further parameters that now serve to pin it down. To do so, we set: $\theta_{\$1} = 0.11666$; $\theta_{\$2} = 0.0009$; and $X_\$ = 60$. These values are chosen so that, in the case where local central banks choose reserve holdings and capital requirements, $Q_\$$ endogenously turns out to be about 0.97, consistent with the value in the partial-equilibrium version of the example in Table 3.

Table 4: Numerical Example

	No Regulation or Reserve Holdings	Local Planners Set Reserves and Capital	Global Planner Sets Reserves and Capital	Planner Also Sets Funding Mix
$Q_\$$	0.961	0.970	0.967	0.986
S	0.017	0.027	0.024	0.043
$B_\$$	51.744	67.737	63.140	37.084
B_h	53.196	26.538	17.923	45.243
K	0	10.242	24.422	22.996
$R_\$$	0	25.888	18.447	12.536

Table 4 summarizes this example, showing how all the endogenous variables are affected as we consider different policy regimes. Column 1 displays the outcomes for a completely unregulated economy, in which there are no reserve holdings or capital requirements. Column 2 examines the case where policies are set by local central banks, which control both reserve holdings and capital requirements. (Note that column 2 of Table 4 is identical, up to rounding error, to column 2 of Table 3 from the partial-equilibrium case.) Column 3 asks what happens when instead the global planner chooses reserve holdings. And finally, column 4 shows the outcome when a regulator—either local or global—can control reserves, capital, and the funding mix.

One policy-relevant comparison in the table is between columns 2 and 3 of Table 4, which contrasts local central-bank determination of reserves and capital requirements with the globally coordinated solution. One can see that in the latter case, reserve holdings decline markedly, from 25.89 to 18.45. At the same time, the capital requirement becomes much stricter, with K rising from 10.24 to 24.42. This comparison highlights our central point: when regulation is imperfect, so that dollar borrowing cannot be directly controlled, a global planner prefers tougher capital regulation and less reserve accumulation than does a local central bank.[31] And as a result of the reduced reserve holdings, the interest rate spread S is lower—i.e. the dollar interest rate is higher—in the global-planner regime. One important consequence of this drop in S is that even though regulation cannot control banks' dollar borrowing $B_\$$ directly, dollar borrowing is nevertheless meaningfully reduced, from 67.74 to 63.14, in the global-planner case. This is because the incentive for banks to borrow in dollars declines when the dollar interest rate goes up.

Column 4 of Table 4 makes the point that when regulators can in fact control dollar borrowing $B_\$$ directly, they make aggressive use of this authority, knocking it down to 37.08. Having done so, they are content to operate with lower levels of both reserves and capital as compared to the case in column 3. Also noteworthy is that with less dollar borrowing, the dollar interest rate is now significantly lower, as can be seen in the elevated value of S in column 4.

Table 5 presents a detailed welfare decomposition, showing how each component of aggregate social welfare varies across the policy regimes. The values are normalized so that total welfare in the case without regulation or reserve holdings is equal to 100.

Table 5: Welfare Decomposition

	No Regulation or Reserve Holdings	Local Planners Set Reserves and Capital	Global Planner Sets Reserves and Capital	Planner Also Sets Funding Mix
Total Welfare	100	114.707	115.433	119.548
U.S. Welfare	42.057	48.188	46.426	58.907
Small-Country Welfare	57.943	66.519	69.007	60.641
Bank Profits	63.736	68.104	58.110	59.769
HH Utility	64.472	53.560	56.593	36.910
Reserves Carry	0	-20.791	-14.274	-12.307
Deadweight Tax	-62.324	-20.743	-19.595	-19.651
Liquidity Cost	-7.942	-13.610	-11.826	-4.079

[31] Interestingly, in our model, once the global planner has set reserve holdings, the choice of the capital requirement can be decentralized back to the local central banks. Of course, in a richer setting, there are reasons why international coordination in setting capital requirements may have additional value. See, e.g., Clayton and Schaab (2022).

Comparing columns 2 and 3 of the table, we can see how moving from the local to globally coordinated regime affects different stakeholders. A first observation is that although total welfare goes up, and the small countries benefit as a whole, the higher interest rates associated with the global planner's solution actually harm U.S. borrowers. There are also winners and losers within the small countries: bank profits decline significantly, but this is more than offset by the cumulative impact of an increase in household utility from holding dollar deposits, as well as by reductions in the carrying cost of reserves, the deadweight costs of taxation and the liquidity costs associated with bank mismatch.

By contrast, in the less realistic case where regulators can also control dollar mismatch directly, the sharp decline in dollar borrowing $B_{\$}$, and the associated reduction in the dollar interest rate benefits the U.S., and raises overall global welfare, but now the small countries are collectively worse off. This is mostly because their households have access to less in the way of safe dollar assets to invest in, which reduces their utility. Interestingly, according to Proposition 3, the adverse outcome for small countries in column 4 of Table 5 occurs regardless of whether regulation is set in this case by a global planner, or by local planners acting independently. In the latter case, the comparison between column 4 and column 2 tells us that, paradoxically, the small countries as a whole are made worse off when they have stronger regulatory tools—i.e. when they can control both dollar borrowing and bank capital, as opposed to just bank capital. This is because no individual small country internalizes the fact that when they clamp down on dollar borrowing, this reduces the aggregate supply of safe dollar claims available to their households.

5. Further Implications: Global Risk Sharing

In the previous section, we assumed that banking crises were perfectly correlated across countries. This assumption helps to cleanly isolate the externalities in reserve accumulation that are our primary interest. However, one can also ask how things change if crises are imperfectly correlated, so that there is scope for global risk-sharing in reserve holdings. Crucially, however, such risk-sharing is only possible if countries can agree to a mechanism that allows them to re-distribute reserves ex post to those who are experiencing a crisis. For example, a supra-national institution might hold reserves of its own, and then allocate them to countries on an as-needed basis—much like a bank that offers credit lines to its clients, thereby reducing the need for them to hold their own individual buffer stocks of securities. This approach, which amounts to a form of insurance, raises a set of challenging moral hazard and monitoring issues that do not arise when simply capping the reserve holdings of individual central banks. Will countries now take the proper ex ante precautions to avert crises? What conditions would need to be imposed on the availability of the credit lines, both ex ante and ex post, to minimize these concerns?

For the moment, we set aside these important considerations, and just assume that there is a frictionless mechanism to implement the ex-post allocation of reserves. To see the forces at play in the simplest possible way, we revert back to the more tractable case where $h = 0$, so that there is no correlation between exchange rates and banking crises. We also set the spreads S and S_K to be fixed constants, which is tantamount to saying that the demand for dollar safe assets is linear, i.e. that $\theta_{\$2} = 0$. However, we now assume that, instead of there being a probability q that all countries experience a banking crisis simultaneously at time 1, it is a certainty that a fractional mass q of countries will experience a crisis; this is equivalent to thinking of crises as completely independent and uncorrelated occurrences in our continuum of countries.

With dollar interest rates exogenously fixed, we can ignore U.S. welfare, which is constant. Thus for the case of $h = 0$, the global planner's objective function is the same as in equation (13), which we reproduce here for convenience:

$$W_G = B_\$(Q_\$ - \beta) + B_h(Q_h - \beta) + (f(D_\$) - D_\$ f'(D_\$)) - \beta \left\{ \frac{(1-pq)\gamma B_\$^2}{2I} + S_K R_\$ + \Omega_c(\tau) \right\} \quad (46)$$

where the deadweight costs of taxation $\Omega_c(\tau)$ (with the subscript "c" denoting the correlated-crises case) could be written as:

$$\Omega_c(\tau) = \frac{\psi q}{2} [(pB_h + (1+z)pB_\$ - zR_\$)^2 + (pB_h + (1-z)pB_\$ + zR_\$)^2] \quad (47)$$

By contrast, when banking crises are uncorrelated, the only modification to the global planner's objective function is in this cost-of-taxation term, which we denote by $\Omega_u(\tau)$ and which now takes the form:

$$\Omega_u(\tau) = \frac{\psi q}{2}[\left(pB_h + (1+z)pB_\$ - \frac{z}{q}R_\$\right)^2 + \left(pB_h + (1-z)pB_\$ + \frac{z}{q}R_\$\right)^2] \quad (48)$$

The only change from (47) to (48) is that the terms involving $R_\$$ are multiplied by $\frac{z}{q}$, rather than by z. This reflects the fact that an individual country in crisis now has access to a $\frac{1}{q}$ share of the pool of reserves, rather than just a pro-rata share. Or said differently, with uncorrelated crises, a dollar of reserves held by the supra-national institution goes further than a dollar of reserves held at the individual-country level, because it can be reallocated to those countries who need it.

With $h = 0$ and S_K fixed, we have already solved for the optimal level of reserve holdings in the correlated-crises case; it is given by equation (9), reproduced below:

$$R_{\$c}^{***} = pB_\$ - \frac{S_K}{2qz^2\psi} \quad (49)$$

If we recompute the first-order condition for optimal reserves using the new expression in (48) for the deadweight costs of taxation in the uncorrelated-crises case, we get:

$$R_{\$u}^{***} = pqB_\$ - \frac{qS_K}{2z^2\psi} \quad (50)$$

Comparing equations (49) and (50), we can see that there are two competing effects. On the one hand, the first term in (50) is reduced by a factor of q relative to that in (49). This cuts in the direction of reserves being lower in the uncorrelated-crises case. The intuition is that it only takes reserves of $pqB_\$$, as opposed to $pB_\$$, to cover all possible needs, on account of the risk-sharing effect. On the other hand, the second term in (50) is also reduced relative to its counterpart in (49), this time by a factor of q^2. This cuts in the other direction. The idea here is that when one spends an amount S_K to add a unit of reserves, it now buys more effective coverage than before, since the reserves can be deployed more efficiently.

Putting it together, it is apparent that for relatively small values of S_K, the first effect will dominate, and the ability of countries to share risk will lead to a lower equilibrium value of reserve holdings when crises are uncorrelated. However, it is possible for this conclusion to be reversed if

S_K is sufficiently high. To see why, set S_K high enough so that reserves $R_{\$c}^{***}$ are exactly equal to zero in the correlated-crises case, i.e., so that $pB_\$ = \frac{S_K}{2qz^2\psi}$. From (47), we can see that reserves in the uncorrelated-crises case $R_{\$u}^{***}$ will still be positive and given by $R_{\$u}^{***} = pqB_\$(1-q)$.

To the extent that the small-S_K configuration is the more relevant one, this analysis further underscores the message of the paper, namely that there may be considerable efficiencies to be obtained from international coordination in the management of dollar reserves. We now have seen two distinct mechanisms which can push in this direction: the first being the internalization of the impact of reserve accumulation on the overall scarcity of dollar assets, and the second being a risk-sharing motive that arises when banking crises are imperfectly correlated across countries.

As noted above, taking full advantage of the latter risk-sharing benefit is likely to entail significant institutional challenges. It is worth noting that the IMF offers precautionary credit facilities to member countries—including the Flexible Credit Line (FCL) and the Precautionary and Liquidity Line (PLL)—that are in the spirit of what we have in mind here. To minimize moral hazard issues the IMF has strict eligibility requirements for a country to access these facilities that include sound policy frameworks and economic fundamentals.[32] For varying reasons not all countries that are eligible avail of the precautionary facilities. Those that have tend to hold a smaller level of their own reserves, excluding what they can access through the IMF facility. At end-2022 FCL/PLL users on average held 21.5 percent of GDP in reserves, while East Asian countries that rely mainly on self-insurance held 26.3 percent of GDP in reserves.

Interestingly, the IMF's managing director, Kristalina Georgieva, has recently called for a strengthening of the IMF's role at the center of the global financial safety net. In Georgieva (2023), she writes: "In a world with more frequent and severe shocks, countries have to find ways to cushion the adverse impacts on their economies and people. That will require building economic buffers in good times that can then be deployed in bad times. One such buffer is a country's international reserves—that is, the foreign currency holdings of its central bank…. No country should rely on its reserves alone, of course…. countries are better off if they can complement their own reserves with access to various international insurance mechanisms that are collectively

[32] Descriptions of these facilities can be found at: https://www.imf.org/en/About/Factsheets/Sheets/2023/Flexible-Credit-Line-FCL; and https://www.imf.org/en/About/Factsheets/Sheets/2023/Precautionary-Liquidity-Line-PLL.

known as ‘the global financial safety net.’ At the center of the net is the IMF, which pools the resources of its membership and acts as a cooperative global lender of last resort…Although self-insurance through international reserves has sharply increased for some countries, pooled resources centered on the IMF have increased far less than self-insurance and have shrunk markedly relative to measures of global financial integration. That is why the international community must strengthen the global financial safety net, including by expanding the availability of pooled resources in the IMF.”

6. Conclusions

Central banks around the world hold large volumes of dollar-denominated reserves. Our empirical work suggests that one important motive for these reserve holdings is a concern on the part of central banks with currency mismatch in the composition of private-sector liabilities in their countries, with many firms financing themselves heavily with relatively cheap dollar borrowing. Ironically, however, when the mismatch problem cannot be directly controlled by a surgical form of financial regulation, the collective reserve-accumulation decisions of individual price-taking central banks can exacerbate the problem, because they drive down dollar interest rates and thereby further increase the incentive for the private sector to over-borrow in dollars.

Given this externality, we have shown that a global regulator would prefer to see individual central banks holding fewer dollar reserves, and instead using their existing regulatory tools—such as bank capital requirements—more aggressively in an effort to shore up financial stability. However, unlike with capital regulation, where the importance of international cooperation in standard-setting is well-understood, and is enshrined in the Basel process, the potential benefits of coordinating reserve-holding behavior across countries are less fully appreciated. This paper can be thought of as an initial attempt to highlight these benefits, and perhaps to contribute to a conversation over what such a coordination process might look like.

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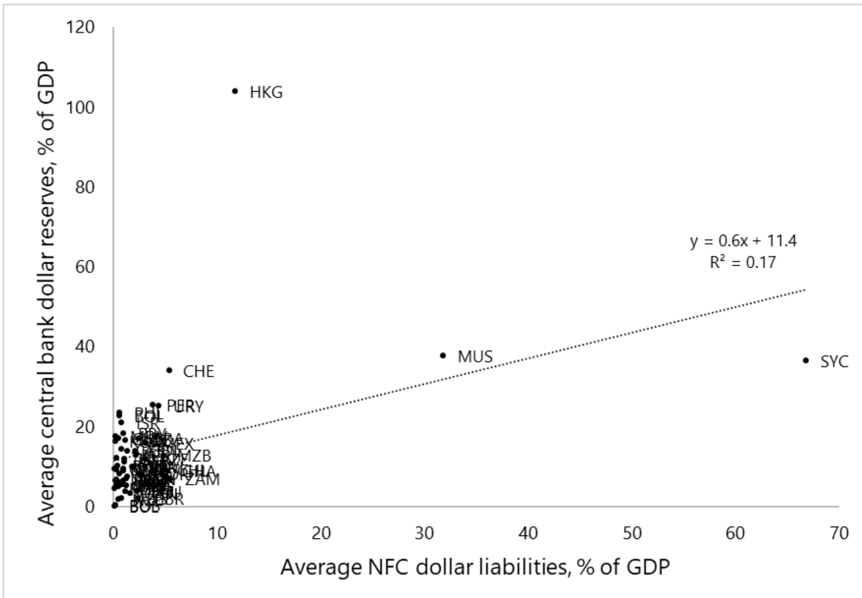
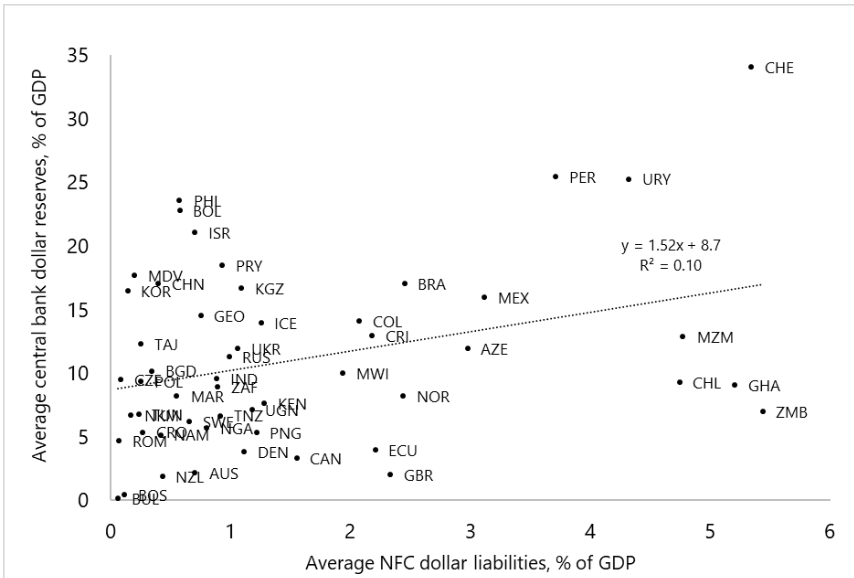
Figure 1
Nonfinancial company dollar loans and central bank dollar reserves: country averages (2013-20, 56 countries)



The horizontal axis shows average NFC dollar loans from cross-border banks, scaled by GDP. The vertical axis shows central bank dollar reserves, also scaled by GDP. Average loans and average reserves are calculated over different years across different countries, but the same years within a country (ranging from 1-8 years).

Sources: BIS, Data.imf.org, State Administration of Foreign Exchange, IMF (2020), Chinn et al. (2021), Arslanalp et al. (2022).

Figure 2
Nonfinancial company dollar loans and central bank dollar reserves: country averages excluding outliers (2013-20, 53 countries)

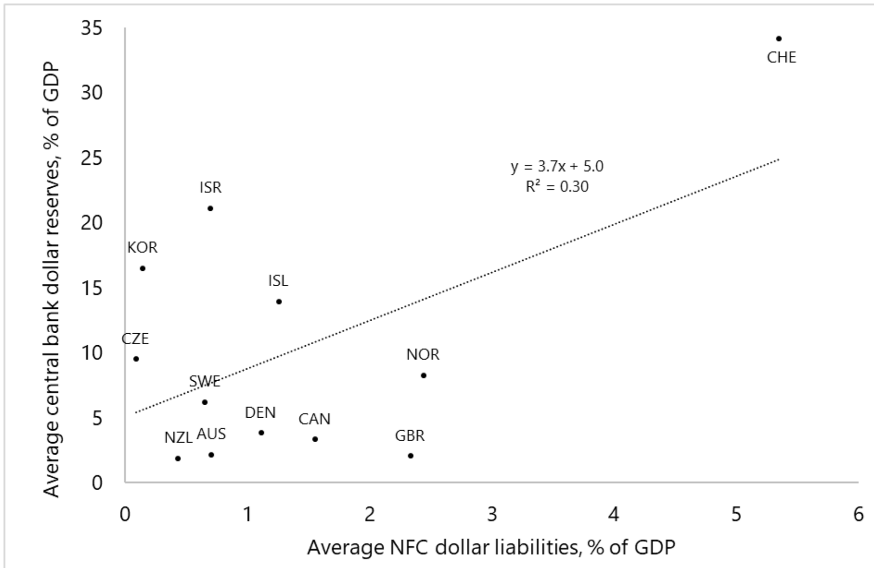


The horizontal axis shows average NFC dollar loans from cross-border banks, scaled by GDP. The vertical axis shows central bank dollar reserves, also scaled by GDP. Average loans and average reserves are calculated over different years across different countries, but the same years within a country (ranging from 1-8 years). Relative to Figure 1, this figure drops Hong Kong SAR (HKG), Mauritius (MUS) and Seychelles (SYC).

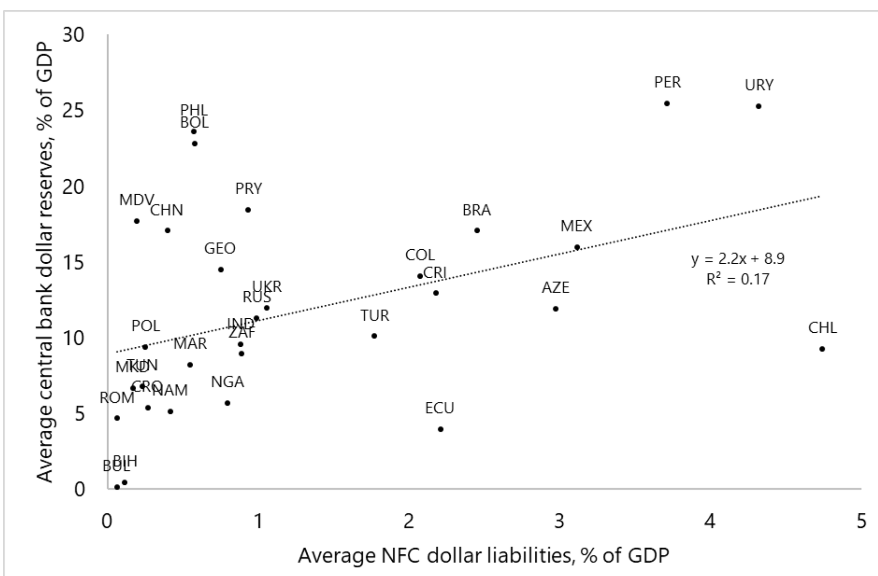
Sources: : BIS, Data.imf.org, State Administration of Foreign Exchange, IMF (2020), Chinn et al. (2021), Arslanalp et al. (2022).

Figure 3
Nonfinancial company dollar loans and central bank dollar reserves: disaggregation across advanced, emerging and developing countries

Advanced economies



Emerging markets



Developing economies

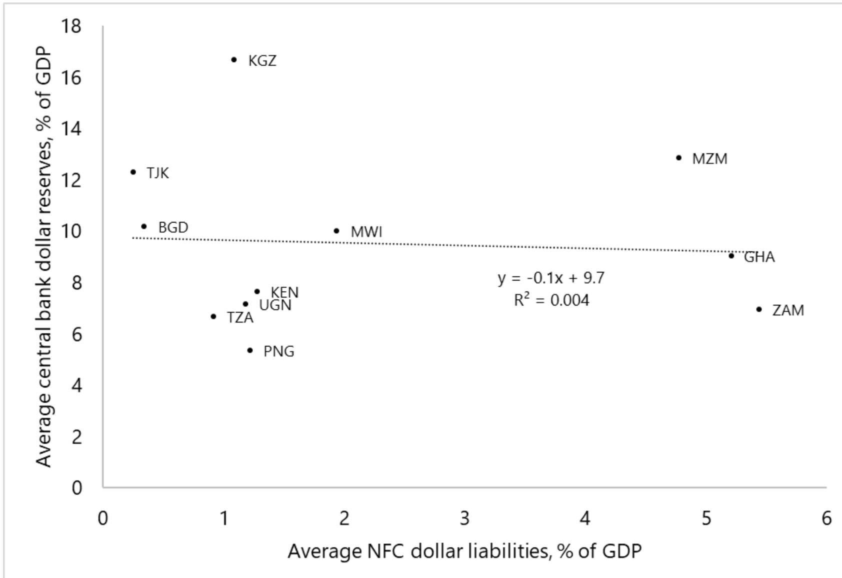
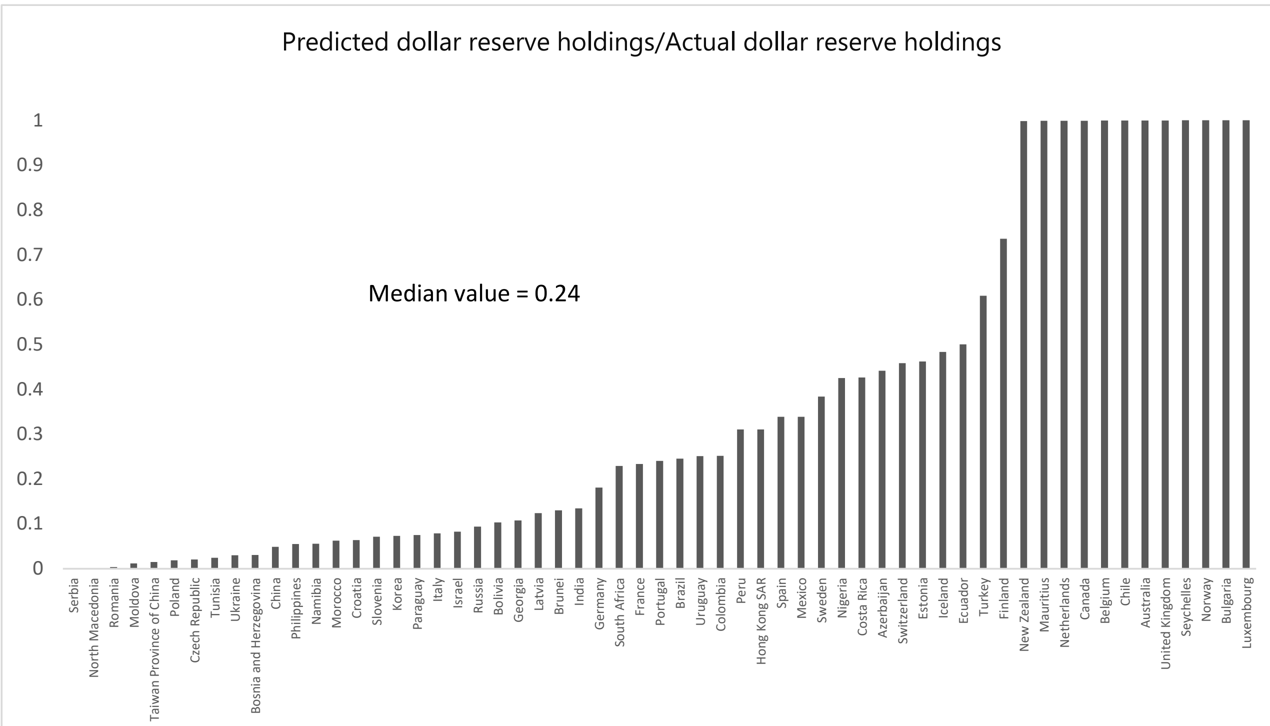


Figure 3 shows the same data as in Figure 2, disaggregated into advanced, emerging and developing economies. The identities of the countries in each group are given in Appendix Table A2.

Sources: : BIS, Data.imf.org, State Administration of Foreign Exchange, IMF (2020), Chinn et al. (2021), Arslanalp et al. (2022).

Figure 4
Central bank dollar reserve holdings:
attribution to proposed mechanism

A. **Countries with known dollar reserve shares**



B. **Countries with unknown dollar reserve shares**

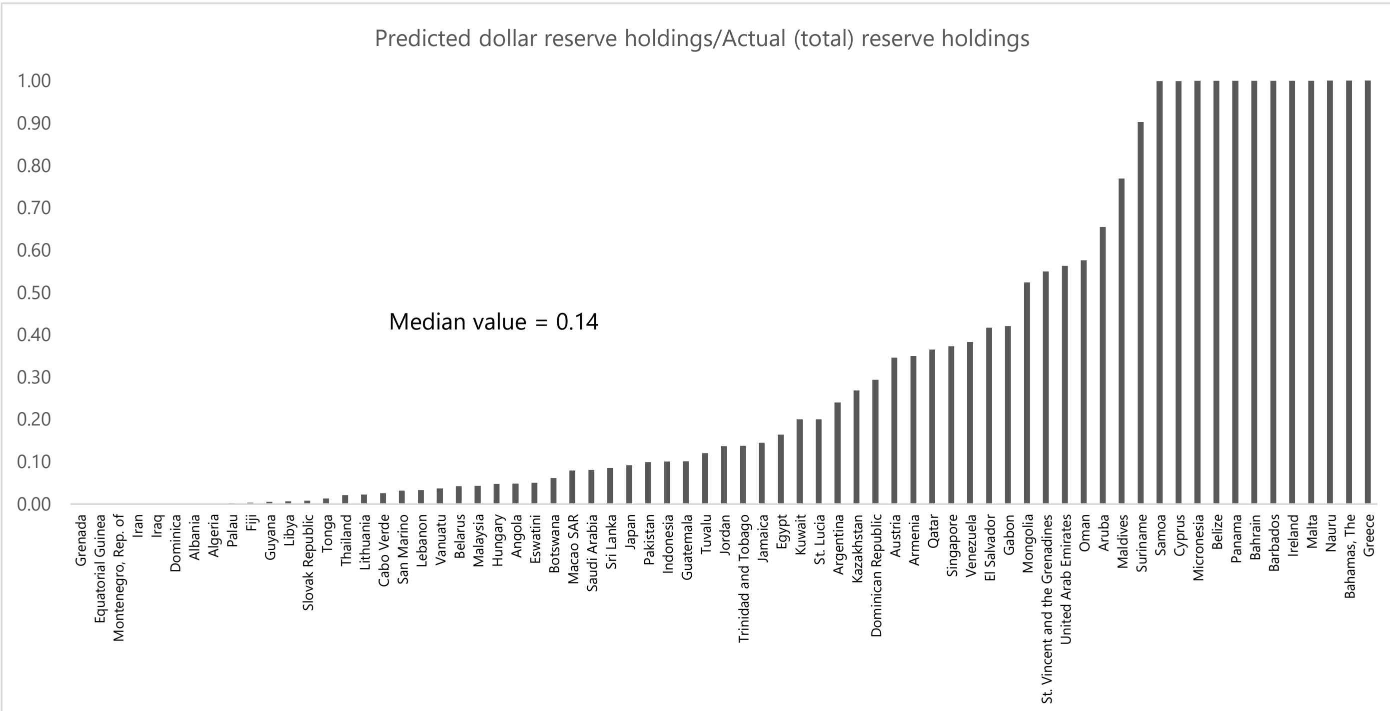


Table 1
Summary statistics: Central bank dollar reserves and nonfinancial company dollar loans, % of GDP

		N	Countries	Mean	Median	Std Dev	Min	Max
Foreign reserves denominated in USD	Total	392	53	11.1	9.3	7.8	0	49.2
	AE	96	12	10.2	6.5	9.9	0	49.2
	EM	208	30	12.1	11.3	7.6	0.003	36.9
	DE	88	11	9.5	8.3	4.8	1.5	29.5
NFC dollar liabilties	Total	392	53	1.5	0.9	1.7	0	8.6
	AE	96	12	1.4	0.9	1.5	0.06	6.8
	EM	208	30	1.3	0.7	1.4	0	6.4
	DE	88	11	2.1	1.3	2.3	0	8.6

Notes. Summary statistics are provided for all country-years for which data on central bank reserve currency composition and NFC dollar liabilities to cross-border banks are available, with the exception of Hong Kong SAR, Mauritius, and Seychelles which are dropped due to significant outliers (see Figure 1) and 12 euro area countries (see text). We also drop 3 countries from the Chinn et al. database where dollar reserve shares in any year were reported to be either greater than 100% or less than 0%.

Sources: Data.imf.org, BIS, State Administration of Foreign Exchange (SAFE), IMF (2020), Chinn et al. (2021), Arslanalp et al. (2022).

Table 2

Regressions of central bank dollar reserves vs. nonfinancial company dollar loans

Dependent variable: central bank dollar reserves as % of GDP

	No fixed effects				No fixed effects				Fixed effects			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	All	AE	EM	DE	All	AE	EM	DE	All	AE	EM	DE
NFC dollar liabilities	1.447*	3.688*	2.114**	0.184	1.484*	3.428*	1.737*	0.171	1.129**	3.541**	0.598	0.787***
	(0.767)	(1.817)	(1.012)	(0.323)	(0.804)	(1.729)	(0.859)	(0.182)	(0.459)	(1.445)	(0.426)	(0.235)
M2					0.0178	0.238***	-0.0391	0.163*				
					(0.0357)	(0.0528)	(0.0418)	(0.0829)				
Financial openness					-1.307	17.26	5.854	-3.270*				
					(3.253)	(11.86)	(4.005)	(1.580)				
Bilateral trade w/US					0.0832	0.0911	-0.0160	-0.570				
					(0.203)	(0.152)	(0.140)	(0.982)				
GDP per capita					-0.0212	-0.457	-0.455***	-0.178				
					(0.0788)	(0.291)	(0.161)	(0.625)				
Ln Population					-0.325	-8.024***	1.223	-1.283*				
					(0.547)	(2.426)	(0.767)	(0.579)				
Nominal dollar ER									2.824***	14.79**	3.535***	1.295
									(0.728)	(5.961)	(0.332)	(0.839)
Observations	392	96	208	88	382	92	208	82	391	96	207	88
# of Countries	53	12	30	11	53	12	30	11	52	12	29	11
Adj r-sq	0.101	0.318	0.158	0.008	0.110	0.599	0.328	0.225	0.853	0.942	0.856	0.500

Notes. NFC dollar liabilities are dollar liabilities to cross-border banks. AE, EM, and DE are as per the IMF classification (Appendix Table A2). Standard errors are clustered by country. Central bank dollar reserves, NFC dollar liabilities, bilateral trade with the US, and M2 are in % of GDP. Nominal dollar ER is the nominal exchange rate vis-à-vis the U.S dollar as defined in Appendix Table A1. Columns (9)-(12) drop Mexico for which we have only one year's data. *** p<0.01, ** p<0.05, * p<0.1.

Appendix Table A1
Data sources

Variable	Source	Notes
NFC cross-border USD liabilities to banks, loans and deposits	BIS, Locational Banking Statistics Table A6.1	Loans and Deposits liabilities in USD only
NFC local USD liabilities to banks, loans and deposits	BIS, Restricted Locational Banking Statistics; central banks and authorities; IMF	Loans and Deposits liabilities in USD only
Foreign reserves	Data.imf.org, IMF country teams	International reserves, billons of USD
Nominal GDP	Data.imf.org	In billions of USD
Currency composition of reserves	IMF (2020), Chinn et al (2021), Arslanalp et al. (2022), State Administration of Foreign Exchange (China)	Share of reserves denominated in USD, EUR, JPY, GBP.
M2	Data.imf.org ,Data.worldbank.org, Haver for EMU	In millions of USD
Bilateral trade with the U.S.	Data.imf.org	Sum of exports and imports; in billions of USD
Financial Openness (index)	Chinn and Ito (2006), updated	Last available observation (2019) is maintained until 2020
Population	Data.worldbank.org	In billions
PPP GDP per capita	Data.worldbank.org	In 1000s (constant 2017 international dollars)
Nominal dollar ER	International Financial Statistics	In 1000s of nominal local currency per U.S. dollar, end of period exchange rate

Appendix Table A2
Countries in advanced, emerging and developing sub-samples

ISO country code	Full Sample	Advanced	Emerging	Developing
AUS	Australia	Australia	Azerbaijan	Bangladesh
AZE	Azerbaijan	Canada	Bolivia	Ghana
BGD	Bangladesh	Czech Republic	Bosnia and Herzegovina	Kenya
BOL	Bolivia	Denmark	Brazil	Kyrgyz Republic
BIH	Bosnia and Herzegovina	Hong Kong SAR	Bulgaria	Malawi
BRA	Brazil	Iceland	Chile	Mozambique
BGR	Bulgaria	Israel	China	Papua New Guinea
CAN	Canada	Korea	Colombia	Tajikistan
CHL	Chile	New Zealand	Costa Rica	Tanzania
CHN	China	Norway	Croatia	Uganda
COL	Colombia	Sweden	Ecuador	Zambia
CRI	Costa Rica	Switzerland	Georgia	
HRV	Croatia	United Kingdom	India	
CZE	Czech Republic		Mauritius	
DNK	Denmark		Mexico	
ECU	Ecuador		Moldova	
GEO	Georgia		Morocco	
GHA	Ghana		Namibia	
HKG	Hong Kong SAR		Nigeria	
ISL	Iceland		North Macedonia	
IND	India		Paraguay	
ISR	Israel		Peru	
KEN	Kenya		Philippines	
KOR	Korea		Poland	
KGZ	Kyrgyz Republic		Romania	
MWI	Malawi		Russia	
MUS	Mauritius		Seychelles	
MEX	Mexico		South Africa	
MDA	Moldova		Tunisia	
MAR	Morocco		Turkey	
MOZ	Mozambique		Ukraine	
NAM	Namibia		Uruguay	
NZL	New Zealand			
NGA	Nigeria			
MKD	North Macedonia			
NOR	Norway			
PNG	Papua New Guinea			
PRY	Paraguay			
PER	Peru			
PHL	Philippines			
POL	Poland			
ROU	Romania			
RUS	Russia			
SYC	Seychelles			
ZAF	South Africa			
SWE	Sweden			
CHE	Switzerland			
TJK	Tajikistan			
TZA	Tanzania			
TUN	Tunisia			
TUR	Turkey			
UGA	Uganda			
UKR	Ukraine			
GBR	United Kingdom			
URY	Uruguay			
ZMB	Zambia			

Appendix Table A3
Central bank dollar reserves attributed to the proposed mechanism

Year	Country	NFC dollar liabilities/ GDP	Predicted dollar reserves/ GDP	Dollar share of reserves	International Reserves/GDP	Min(Pred. dollar reserves/GDP, Actual dollar reserves/GDP)	Nominal GDP, billion USD	Predicted dollar reserves, billion USD
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
				Sample with known dollar shares				
2020	Australia	0.52	1.79	0.55	2.82	1.56	1359	21.20
2020	Azerbaijan	3.52	6.11	0.93	14.92	6.11	43	2.60
2020	Belgium	1.62	5.56	0.83	5.53	4.57	515	23.50
2020	Bolivia	0.55	0.96	0.65	14.30	0.96	37	0.35
2020	Bosnia and Herzegovina	0.00	0.00	0.00	39.94	0.00	20	0.00
2020	Brazil	3.05	5.30	0.89	24.28	5.30	1434	76.00
2020	Brunei	2.54	4.41	1.00	32.22	4.41	12	0.53
2020	Bulgaria	0.10	0.17	0.00	50.08	0.09	69	0.06
2020	Canada	1.85	6.33	0.59	5.18	3.07	1644	50.50
2020	Chile	6.42	11.15	0.50	13.84	6.88	253	17.40
2018	China	0.38	0.66	0.57	23.71	0.66	13800	90.70
2020	Colombia	2.50	4.34	0.85	20.30	4.34	272	11.80
2020	Costa Rica	2.70	4.69	0.90	12.16	4.69	62	2.89
2020	Croatia	0.18	0.31	0.13	37.77	0.31	56	0.17
2020	Czech Republic	0.08	0.27	0.21	62.92	0.27	244	0.65
2020	Denmark	0.90	3.08	0.00	20.03	0.00	355	0.00
2020	Ecuador	2.10	3.65	1.00	7.29	3.65	97	3.53
2020	Estonia	0.43	1.47	0.54	5.94	1.47	31	0.46
2020	Finland	0.72	2.46	0.81	4.14	2.46	271	6.68
2020	France	0.51	1.74	0.94	7.90	1.74	2628	45.70
2020	Georgia	1.09	1.90	0.69	25.74	1.90	16	0.30
2020	Germany	0.31	1.05	0.90	6.44	1.05	3808	39.90
2020	Hong Kong SAR	10.35	35.47	0.80	142.51	35.47	347	123.00
2020	Iceland	2.13	7.29	0.54	27.88	7.29	22	1.58
2017	India	0.72	1.25	0.58	16.18	1.25	2651	33.30
2020	Israel	0.63	2.14	0.66	39.71	2.14	403	8.64
2020	Italy	0.15	0.52	0.64	10.35	0.52	1885	9.84
2020	Korea	0.37	1.25	0.68	25.00	1.25	1638	20.50
2020	Latvia	0.37	1.27	0.71	14.32	1.27	33	0.42
2020	Luxembourg	57.92	198.54	0.81	1.42	1.15	73	0.84
2020	Mauritius	28.83	50.08	0.78	64.21	50.08	11	5.71
2020	Mexico	3.11	5.41	0.97	16.49	5.41	1074	58.10
2020	Moldova	0.15	0.26	0.65	32.61	0.26	11	0.03
2020	Morocco	0.31	0.54	0.31	27.82	0.54	115	0.61
2020	Namibia	0.09	0.16	0.15	18.30	0.16	11	0.02
2020	Netherlands	5.77	19.78	0.64	5.53	3.51	912	32.00
2020	New Zealand	0.42	1.46	0.20	5.69	1.12	209	2.35
2015	Nigeria	1.21	2.10	0.84	5.84	2.10	492	10.30
2020	North Macedonia	0.00	0.00	0.08	33.03	0.00	12	0.00
2020	Norway	3.61	12.38	0.48	18.55	8.95	362	32.40
2020	Paraguay	1.04	1.81	0.84	28.87	1.81	36	0.65
2020	Peru	4.82	8.37	0.72	37.64	8.37	204	17.10
2020	Philippines	0.85	1.48	0.91	29.47	1.48	361	5.34
2020	Poland	0.14	0.24	0.51	24.80	0.24	596	1.41
2020	Portugal	0.51	1.74	0.64	11.25	1.74	231	4.02
2020	Romania	0.01	0.02	0.38	19.41	0.02	249	0.06
2020	Russia	0.62	1.07	0.28	40.88	1.07	1479	15.80
2020	Serbia	0.00	0.00	0.30	26.72	0.00	53	0.00
2020	Seychelles	74.43	129.29	0.95	48.22	45.86	1	0.52
2020	Slovenia	0.05	0.17	1.00	2.28	0.17	53	0.09
2020	South Africa	1.35	2.35	0.70	14.65	2.35	302	7.10
2020	Spain	0.33	1.14	0.69	4.87	1.14	1280	14.60
2020	Sweden	0.69	2.36	0.65	9.53	2.36	538	12.70

2020	Switzerland	6.57	22.54	0.36	137.13	22.54	749	169.00
2018	Taiwan Province of China	0.27	0.91	0.80	78.31	0.91	609	5.56
2020	Tunisia	0.13	0.22	0.44	20.60	0.22	40	0.09
2018	Turkey	2.08	3.61	0.46	13.02	3.61	780	28.20
2020	Ukraine	0.28	0.49	0.83	19.51	0.49	152	0.74
2020	United Kingdom	2.53	8.67	0.51	6.01	3.06	2710	82.90
2020	Uruguay	4.39	7.63	1.00	30.45	7.63	56	4.25

Sample with unknown dollar shares

Year	Country	NFC dollar liabilities/ GDP	Predicted dollar reserves/ GDP	Dollar share of reserves	International Reserves/GDP	Min(Pred. dollar reserves/GDP, Actual reserves/GDP)	Nominal GDP, billion USD	Predicted dollar reserves, billion USD
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2020	Albania	0.01	0.03		29.60	0.03	15	0.00
2020	Algeria	0.02	0.04		38.26	0.04	146	0.06
2020	Angola	0.82	1.43		29.55	1.43	59	0.83
2020	Argentina	1.69	2.93		12.18	2.93	383	11.20
2020	Armenia	4.46	7.75		22.11	7.75	12	0.96
2020	Aruba	18.19	31.59		48.22	31.59	2	0.78
2020	Austria	0.66	2.26		6.52	2.26	431	9.72
2020	Bahamas, The	38.69	67.21		24.42	24.42	11	2.75
2020	Bahrain	13.11	22.77		6.49	6.49	34	2.20
2020	Barbados	19.17	33.31		27.83	27.83	4	1.23
2020	Belarus	0.31	0.55		12.86	0.55	60	0.33
2020	Belize	60.15	104.47		17.00	17.00	2	0.29
2020	Botswana	1.11	1.93		31.18	1.93	16	0.31
2020	Cabo Verde	0.51	0.89		34.06	0.89	2	0.02
2020	Cyprus	33.95	116.37		4.29	4.29	24	1.02
2020	Dominica	0.01	0.02		32.83	0.02	1	0.00
2020	Dominican Republic	2.37	4.12		14.05	4.12	79	3.26
2020	Egypt	0.92	1.60		9.77	1.60	362	5.81
2020	El Salvador	2.97	5.17		12.37	5.17	25	1.27
2020	Equatorial Guinea	0.00	0.00		0.57	0.00	10	0.00
2020	Eswatini	0.36	0.63		12.42	0.63	4	0.02
2020	Fiji	0.05	0.09		22.82	0.09	4	0.00
2020	Gabon	1.95	3.39		8.05	3.39	16	0.53
2020	Greece	5.57	19.08		5.90	5.90	189	11.20
2020	Grenada	0.00	0.00		23.11	0.00	1	0.00
2020	Guatemala	1.40	2.43		24.00	2.43	78	1.89
2020	Guyana	0.04	0.07		12.44	0.07	5	0.00
2020	Hungary	0.70	1.21		25.17	1.21	155	1.87
2020	Indonesia	0.72	1.24		12.36	1.24	1060	13.20
2020	Iran	0.00	0.00		7.69	0.00	835	0.00
2020	Iraq	0.00	0.01		36.53	0.01	172	0.01
2020	Ireland	12.10	41.48		1.60	1.60	418	6.69
2020	Jamaica	2.46	4.27		29.40	4.27	14	0.60
2020	Japan	0.72	2.45		26.72	2.45	5044	124.00
2020	Jordan	3.06	5.32		38.76	5.32	43	2.31
2020	Kazakhstan	3.29	5.71		21.22	5.71	171	9.77
2020	Kuwait	5.13	8.92		44.50	8.92	108	9.63
2020	Lebanon	2.49	4.33		129.43	4.33	19	0.83
2020	Libya	0.58	1.01		145.50	1.01	22	0.22
2020	Lithuania	0.05	0.18		7.92	0.18	56	0.10
2020	Macao SAR	2.30	7.90		99.20	7.90	24	1.92
2020	Malaysia	0.76	1.32		30.45	1.32	339	4.47
2020	Maldives	11.67	20.28		26.34	20.28	4	0.76
2020	Malta	25.25	86.56		5.30	5.30	14	0.77
2020	Micronesia	7.61	13.21		0.58	0.58	0.4	0.00

2020	Mongolia	10.39	18.04	34.44	18.04	13	2.37
2020	Montenegro, Rep. of	0.00	0.00	28.04	0.00	5	0.00
2020	Nauru	59.43	103.22	39.30	39.30	0.1	0.05
2020	Oman	14.60	25.37	43.92	25.37	63	16.00
2020	Pakistan	0.35	0.61	6.15	0.61	262	1.60
2018	Palau	0.01	0.02	10.16	0.02	0.3	0.00
2020	Panama	24.57	42.67	17.39	17.39	53	9.21
2020	Qatar	5.97	10.38	28.35	10.38	147	15.20
2020	Samoa	285.06	495.15	25.40	25.40	1	0.20
2020	San Marino	0.44	1.50	47.10	1.50	2	0.02
2020	Saudi Arabia	2.88	5.00	61.78	5.00	700	35.00
2020	Singapore	10.84	37.16	99.30	37.16	340	126.00
2020	Slovak Republic	0.02	0.07	8.16	0.07	104	0.07
2020	Sri Lanka	0.33	0.58	6.74	0.58	81	0.47
2020	St. Lucia	1.73	3.01	15.02	3.01	2	0.05
2020	St. Vincent and the Grenadines	7.43	12.91	23.49	12.91	1	0.10
2020	Suriname	13.61	23.63	26.19	23.63	2	0.57
2020	Thailand	0.62	1.07	49.51	1.07	502	5.36
2014	Tonga	0.28	0.48	35.62	0.48	0.4	0.00
2020	Trinidad and Tobago	2.64	4.59	33.33	4.59	22	0.99
2015	Tuvalu	9.03	15.69	129.92	15.69	0.04	0.01
2020	United Arab Emirates	9.87	17.15	30.47	17.15	354	60.80
2020	Vanuatu	1.36	2.36	62.98	2.36	1	0.02
2020	Venezuela	3.21	5.58	14.57	5.58	47	2.64

Notes. See Appendix C for details about the calculations in this table. Cols (3), (4), (6) and (7) are in percent, e.g., X represents X percent of GDP. Dollar shares are rounded such that, for example, 0.00 or 1.00 do not necessarily equal exactly zero or exactly one.

Appendix B: Proofs
(For Online Publication Only)

B.1. Derivation of equations (32), (33) and (34)

Take the case of the local central bank, which takes the dollar spread S as given, allowing banking and currency crises to be correlated. The local planner's objective function is given by equation (23) in the text, dropping the term corresponding to household utility from dollar assets, $\left(f(D_\$) - D_\$ f'(D_\$)\right)$:

$$W_L = B_\$(Q_\$ - \beta) + B_h(Q_h - \beta) - \beta\left\{\frac{(1-p(q+h))\gamma B_\$^2}{2I} + S_K R_\$ + \Omega(\tau)\right\}$$

where the deadweight cost of taxation is:

$$\Omega(\tau) = \frac{\psi}{2}\left((q+h)(pB_h + (1+z)pB_\$ - zR_\$)^2 + (q-h)(pB_h + (1-z)pB_\$ + zR_\$)^2\right)$$

We are interested in the case where the planner chooses the level of dollar reserves ($R_\$$) and capital requirements (B_h). In this case, $B_\$ = \frac{I((1-qp)S+hpz)}{(1-p(q+h))\gamma}$ is set by the unregulated bank. Take the first-order condition of W_L with respect to B_h and we recover:

$$(Q_h - \beta) - \beta\frac{d\Omega(\tau)}{dB_h} = 0$$

where $\frac{dB_\$}{dB_h} = 0$ and $\frac{dR_\$}{dB_h} = 0$. Plugging in for $\frac{d\Omega(\tau)}{dB_h}$ and solving for B_h^{**} :

$$(Q_h - \beta) - \beta\psi p[(q+h)(pB_h + (1+z)pB_\$ - zR_\$) + (q-h)(pB_h + (1-z)pB_\$ + zR_\$)] = 0$$

$$(Q_h - \beta) - \beta\psi p[2qpB_h + 2(qp + zhp)B_\$ - 2hzR_\$] = 0$$

$$B_h^{**} = \frac{(Q_h-\beta)}{2\beta\psi qp^2} - \left(1 + \frac{zh}{q}\right)B_\$ + \frac{zh}{pq}R_\$$$

Next, we take the first-order condition of W_L with respect to $R_\$$. Note that in the case of the local planner, they do not internalize the effect of $R_\$$ on the dollar spreads S and S_K.

$$-\beta\frac{d(S_K R_\$)}{dR_\$} - \beta\frac{d\Omega(\tau)}{dR_\$} = 0$$

Using that $S_K R_\$ = \left(\frac{Q_\$}{\beta} - 1\right)R_\$$, this is equal to:

$$-(Q_\$ - \beta) - \beta\frac{\Omega(\tau)}{dR_\$} = 0 \tag{B1.1}$$

Plug in for $\frac{d\Omega(\tau)}{dR_\$}$ and re-express the first term using the spread S_K:

$$-S_K - z\psi[-(q+h)(pB_h + (1+z)pB_\$ - zR_\$) + (q-h)(pB_h + (1-z)pB_\$ + zR_\$)] = 0$$

$$[-2hpB_h - 2p(qz+h)B_\$ + 2qzR_\$] = -\frac{S_K}{\psi z}$$

$$R_\$^{**} = \frac{hp}{qz}[B_h + B_\$] + pB_\$ - \frac{S_K}{2\psi q z^2}.$$

We can rewrite $R_\$^{**}$ as

$$R_\$^{**} = \frac{2\beta\psi zhp(B_\$ + B_h) + 2\beta\psi q z^2 pB_\$ - \beta S_K}{2\beta\psi q z^2}$$

Now, we can write the first order conditions for the small open economy as:

$$B_\$^{*} = \frac{I((1-qp)S + hpz)}{(1-p(q+h))\gamma} \equiv a_1 S + a_2$$

$$B_h^{**} = \frac{(Q_h - \beta)}{2\beta\psi q p^2} - \left(1 + \frac{zh}{q}\right)B_\$ + \frac{zh}{pq}R_\$$$

$$R_\$^{**} = \frac{hp}{qz}[B_h + B_\$] + pB_\$ - \frac{S_K}{2\psi q z^2}$$

Note that $B_\$$ is a linear function of S where $a_1 \equiv \frac{I(1-qp)}{\gamma(1-p(q+h))}$ and $a_2 \equiv \frac{hpzI}{\gamma(1-p(q+h))}$. Using the expression for B_h^{**}, we can write the term $\frac{h}{qz}\left(B_h^{**} + B_\$^{**}\right) + B_\$^{**}$, which appears in the simplified version of $R_\$^{**}$, as:

$$\frac{h}{qz}\left(B_h^{**} + B_\$^{**}\right) + B_\$^{**} = \frac{h(Q_h - \beta)}{2\beta\psi q^2 p^2 z} - \frac{h^2}{q^2}B_\$ + \frac{h^2}{pq^2}R_\$ + B_\$.$$

Plug this and $S_K = \left(1 + \frac{\theta_d}{\beta}\right) S + \frac{\theta_d}{\beta}$ into the expression for $R_\$^{**}$,

$$R_\$^{**} = p\left(\frac{hp}{qz}\left[B_h^{**} + B_\$^{**}\right] + B_\$^{**}\right) - \frac{S_K}{2\psi q z^2}$$

$$R_\$^{**} = p\left(\frac{h(Q_h - \beta)}{2\beta\psi q^2 p^2 z} - \frac{h^2}{q^2} B_\$ + \frac{h^2}{pq^2} R_\$ + B_\$\right) - \frac{S\,(\beta + \theta_d)}{2\beta\psi q z^2} - \frac{\theta_d}{2\beta\psi q z^2}$$

$$\left(1 - \frac{h^2}{q^2}\right) R_\$^{**} = p\left(\frac{h(Q_h - \beta)}{2\beta\psi q^2 p^2 z} + \left(1 - \frac{h^2}{q^2}\right) B_\$\right) - \frac{S\,(\beta + \theta_d)}{2\beta\psi q z^2} - \frac{\theta_d}{2\beta\psi q z^2}$$

$$R_\$^{**} = pB_\$ + \frac{h(Q_h - \beta)}{2\beta\psi p z (q^2 - h^2)} - \frac{\theta_d q}{2\beta\psi z^2 (q^2 - h^2)} - \frac{Sq(\beta + \theta_d)}{2\beta\psi z^2 (q^2 - h^2)}$$

Plug in for $B_\$^{**}$ to solve explicitly for the optimal level of dollar reserves as a function of the dollar spread, S:

$$R_\$^{**} = p\,\frac{I\big((1 - qp)S + hpz\big)}{\big(1 - p(q + h)\big)\gamma} + \frac{h(Q_h - \beta)}{2\beta\psi p z (q^2 - h^2)} - \frac{\theta_d q}{2\beta\psi z^2 (q^2 - h^2)} - \frac{Sq(\beta + \theta_d)}{2\beta\psi z^2 (q^2 - h^2)}$$

$$R_\$^{**} \equiv b_1 S + b_2$$

where:

$$b_1 = \frac{I(1 - qp)p}{\gamma\big(1 - p(q + h)\big)} - \frac{q(\beta + \theta_d)}{2\beta\psi z^2 (q^2 - h^2)},\ b_2 = \frac{hp^2 z I}{\gamma\big(1 - p(q + h)\big)} + \frac{h(Q_h - \beta)}{2\beta\psi p z (q^2 - h^2)} - \frac{\theta_d q}{2\beta\psi z^2 (q^2 - h^2)}.$$

We want to solve for the equilibrium dollar spread. Note that:

$$B_\$^{**} - R_\$^{**} = a_1 S + a_2 - (\,b_1 S + b_2)$$

$$B_\$^{**} - R_\$^{**} = (a_1 - b_1)S + (a_2 - b_2)$$

To solve for the equilibrium spread in the local planner case, we use the equilibrium spread condition given by equation (28). Since we assume a unit mass of identical local planners, we plug in for the local planner's optimal decision (found above) and solve for the equilibrium spread. We have from equation (28):

$$S = \frac{\theta_{\$1} - \theta_{\$2}\left(B_\$ + X_\$ - R_\$\right)}{\beta + \theta_d} = \frac{\theta_{\$1} - \theta_{\$2}\left(X_\$ + (a_1 - b_1)S + (a_2 - b_2)\right)}{\beta + \theta_d}$$

Hence, we can pin down the explicit equilibrium solution as follows:

$$S = \frac{\theta_{\$1} - \theta_{\$2}\left(X_\$ + a_2 - b_2\right)}{\beta + \theta_d + \theta_{\$2}(a_1 - b_1)}$$

$$B_\$^{**} = \frac{I((1-qp)S + hpz)}{\left(1 - p(q+h)\right)\gamma}$$

$$R_\$^{**} = pB_\$ + \frac{h(Q_h - \beta)}{2\beta\psi pz(q^2 - h^2)} - \frac{Sq}{2\psi z^2(q^2 - h^2)}$$

$$B_h^{**} = \frac{(Q_h - \beta)}{2\beta\psi qp^2} - \left(1 + \frac{zh}{q}\right)B_\$ + \frac{zh}{pq}R_\$.$$

B.2. Derivation of equation (42)

In this section, we solve for the system of equations that implicitly define the equilibrium solution for the global planner problem when the planner chooses the amount of dollar reserves, $R_\$$, and capital requirements, B_h, allowing for correlated banking and currency crises. This is the global planner equivalent of Appendix B.1. The explicit solution to this system of equations in terms of primitive parameters is derived in Appendix B.6. In this case, $B_\$$ is chosen by the banking sector and given by:

$$B_\$^{*} = \frac{I((1-qp)S + hpz)}{\left(1 - p(q+h)\right)\gamma}.$$

Note that the equilibrium dollar spread will solve:

$$S = \frac{\theta_{\$1} - \theta_{\$2}\left(X_\$ + B_\$ - R_\$\right)}{\beta + \theta_d}$$

where $B_\$$ is that given above and $R_\$$ will come from the optimization problem of the global planner. The welfare function for the global planner is given by equation (35) in the text:

$$W_G = D_\$(Q_\$ - \beta) + B_h(Q_h - \beta) + \left(f(D_\$) - f'(D_\$)\right)$$
$$-\beta\left(\left(1 - p(q+h)\right)\gamma B_\$^2/2I + \Omega(\tau)\right)$$

Consider first the first-order condition with respect to B_h. We can see from the welfare function above that the first-order condition for B_h will take the same form as that for the local planner in Appendix B.1. Hence, we have:

$$B_h^{***} = \frac{(Q_h - \beta)}{2\beta\psi q p^2} - \left(1 + \frac{zh}{q}\right) B_\$ + \frac{zh}{pq} R_\$.$$

Next, we need to determine the equilibrium dollar reserve policy for the global planner. In the global planner case, we must now take into account that the global planner internalizes the impact $R_\$$ has on the dollar spread, S. The global planner's first-order condition with respect to $R_\$$ is given by:

$$\frac{dW_G}{dR_\$} = \frac{d}{dR_\$}\left((B_\$ + X_\$ - R_\$)(Q_\$ - \beta)\right) - \beta \frac{d}{dR_\$}\left(\frac{\left(1 - p(q+h)\right)\gamma B_\$^2}{2I}\right) +$$
$$\frac{d}{dR_\$}\left(f(D_\$) - f'(D_\$)\right) - \beta \frac{d}{dR_\$}\Omega(\tau) = 0.$$

Note that $B_\$$ is a linear function of *S* where $a_1 \equiv \frac{I(1-qp)}{\gamma\left(1-p(q+h)\right)}$ and $a_2 \equiv \frac{hpzI}{\gamma\left(1-p(q+h)\right)}$. Moving forward, using *that* $S = \frac{Q_\$}{Q_h} - 1$ and $Q_\$ = \beta + \theta_d + \theta_{\$1} - \theta_{\$2} D_\$$ we have:

$$B_\$ = \frac{I\left((1-qp)\left(\frac{\left(\beta + \theta_d + \theta_{\$1} - \theta_{\$2}\left(B_\$ + X_\$ - R_\$\right)\right)}{Q_h} - 1\right) + hpz\right)}{\left(1-p(q+h)\right)\gamma}$$

which leads to:

$$\frac{dB_\$}{dR_\$} = \frac{I(1-qp)\theta_{\$2}}{\left(\left(1-p(q+h)\right)\gamma Q_h + I(1-qp)\theta_{\$2}\right)} \equiv \phi$$

$$\frac{dD_\$}{dR_\$} = \frac{dB_\$}{dR_\$} - 1 = \phi - 1$$

$$\frac{dQ_\$}{dR_\$} = \theta_{\$2}(1 - \phi)$$

Using these expressions and equation (28) in the text for $f(D_\$)$, we have that the derivatives of each term in W_G with respect to $R_\$$ are below (and given by equations (37)-(40) in the text):

$$\frac{d}{dR_\$}\big((B_\$ + X_\$ - R_\$)(Q_\$ - \beta)\big) = (\phi - 1)(Q_\$ - \beta) + (B_\$ + X_\$ - R_\$)\big(\theta_{\$2}(1 - \phi)\big)$$

$$\frac{d}{dR_\$}\left(\frac{\big(1-p(q+h)\big)\gamma B_\$^2}{2I}\right) = \frac{\phi\big(1-p(q+h)\big)\gamma B_\$}{I}$$

$$\frac{d}{dR_\$}\left(f(D_\$) - D_\$ f'(D_\$)\right) = -(1-\phi)\theta_{\$2}(B_\$ + X_\$ - R_\$)$$

$$\frac{d}{dR_\$}\Omega(\tau) = \big(2\psi\phi q p^2 - 2\psi z h p(1 - p\phi)\big)(B_h + B_\$) +$$

$$\big(2\psi\phi z p h - 2\psi q z^2(1 - p\phi)\big)(pB_\$ - R_\$),$$

and where:

$$\phi \equiv \frac{dB_\$}{dR_\$} = \frac{\left(\frac{\theta_{\$2} I(1-qp)}{\gamma}\right)}{\left(\big(1-p(q+h)\big)(\beta+\theta_d) + \frac{\theta_{\$2} I(1-qp)}{\gamma}\right)}$$

Summing up these terms, we have

$$\frac{dW_G}{dR_\$} = -(1-\phi)(Q_\$ - \beta) - \frac{\beta\phi\big(1-p(q+h)\big)\gamma B_\$}{I} - \beta\left(\frac{\partial\Omega}{\partial R_\$} + \phi\frac{\partial\Omega}{\partial B_\$}\right) = 0 \qquad \text{(B2.1)}$$

Arranging the terms, we can write this as

$$\frac{dW_G}{dR_\$} = \underbrace{-(Q_\$ - \beta) - \beta\frac{\partial\Omega}{\partial R_\$}}_{\textit{Local Planner's FOC}} + \underbrace{\phi\left((Q_\$ - \beta) - \frac{\beta\big(1-p(q+h)\big)\gamma B_\$}{I} - \beta\frac{\partial\Omega}{\partial B_\$}\right)}_{\textit{Wedge Between Global and Local Planner}}$$

where, from equation (B1.1) in Appendix B.1., we can see that the first to terms are the same expression as the local planner's first order condition with respect to $R_\$$.

The equations that implicitly express the equilibrium solution to the global planner problem are

$$S^{***} = \frac{\theta_{\$1} - \theta_{\$2}\left(X_\$ + B_\$^* - R_\$^{***}\right)}{\beta + \theta_d}$$

$$B_\$^* = \frac{I((1-qp)S^{***} + hpz)}{\left(1 - p(q+h)\right)\gamma}$$

$$B_h^{***} = \frac{(Q_h - \beta)}{2\beta\psi q p^2} - \left(1 + \frac{zh}{q}\right)B_\$^* + \frac{zh}{pq}R_\$^{***}$$

$$-(1-\phi)\left(Q_\$^{***} - \beta\right) - \frac{\beta\phi\left(1 - p(q+h)\right)\gamma B_\$^*}{I} - \beta\left(\frac{\partial \Omega}{\partial R_\$}|_{R_\$^{***}, B_\$^*, B_h^{***}} + \phi\frac{\partial \Omega}{\partial B_\$}|_{R_\$^{***}, B_\$^*, B_h^{***}}\right) = 0$$

where $|_{R_\$^{***}, B_\$^*, B_h^{***}}$ denotes that the term is to be evaluated at the equilibrium values, $R_\$^{***}$, $B_\$^*$, and B_h^{***}.

B.3. Proof of Proposition 1

Proposition 1 follows directly from equation (42).

B.4. Proof of Proposition 3

The global planner's first-order condition with respect to $R_\$$ is again given by:

$$\frac{dW_G}{dR_\$} = \frac{d}{dR_\$}\left((B_\$ + X_\$ - R_\$)(Q_\$ - \beta)\right) - \beta\frac{d}{dR_\$}\left(\left(1 - p(q+h)\right)\gamma B_\$^2/2I\right) + \frac{d}{dR_\$}\left(f(D_\$) - f'(D_\$)\right) - \beta\frac{d}{dR_\$}\Omega(\tau) = 0.$$

Note that:

$$\frac{dD_\$}{dR_\$} = -1, \qquad \frac{dQ_\$}{dR_\$} = \theta_{\$2}$$

We have that the derivatives of each term in W_G with respect to $R_\$$ are:

$$\frac{d}{dR_\$}\left((B_\$ + X_\$ - R_\$)(Q_\$ - \beta)\right) = -(Q_\$ - \beta) + (B_\$ + X_\$ - R_\$)\theta_{\$2}$$

$$\frac{d}{dR_\$}\left(\left(1 - p(q+h)\right)\gamma B_\$^2/2I\right) = 0$$

$$\frac{d}{dR_\$}\left(f(D_\$) - D_\$ f'(D_\$)\right) = -\theta_{\$2}(B_\$ + X_\$ - R_\$)$$

$$\frac{d}{dR_\$}\Omega(\tau) = -2\psi zhp(B_h + B_\$) - 2\psi qz^2(pB_\$ - R_\$)$$

in light of:

$$\Omega(\tau) = \frac{\psi}{2}\left((q+h)(pB_h + (1+z)pB_\$ - zR_\$)^2 + (q-h)(pB_h + (1-z)pB_\$ + zR_\$)^2\right)$$

Arranging the terms, we have

$$-(Q_\$ - \beta) - 2\psi\beta z\left(-hp(B_h + B_\$) - qz(pB_\$ - R_\$)\right) = 0$$

Or,

$$R_\$ = pB_\$ + \frac{hp}{qz}(B_h + B_\$) - \frac{(Q_\$ - \beta)}{2\psi\beta qz^2} \qquad \text{(B4.1)}$$

Turning to the first-order condition with respect to $B_\$$, we have

$$\frac{d}{dB_\$}\left((B_\$ + X_\$ - R_\$)(Q_\$ - \beta)\right) = (Q_\$ - \beta) - (B_\$ + X_\$ - R_\$)\theta_{\$2}$$

$$\frac{d}{dB_\$}\left(\left(1 - p(q+h)\right)\gamma B_\$^2/2I\right) = \left(1 - p(q+h)\right)\gamma B_\$/I$$

$$\frac{d}{dB_\$}\left(f(D_\$) - D_\$ f'(D_\$)\right) = \theta_{\$2}(B_\$ + X_\$ - R_\$)$$

$$\frac{d}{dB_\$}\Omega(\tau) = \psi(q+h)p(1+z)(pB_h + (1+z)pB_\$ - zR_\$)$$
$$+ \psi(q-h)p(1-z)(pB_h + (1-z)pB_\$ + zR_\$)$$

$$= 2\psi(q + hz)p^2(B_h + B_\$) + 2\psi(qz + h)pz(pB_\$ - R_\$)$$

$$= 2\psi(q + hz)p^2\, B_h + 2\psi p^2(q(1 + z^2) + 2hz)B_\$ - 2\psi(qz + h)pzR_\$$$

Arranging the terms, we have

$$(Q_\$ - \beta) - 2\psi\beta(q + hz)p^2\, B_h - [2\psi\beta p^2(q(1 + z^2) + 2hz) +]B_\$ +$$

$$2\psi\beta(qz + h)pzR_\$ = 0 \qquad \text{(B4.2)}$$

The first order condition with respect to B_h is given by

$$(Q_h - \beta) - \beta\frac{d\Omega(\tau)}{dB_h} = 0$$

which can be rearranged into:

$$B_h = \frac{(Q_h-\beta)}{2\beta\psi qp^2} - \left(1 + \frac{zh}{q}\right)B_\$ + \frac{zh}{pq}R_\$ \qquad \text{(B4.3)}$$

Finally, we have

$$Q_\$ = \beta + \theta_d + \theta_{\$1} - \theta_{\$2}(B_\$ + X_\$ - R_\$) \qquad \text{(B4.4)}$$

Equations (B4.1), (B4.2), (B4.3) and (B4.4) constitute a linear system of equations. Turning to the local planner's objective function, we have:

$$W_L = B_\$(Q_\$ - \beta) + B_h(Q_h - \beta) - \frac{\beta\big(1-p(q+h)\big)\gamma}{2I}B_\$^2 - (Q_\$ - \beta)R_\$ - \beta\Omega(\tau)$$

The FOCs for the local planner are:

$$\frac{dW_G}{dB_h} = (Q_h - \beta) - \frac{\beta d\Omega(\tau)}{dB_h} = 0$$

$$\frac{dW_G}{dB_\$} = (Q_\$ - \beta) - \frac{\beta\big(1-p(q+h)\big)\gamma}{I}B_\$ - \frac{\beta d\Omega(\tau)}{dB_\$} = 0 \qquad \text{(B4.5)}$$

$$\frac{dW_G}{dR_\$} = -(Q_\$ - \beta) - \frac{\beta d\Omega(\tau)}{dR_\$} = 0$$

Comparing these FOCs, we can see that they are the same as those of the global planner, where the derivatives of the deadweight cost of taxation are the same across the two planner cases. Thus, in the full regulation case, the local and global planner problems will yield the same solutions.

B.5. Proof of Proposition 2

From equation (B4.5) just above, we have $\frac{dW_G}{dB_\$} = (Q_\$ - \beta) - \frac{\beta(1-p(q+h))\gamma}{I} B_\$ - \frac{\beta d\Omega(\tau)}{dB_\$}$. Proposition 1 states that if, starting from the local planner's optimum, it is the case that $(Q_\$^{**} - \beta) - \frac{\beta(1-p(q+h))\gamma B_\$^*}{I} - \beta \frac{\partial \Omega}{\partial B_\$} < 0$, then $R_\$^{***} < R_\$^{**}$. The condition that is required for $R_\$^{***} < R_\$^{**}$ thus implies that, starting from the local planner's optimum, $\frac{dW_G}{dB_\$} < 0$. This in turn means that starting from this point, if the planner could choose $B_\$$ directly, they would choose to reduce it. This is precisely our definition of mismatch being excessive.

B.6. Derivation of equations (43), (44) and (45)

Unpacking the terms, we can write equation (B2.1) as:

$$\phi(Q_\$ - \beta) - \beta\phi\big(1 - p(q+h)\big)\gamma B_\$/I - (Q_\$ - \beta) -$$

$$\beta\big(2\psi\phi q p^2 - 2\psi z h p(1 - p\phi)\big)(B_h + B_\$) - \beta\big(2\psi\phi z p h - 2\psi q z^2(1 - p\phi)\big)(pB_\$ - R_\$) = 0.$$

Isolate the $R_\$$ terms to get:

$$[-2\beta\psi\phi z p h + 2\beta\psi q z^2(1 - p\phi)]R_\$ = \phi(Q_\$ - \beta) - (Q_\$ - \beta) + (2\beta\psi z h p(1 - p\phi) -$$

$$2\beta\psi\phi q p^2)(B_h + B_\$) - \beta\left(2\psi\phi z p^2 h - 2\psi q z^2(1 - p\phi)p + \frac{\phi(1-p(q+h))\gamma}{I}\right) B_\$$$

Plug in that $B_h^{***} = \frac{(Q_h - \beta)}{2\beta\psi q p^2} - \left(1 + \frac{zh}{q}\right) B_\$ + \frac{zh}{pq} R_\$$:

$[-2\beta\psi\phi zph + 2\beta\psi qz^2(1-p\phi)]R_\$ = \phi(Q_\$ - \beta) - (Q_\$ - \beta) + (2\beta\psi zhp(1-p\phi) -$

$2\beta\psi\phi qp^2)\left(\frac{(Q_h-\beta)}{2\beta\psi qp^2} - \frac{zh}{q}B_\$ + \frac{zh}{pq}R_\$\right) - \beta\left(2\psi\phi zp^2h - 2\psi qz^2(1-p\phi)p + \frac{\phi(1-p(q+h))\gamma}{I}\right)B_\$$

Isolate the $R_\$$ terms and combine the $B_\$$ terms to get:

$\left[-\frac{2\beta\psi z^2h^2(1-p\phi)}{q} + 2\beta\psi\phi pzh - 2\beta\psi\phi zph + 2\beta\psi qz^2(1-p\phi)\right]R_\$ = \phi(Q_\$ - \beta) -$

$(Q_\$ - \beta) + (2\beta\psi zhp(1-p\phi) - 2\beta\psi\phi qp^2)\left(\frac{(Q_h-\beta)}{2\beta\psi qp^2}\right) - \left(\left(\frac{zh}{q}\right)(2\beta\psi zhp(1-p\phi) -\right.$

$\left.2\beta\psi\phi qp^2) + 2\beta\psi\phi zp^2h - 2\beta\psi qz^2(1-p\phi)p + \frac{\beta\phi(1-p(q+h))\gamma}{I}\right)B_\$$

Rearranging and combining terms results in:

$\left[-\frac{2\beta\psi z^2h^2(1-p\phi)}{q} + 2\beta\psi qz^2(1-p\phi)\right]R_\$ = \left(2\beta\psi qz^2(1-p\phi)p - \frac{2\beta\psi z^2h^2p(1-p\phi)}{q} -\right.$

$\left.\frac{\beta\phi(1-p(q+h))\gamma}{I}\right)B_\$ + \phi(Q_\$ - \beta) - \phi(Q_h - \beta) - (Q_\$ - \beta) + \left(\frac{zh(1-p\phi)(Q_h-\beta)}{qp}\right)$ (B.6.1)

Substituting $B_\$ = \frac{I((1-qp)S+hpz)}{(1-p(q+h))\gamma}$ and $Q_\$ = Q_h(S+1)$ into the equation,

$\left(2\beta\psi qz^2 - 2\beta p\psi\phi qz^2 - \frac{2\beta\psi z^2h^2(1-p\phi)}{q}\right)R_\$ =$

$\left(2\beta\psi qz^2p(1-p\phi) - \frac{2\beta\psi z^2h^2p(1-p\phi)}{q} - \frac{\beta\phi(1-p(q+h))\gamma}{I}\right)\frac{I((1-qp)S+hpz)}{(1-p(q+h))\gamma} - (Q_\$ - \beta) +$

$\phi Q_hS + \left(\frac{zh(1-p\phi)(Q_h-\beta)}{qp}\right)$

Plug in that $(Q_\$ - \beta) = Q_h(S+1) - \beta$ to get:

$\left(\frac{2\beta\psi z^2(1-p\phi)(q^2-h^2)}{q}\right)R_\$ =$

$$\left(\frac{2\beta\psi z^2 p(1-p\phi)(q^2-h^2)}{q} - \frac{\beta\phi(1-p(q+h))\gamma}{I}\right)\frac{I((1-qp)S+hpz)}{(1-p(q+h))\gamma} + (\beta - Q_h) + (\phi-1)Q_h S +$$

$$+\left(\frac{zh(1-p\phi)(Q_h-\beta)}{qp}\right)$$

We can explicitly solve for $R_\$$ and express it as a linear function of S:

$$R_\$ = b_3 S + b_4$$

where:

$$b_3 \equiv \frac{q(\phi-1)Q_h + \left(2\beta\psi z^2 p(1-p\phi)(q^2-h^2) - \frac{\beta q\phi(1-p(q+h))\gamma}{I}\right)\frac{I(1-qp)}{(1-p(q+h))\gamma}}{2\beta\psi z^2(1-p\phi)(q^2-h^2)}$$

$$b_4 \equiv \frac{q(-Q_h+\beta) + \frac{zh(1-p\phi)(Q_h-\beta)}{p} + \left(2\beta\psi z^2 p(1-p\phi)(q^2-h^2) - \frac{\beta q\phi(1-p(q+h))\gamma}{I}\right)\frac{hpzI}{(1-p(q+h))\gamma}}{2\beta\psi z^2(1-p\phi)(q^2-h^2)}.$$

Finally, recall that:

$$S = \frac{\theta_{\$1} - \theta_{\$2}(X_\$ + a_1 S + a_2 - b_3 S - b_4)}{\beta + \theta_d}$$

The explicit solution in the global planner case is therefore described by the following equations:

$$S = \frac{\theta_{\$1} - \theta_{\$2}(X_\$ + a_2 - b_4)}{\beta + \theta_d + \theta_{\$2}(a_1 - b_3)}$$

$$B_\$^* = \frac{I((1-qp)S+hpz)}{(1-p(q+h))\gamma}$$

$$R_\$^{***} = b_3 S + b_4$$

$$B_h^{***} = \frac{(Q_h-\beta)}{2\beta\psi qp^2} - \left(1+\frac{zh}{q}\right)B_\$^{**} + \frac{zh}{pq}R_\$^{***}$$

Appendix C: Details of Numerical Exercise
(For Online Publication Only)

Preliminary comments about our data sources:

- We use all known sources of dollar reserve shares to construct the sample for our analysis. Consistent with the papers referenced in Goldberg and Hannaoui (2024), they are: IMF (2020), Chinn, Ito and Macauley (2021), Arslanalp, Eichengreen and Simpson-Green (2023), and S.A.F.E (for China).
- This yields a sample of 71 countries for which we have an unbalanced time series of dollar reserve shares between 2013 and 2020.[33] When estimating the regressions, we drop 12 euro area countries (see text), 3 countries that are outliers (Hong Kong SAR, Mauritius and Seychelles; (see Figure 1) and 3 countries for which the financial openness Chinn-Ito index is unavailable in any year (Brunei, Serbia, Taiwan POC). The resulting regression sample has 53 countries of which 12 are advanced, 30 are emerging, and 11 are developing economies.
- For the attribution calculations, we divided the data into two samples: those for which we have dollar reserve shares ("*dollar shares known*" sample) and those for which we don't ("*dollar shares unknown"* sample).
- For the *dollar shares known* sample: we start with the regression sample, then drop the 11 developing economies, but include the 12 euro area countries which were dropped from the regression,[34] as well as the 6 countries dropped either because they were outliers (Hong Kong SAR, Mauritius and Seychelles) or because they were missing financial openness data (Brunei, Serbia, and Taiwan POC). This results in a sample of 60 countries.
- For the *dollar shares unknown* sample, we begin with all the advanced and emerging economies (excluding those in the *dollar shares known* sample) for which the BIS reports cross-border dollar liabilities. We then drop the Marshall Islands which, with 2020 cross-border dollar liabilities reported at more than 10000% of GDP is a significant outlier, and Turkmenistan, which does not disclose its international reserves. This results in a sample of 69 countries.

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[33] These 71 countries do not include 3 nations (Kazakhstan, Pakistan, and Sri Lanka) for which reported dollar reserve shares are negative in some years. We exclude these countries for all years due to unreliability of the data.

[34] They are Belgium, Estonia, France, Germany, Italy, Latvia, Luxembourg, Netherlands, Finland, Portugal, Slovenia and Spain. Croatia, which is now in the euro area, was not in the euro area prior to 2023, and is included in our EM sample.

Attribution calculations:

- Appendix Table A3 reports all the inputs used in calculating the attribution of dollar reserve holdings to our proposed mechanism. The 60 advanced economies and emerging markets in the *dollar shares known* sample are listed first, and the 69 advanced and emerging markets in the *dollar shares unknown* sample are listed below them.
- Our calculations are done using the latest data available, which is dictated by the dollar reserves share variable for the *dollar shares known* sample. That year is 2020 for all countries except Nigeria (2015), India (2017), and China, Turkey, and Taiwan POC (all 2018). Data for the other variables in Appendix Table A3 (cross-border dollar liabilities in percent of GDP, nominal GDP, and international reserves in percent of GDP) are drawn from the same year that the latest dollar reserve shares are available. For the *dollar shares unknown* sample, data for all variables and all countries are from 2020, with the exception of Tonga (2014), Tuvalu (2015) and Palau (2018).
- We first describe the calculations for the *dollar shares known* sample.
- The first step is calculating the predicted value of dollar reserves in % of GDP by multiplying the country's cross-border dollar liabilities in percent of GDP (reported in Column 3) with its estimated coefficient from Table 2.[35] These coefficient estimates are: 3.428 for advanced economies (Table 2, Column 6) and 1.737 for emerging markets (Table 2, Column 7). The predicted values are reported in Column 4.
- Next, we compare the predicted values to actual dollar reserve holdings in % of GDP. The actual dollar reserves holdings are the product of dollar reserve shares (Column 5) and total international reserves in % of GDP (Column 6). We then select the minimum of the predicted dollar reserves in % of GDP and the actual dollar reserves in % of GDP, reporting that minimum in Column 7.
- To calculate the predicted dollar reserves in levels*,* we use the product of the minimum (Column 7) and nominal GDP (Column 8), reporting the predicted dollar reserves in levels (USD) in Column 9. The sum of the numbers in Column 9 for the first 60 countries (Australia through Uruguay) is $1.10 trillion.

[35] Note that we refer to "predicted values" although strictly speaking, as a product of the covariate and its estimated coefficient only (without the addition of the estimated intercept), it is perhaps more accurately the "marginal predicted value".

- We next describe the calculations for the *dollar shares unknown* sample: this pertains to the 61st through 129th countries in Table A3 (Albania through Venezuela).
- The predicted value of dollar reserves in % of GDP is calculated exactly as for the *dollar shares known* sample: as the product of cross-border dollar liabilities (Column 3) with either 3.428 (for advanced economies) or 1.737 (for emerging markets).
- As we do not have dollar shares for this subsample, we next compare the predicted values (reported in Column 4) with actual *total* international reserves in % of GDP (Column 6) and report the minimum of the two values in Column 7.
- We then calculate the predicted dollar reserves in levels for the *dollar shares unknown* sample as the product of the minimum (Column 7) and nominal GDP (Column 8), reporting that value in Column 9. The sum of the numbers in Column 9 for the 61st through 129th country (Albania through Venezuela) is $509 billion.