Countries have accumulated massive foreign reserve portfolios, but the reasons for doing so remain debated. I document a new empirical fact on the compositions of foreign reserve portfolios, and argue that the prevalence of the dollar supports an explanation in which foreign reserves hedge liquidity shocks to dollarized financial systems. First, I fit a Bayesian dynamic linear model to extract currency shares for the foreign reserves of seventy-seven developed and emerging countries, and show that foreign reserves are poorly-diversified and overwhelmingly consist of dollar assets. Second, I show that the dollar shares of foreign reserves are explained by the dollarization of their financial systems' liabilities across countries, particularly for countries that cannot easily borrow dollars from the Federal Reserve directly. Third, I build a model in which central banks build up dollar reserves to mitigate liquidity shocks for financial systems with currency mismatches, particularly in the presence of foreign exchange transaction costs.
1 Introduction

The foreign reserve portfolios of central banks vary greatly in size and in composition. For instance, Hong Kong’s reserves exceed its GDP while Australian reserves are twenty times smaller than its GDP, and Peruvian reserves are overwhelmingly dollars while Romanian reserves are biased towards euros. The literature has posited both theoretical and empirical explanations to understand why countries hold foreign reserves, and papers have relied on the one piece of available information — the sizes of foreign reserves — to test theories. This paper generates a second piece of information — their compositions by currency — to explain foreign reserves.

In this paper, I estimate the currency composition of countries’ foreign reserves, and show that the currency shares of countries’ foreign reserves can be explained by the foreign currency shares of their financial systems’ liabilities. First, I estimate currency shares of foreign reserves using a Bayesian dynamic linear model, in which I project changes in the size of a country’s foreign reserves onto the returns of major reserve currencies. The results are novel, and show that dollars are far more prevalent than believed in foreign reserve portfolios. Second, I show that the dollar shares of countries’ portfolios are correlated in the cross-section with the dollar shares of their financial systems’ liabilities, particularly when controlling for swap lines — a form of emergency central bank-to-central bank lending that substitute for official foreign reserves. Third, I explain these findings using a model in which central banks use foreign reserves to hedge liquidity shocks to their financial sectors, which have foreign currency liabilities — particularly in the presence of foreign exchange transactions costs. Separately, the empirical findings also provide suggestive evidence against other explanations for foreign reserves. For instance, they are inconsistent with explanations in which foreign reserves provide fiscal space to governments during recessions, as these dollar-heavy portfolios are too lightly diversified across other reserve assets that appreciate during recessions.

The paper’s main empirical finding is that the dollar shares of foreign reserve portfolios are massive: across the foreign reserves of seventy-seven emerging and developed countries, the average dollar share is 80-85%, and this number is fairly stable over time. The euro represents a small share for most countries; but for a handful of countries (e.g. Romania and Morocco), its share is comparable or larger than that of the dollar. These results are novel to the literature, as few countries report the composition of their foreign reserves publicly, and even fewer do so at any reasonable frequency. The only comprehensive public source of information — the IMF’s currency composition of official foreign exchange reserves (COFER) data — only publishes currency shares aggregated across reporting countries, and
does not even release the names of the countries who report to preserve their confidentiality. As such, the aggregated estimates are both skewed by large countries and are incomplete due to non-reporting countries. For instance, at the start of 2015, the IMF reported that they had recorded the currency composition for 55-60% of all foreign reserves, and 65% of those verified reserves were held in dollars.

The paper’s second finding is that these dollar and euro shares correlate with the dollar and euro shares of external financial liabilities for emerging markets, although not for developed markets. There are two plausible reasons for this divergence. First, developed countries have been historically more willing than emerging countries to seek assistance from the International Monetary Fund, as Bird and Mandilaras [2011] find, and thus do not rely upon foreign reserves to stabilize their financial systems. This weakens the link between the currency shares of foreign reserves and financial liabilities for developed countries. Second and more recently, developed countries have largely benefited from “swap lines” to the Federal Reserve — a form of direct lending between central banks — which provide emergency dollar funding. The ECB has also established euro swap lines, although these have not been used widely yet. Swap lines generate dollar and euro reserves on demand, and thus substitute for actual dollar and euro reserves during liquidity crises. Indeed, the correlation between the foreign currency shares of reserves and banking liabilities holds when restricting to the countries that historically did not receive dollar or euro swap lines during crises.

To estimate the currency compositions of foreign reserves, I develop a dynamic linear model that projects returns in a country’s aggregate portfolio value onto returns in reserve currencies over time. While the underlying portfolio shares of currencies are confidential, this is feasible because most countries report the values of their total portfolios at monthly frequencies. To illustrate the core insight, suppose a portfolio (with unknown dollar and euro shares) grows by 10% (in dollar terms) over a period in which the euro appreciates by 20% against the dollar. This portfolio must be 50% dollars and 50% euros. In practice, the methodology is more complicated for a few reasons. Portfolio weights may change over time, portfolios may grow or shrink due to inflows and outflows, and the set of potential reserve currencies is potentially large. Thus, the paper augments the dynamic linear model to allow for these complications. Finally, limited public data on currency shares are available for a handful of countries and in the aggregate, and so the paper further augments the dynamic linear model to incorporate this information, and uses Bayesian algorithms to find solutions. The methodology is novel, and can be applied to other cases in which the compositions of liquid portfolios are unavailable.

These two facts — the prevalence of dollar reserves and the correlation between dollar (and euro) shares in foreign reserves and financial liabilities — seem most consistent with
models of financial stability, and I develop one. Specifically, I build a model in which a central bank hedges liquidity shocks for its banks that have borrowed cheaply and excessively in dollars, due to limited liability frictions. The central bank has one of three choices to mitigate liquidity shocks: it can print local currency and exchange it for dollars, it can hold diversified foreign reserves and exchange those for dollars, or it can hold dollars directly. However, the central bank faces foreign exchange costs for the first two strategies, and so it hold dollar reserves \textit{ex ante}.\footnote{Although currency markets are liquid, foreign exchange costs should be conceptualized broadly, e.g. the market panic that may follow large and sudden foreign exchange transactions by a central bank.} This model generates a causal link between dollar shares of foreign reserves and financial liabilities. The model does not formally incorporate swap lines, but these are natural substitutes in practice for foreign reserves as they allow central banks to produce dollars on demand.\footnote{In the baseline model, liquidity shocks are exogenous and banks are financed in dollars. In a refinement of the model, liquidity shocks are endogenous, and banks could be financed in local currency — but crucially by investors whose stochastic discount factors are dollar-based. Even in this setting, foreign reserves are necessary to mitigate liquidity shocks. Since investors care about dollar returns, they may refuse to rollover funding to a solvent and liquid country if they anticipate a currency depreciation. Foreign reserves allow a central bank to stabilize the exchange rate, which stops emergent liquidity shocks. The model’s predictions are still being developed, and so this model is not presented in this version.}

In addition to supporting an explanation grounded in financial stability, the empirical findings on the currency shares can also provide new evidence against competing explanations for the purpose of foreign reserves. The literature has used the sizes of foreign reserves to argue against several possible explanations, by showing that foreign reserves are too large to smooth exchange rate fluctuations arising from current account imbalances, to be byproducts of sterilized exchange rate intervention, or to hedge rollover risk for short-term government debt. But size data cannot easily distinguish an explanation focused on financial stability from an alternate explanation: foreign reserves provide fiscal space to governments during recessions, as discussed by Fernandez-Arias and Montiel \cite{Fernandez-AriasMontiel2009}, or more generally foreign reserves smooth consumption shocks, as discussed by Dominguez \cite{Dominguez2010}. However, my findings on the currency compositions of foreign reserves are more consistent with an explanation based on financial stability than one based on fiscal space. Under the fiscal space explanation, reserve portfolios — which are similar to sovereign wealth funds — should be broadly diversified, with meaningful positions in Swiss francs and yen (currencies that appreciate strongly during global recessions). The overwhelming dominance of dollars in foreign reserve portfolios contradicts this alternate explanation, and supports the financial stability explanation, in which foreign reserves mitigate shocks to dollarized financial systems.\footnote{In addition, the popularity of swap lines is further suggestive evidence in favor of a financial stability explanation. Swap lines are a source of temporary funding that entail no nominal capital gains. Thus, they should only be valuable to mitigate liquidity shocks, and not to increase a country’s budget.}
The paper proceeds as follows. Section 2 reviews the literature on foreign reserves. Section 3 discusses the empirical framework and the data used to estimate the currency shares of foreign reserves. Section 4 documents the results and tests them against financial liabilities data. Section 5 develops a model that links foreign reserves and financial liabilities. Section 6 concludes.

2 Literature Review

This paper contributes to two groups of literature: on the motivations for holding foreign reserves, and on the dollar’s dominance in the international financial system. With respect to the first strand of literature, reserves are strongly associated with lower risks of crises, as Catao and Milesi-Ferretti [2014] find empirically, and policymakers are broadly advised to follow the Greenspan-Guidotti rule-of-thumb, which advises foreign reserves in excess of external short-term debt.

However, the specific reason that countries hold foreign reserves remains contested. Consider the five most popular (partially overlapping) hypotheses: (i) foreign reserves are the byproduct of sterilized exchange rate interventions, (ii) foreign reserves stabilize exchange rates during current account fluctuations, (iii) foreign reserves hedge rollover risk for short-term government debt, (iv) foreign reserves stabilize consumption during recessions, and (v) foreign reserves ensure financial stability. Dominguez [2010] argues against the first explanation by noting that foreign reserve buildups are too large to be accidental. The second and third explanations have generated more serious debates. For instance, Aizenman and Sun [2012] argues against the second explanation, noting that countries were unwilling to spend reserves to stabilize their currencies during the financial crisis. On the other hand, Dominguez [2012] argues for this explanation, arguing that countries did actively manage their currencies during the crisis; and Dominguez [2014] discusses examples from non-Eurozone European countries. The third explanation originates in the literature on “original sin” (a country’s inability to issue local-currency debt), and recent work includes Bianchi et al. [2013], who build and calibrate a model to generate policy recommendations. However, Obstfeld et al. [2010] argue that these two explanations seem largely inconsistent with the sizes of foreign reserve portfolios. They use back-of-the-envelope calculations to argue that these explanations would require foreign reserves worth 0.1-0.5% of GDP weekly, whereas in practice foreign reserves vastly dwarf that estimate, even under extreme assumptions on the length of crises.

The fourth and fifth explanations are more consistent with large foreign reserve portfolios, and have been supported alternately by Fernandez-Arias and Montiel [2009] and Dominguez
[2010] and by Obstfeld et al. [2010] respectively, among others. Other papers include Kim and Ryou [2011], who argue that foreign reserve portfolios largely fail mean-variance efficiency tests, suggesting that they have purposes beyond stores of value. None of these papers utilize portfolio compositions to test hypotheses, however; and that is where my paper can contribute to this literature. Finally, Eichengreen et al. [2017] has floated non-economic reasons that countries hold foreign reserves (e.g. to strengthen geopolitical alliances), but that is beyond the scope of this paper.

Moreover, a set of papers indirectly argues that foreign reserves are useful for financial stability by noting that countries are reluctant to turn to the IMF, and foreign reserves substitute for IMF programs. Bird and Mandilaras [2011] and Fernandez-Arias and Levy-Yeyati [2012] argue that the IMF is unpopular for several reasons: programs take a long time to negotiate and often involve conditionality. Furthermore, Joyce and Razo-Garcia [2011] put forward a model to show why reserves are favored over IMF programs, and note that the programs are often too small in practice. (They were both insufficient for the Mexican and East Asian crises of the 1990s, and despite the recent quota expansions, emerging markets often hold reserves many times larger than their IMF allocations.) Finally, while regional funds have emerged, e.g. the Latin American Reserve Fund, Rosero [2014] note that their advantages over foreign reserves are still unproven.

Separately, this paper contributes to the literature on the dollar’s dominance in the international financial system, by establishing its dominance in most countries’ reserve portfolios. The dollar’s ubiquity has been well-established in other domains, e.g. Gopinath [2015] in trade invoicing and Bruno and Shin [2015] in bank lending. However, there are concerns that foreign reserve portfolios are adjusting away from the dollar. Truman and Wong [2006], Wong [2007], and Wooldridge [2006] discuss the composition of foreign reserves from limited public data, and note cautiously that these fears may be overstated. My results validate this claim more forcefully, showing that the dollar remains as prevalent as ever across a wider set of countries.

3 Empirical Framework

The paper’s core contribution is to estimate the currency composition of foreign reserves for individual countries, as most countries do not report their own breakdown, and the IMF only reports an aggregated and incomplete breakdown to preserve confidentiality. (In fact, the IMF does not release the names of the countries who contribute to the series.) I estimated a modified dynamic linear model using Bayesian algorithms.

The paper uses two main pieces of data: the sizes of reserves holdings at the country
level and reserve currency returns, and projects the former onto the latter. To illustrate the key insight, consider the following toy scenario: a country who passively holds only dollars and euros reports that its foreign reserves have risen (in dollar terms) by 20% over a month. If the euro appreciated against the dollar by 40% during that month, the portfolio must be 50% dollars and 50% euros.

Of course, this insight does not generalize to multiple assets without further structure. For instance, consider a third asset: the Japanese yen. If that appreciates versus the dollar by, say, 20%, the portfolio holdings are indeterminate. More observations alone are insufficient, as countries may change their portfolio weights continuously. However, under some reasonable assumptions about portfolio share stickiness and under some prior beliefs on overall portfolio shares (released either in the aggregate by the IMF, or by a few specific countries), solutions can be found. As such, I augment a dynamic linear model with a Bayesian prior, and use Bayesian methods (Markov Chain Monte Carlo) to find the solution.

In addition, this approach does not account for flows: portfolios can grow or shrink outside of currency fluctuations, if foreign reserves are actively added. If inflows are correlated with currency returns, this can potentially bias the estimated currency shares. Finding a suitable instrument or bias-free sub-sample is difficult, and so I use various structural assumptions to control the bias.

This methodology of uncovering portfolios is novel, although the general insight has been used to estimate confidential baskets to which countries peg their currencies. Specifically, Fidrmuc [2010], Frankel and Wei [2008], and Frankel and Xie [2010] similarly decompose local currency movements into various reserve currencies, to find the de facto peg. However, in these papers, portfolio weights are much stickier, and the methodologies do not worry about incorporating prior data or adjusting for flows.

3.1 Data

All but a handful of central banks do not disclose the composition of their foreign reserves. But the IMF, on behalf of central banks, reports two key pieces of information: the total value of individual central bank reserves on a monthly basis (e.g. Japan holds $1.212 trillion as of August 2014), and the quarterly composition of central bank portfolios in aggregate (e.g. Euros composed 24.7% of known central bank portfolios in 2004, worldwide). The paper relies on these two pieces of information, along with monthly currency returns for large reserve currencies (obtained from the Federal Reserve).

The first piece of data — the total value of individual central bank reserves, on a monthly basis — are collected by the IMF for seventy-five central banks, and by the Federal Reserve
for two more central banks. (Supranational entities like the European Central Bank are omitted.) The seventy-seven countries are broken down by region: twenty-five in Western Europe, fifteen in Eastern Europe, eleven in Middle East and North Africa, twelve in East Asia, and fourteen in the Americas. Coverage naturally gets better over time, with approximately forty countries reporting their total values as early as 2000 and almost all countries reporting by 2010. Each country is analyzed from when they start reporting reserves to the IMF (at the earliest, in 2000) until 2013.

The second piece of data, formally known as the Currency Composition of Official Foreign Exchange Reserves (COFER) database, is particularly tantalizing. In its disaggregated form, it is precisely what this paper seeks. Yet the disaggregated version is inaccessible; the IMF states:

[Composition] data for individual countries are kept strictly confidential given the sensitive nature of the data. Access to individual country data is limited to only four IMF staff on a need-to-know basis.

No modern papers have bypassed this restriction; to my knowledge, the only exception is Eichengreen and Mathieson [2000], which accessed the underlying data two decades ago. Thus, I use the public and aggregated version, which is used to construct prior beliefs about portfolio composition. In addition, a handful of countries report their currency shares publicly, as documented by Wong [2007] and Truman and Wong [2006]. This information is not incorporated in the current paper, but it will be used in a future version.

Finally, I use monthly currency returns, collected by the US Federal Reserve. Seven currencies correspond to approximately 97% of global reserves, and so the set of reserve currencies is defined as: the dollar, the euro, the pound, the yen, the Swiss franc, the Canadian dollar, and the Australian dollar. While the Chinese yuan has been discussed for several years as an emerging reserve currency, this has failed to appear in the data, and so it is not included. The IMF only broke out the yuan in the December 2016 COFER update, and it constituted a mere 1% of portfolio holdings.

Since the IMF data breaks out gold from currencies, I also do not consider gold. Gold may be formally incorporated in a future version, but most countries have small gold reserves (with a few notable examples, e.g. Switzerland).

Finally, foreign reserves are typically invested in riskfree bonds in that currency than just in the currency itself. However, the monthly variation in riskfree returns is minuscule compared to the monthly variation in exchange rates, and Wooldridge [2006] similarly notes that foreign reserve managers are largely concerned about currency rather than interest rate risk. In my specification, constant differences in riskfree rates across countries will be captured by a constant.
3.2 Methodology

This section develops the dynamic linear model for estimating the currency shares. The portfolio size at time $t + 1$ reflects two components: the portfolio size at time $t$ (times the gross return on that portfolio) plus any inflows or outflows:

$$P_{t+1} = P_t(1 + r_{t+1}) + F_{t+1}$$

Therefore, the overall growth rate of the portfolio can be decomposed into the net return and (scaled) inflows and outflows:

$$g_{t+1} = \frac{P_{t+1} - P_t}{P_t} = r_{t+1} + f_{t+1}$$

Finally, I decompose the portfolio net return into the weighted return by currency, where weights can also adjust at every point in time. This formulation — in which coefficients can change over time — is known as a dynamic linear model, and it can be written as:

$$g_{t+1} = \sum_{k=1}^{K} w_k^t r_k^{t+1} + f_{t+1}$$

In addition, I impose the restrictions that weights sum to one and are non-negative, as central banks do not meaningfully short currencies in their foreign reserves portfolios.

$$w_k^t \in [0, 1] \quad \sum_{k=1}^{K} w_k^t = 1$$

There are three small adjustments. First, I estimate Equation (1) in logs. Second, I embed the restriction that weights sum to one by using relative returns rather than absolute returns. Third, I allow weights to adjust at annual rather than the monthly level, to keep the parameter space relatively compact. In the revised formulation, Equation (2), $T(t)$ is defined as a function that converts a given month $t$ into the corresponding year.

$$g_{t+1} - r_{t+1}^K = \sum_{k=1}^{K-1} w_{T(t)}^k (r_k^{t+1} - r_k^K) + f_{t+1}$$

3.2.1 Flows

In Equation (2), the estimation strategy must contend with $f_{t+1}$, which represents active inflows and outflows from the foreign reserves. Flows are likely correlated with currency
movements, and they are almost always unobserved, although Dominguez et al. [2012] notes that the IMF has recently started requesting more nuanced information that may help in estimating these components. Depending on the coverage of the results, this may be incorporated in a future iteration of the estimation strategy.

This classic omitted variables problem leads to misleading portfolio estimates. For instance, consider a defensive central bank that always increases its US dollar holdings when negative economic shocks hit the world. Since the dollar also tends to appreciate during such periods, estimating Equation (2) naively will overestimate the portfolio weight on dollars. Reserves increase precisely when dollars are performing well, and I will give too much credit to existing dollar holdings.

There are two broad classes of solutions: an instrumental variables approach, or a structural approach. The former is virtually impossible: it requires a variable that drives currency returns (e.g. the dollar-euro exchange rate) but does not affect how a central bank actively responds. All the classic macroeconomic drivers of exchange rates (e.g. interest rates, current account imbalances, etc) would not pass the exclusion restriction.

The second solution is more feasible, by using a flexible structural model to model central bank choices. The key assumption is that central banks respond disproportionately to larger moves in currency markets, i.e. small shocks trigger no policy change, whereas large shocks do. This can be embedded through three steps. First, I incorporate a cubic term for the local exchange rate against a basket of SDRs (a mix of dollars, euros, yen, and pounds). This allows large movements in the exchange rate to absorb variation in portfolio returns.

\[
g_{t+1} - r_{t+1}^K = \sum_{k=1}^{K-1} w_{T(t)}^k (r_{t+1}^k - r_{t+1}^K) + \sum_{m=0}^{3} \beta_{T(t)}^m e_t^m
\]

Second, I detrend the portfolio returns using a standard Hodrick-Prescott filter, allowing for slow-changing trends in foreign reserve accumulation. Finally, I weight the residuals inversely to the size of local currency returns, allowing small movements (representing calm and stable times) to drive the model’s estimation.

3.2.2 Weights

The dynamic linear model in Equation (3) requires further structure, particularly on time-varying coefficients \( w_t \) and \( \beta_t \). First, I impose a Markovian assumption on how these coefficients change through time; and second, I parameterize that stochastic process.

First, a dynamic linear model imposes the Markovian assumption that the values of these coefficients at a given point in time are only directly related to the previous and subsequent values. This assumption seems reasonable: conditional on knowing the portfolio share of
dollars in 2004, I can assume that the portfolio shares of dollars in 2003 and 2005 are independent. This allows a simplification of the standard likelihood function into a more tractable representation, where $D_t$ represents data and $\theta$ all other parameters:

$$\mathbb{P}(\{w_j, \beta_j, \theta\}|\{D_t\}) \propto \mathbb{P}(\{D_t\}|\{w_j, \beta_j, \theta\})\mathbb{P}(\{w_j, \beta_j, \theta\})$$

$$\mathbb{P}(\{w_j, \beta_j, \theta\}|\{D_t\}) \propto \left[\prod_{t=1}^{T} \mathbb{P}(D_t|w_j, \beta_j, \theta)\right] \left[\prod_{j=2}^{T(t)} \mathbb{P}(w_j|w_{j-1})\right] \times$$

$$\left[\prod_{j=2}^{T(t)} \mathbb{P}(\beta_j|\beta_{j-1})\right] \mathbb{P}(w_1)\mathbb{P}(\beta_1)\mathbb{P}(\theta)$$

(4)

Second, I select the functional forms for the probability distributions of weights at $t + 1$, conditional on weights at $t$. Specifically, weights $w_{t+1}$ are distributed according to a product prior of the trapezoid and normal distribution. The normal distribution comes from IMF’s COFER data, which holds the aggregate portfolio weights across many countries. The trapezoid distribution relates $w_{t+1}$ to $w_t$, and it is calibrated to reflect some portfolio stickiness across time. (The trapezoid distribution obeys the bounds $[0, 1]$ on portfolio weights, unlike the normal distribution, and so it is very similar to a truncated normal distribution.) Moreover, $\beta_{t+1}$ is distributed normally, centered around $\beta_t$, which suggests that response functions of central banks to local currency volatility are sticky across time. These assumptions of portfolio stickiness seem reasonable, as Lim [2007] shows that portfolio weights are relatively stable in the aggregate data.

### 3.2.3 Markov Chain Monte Carlo

Finally, I estimate the distribution of parameters in Equation (4) using the Metropolis-Hastings algorithm. This algorithm is applied to each country in isolation, to find each country’s set of parameters.

The Metropolis-Hastings algorithm stochastically searches the parameter space, moving to regions with higher density and away from regions with lower density, using a “jumping distribution.” While calibrating the jumping distribution can be difficult in practice, I use the adaptive MCMC approach given by Roberts and Rosenthal [2009], in which the distribution is calibrated automatically to yield reasonable search processes. Moreover, the exact choice of a jumping distribution does not affect the long-run convergence properties, as long as it searches the parameter space adequately.

I run the algorithm 50 million times per country, and discard the first 49 million as the “burn-in” period. For almost all countries, the parameter draws appear stationary and convergence seems reasonable.
4 Results

This section depicts the results from the simulation. First, I show the summary statistics that emerge from the dynamic linear model, which are economically interesting on their own. Dollar shares in foreign reserves are large, and this is relatively stable across countries and across time. Euro shares are smaller, and most other currencies have negligible shares. Second, I show that the dollar and euro shares of foreign reserves can be explained by the shares of external financial liabilities denominated in those currencies. This is suggestive of a model of financial stability, which I develop further in Section 5.

4.1 Summary Statistics

In this section, I first show the average dollar and euro shares across countries, taking the simple average across different groups of countries. I also focus on the dollar, euro, pound, and yen; although I also generate results for the Swiss franc, the Australian dollar, and the Canadian dollar.

Figure 1 shows the average dollar share by region, and these are uniformly high. Unsurprisingly, the shares are especially high in the Americas. More surprisingly, they are especially high in Europe; but this may be because holding euros for Eurozone countries is inefficient, leaving the dollar as the main reserve asset.

Figure 2 shows the average euro share by region, and these are generally low, although the graph masks some large outliers. For instance, a handful of non-Eurozone eastern European countries and Middle East / North Africa countries (e.g. Romania and Morocco) have enormous euro shares.

Figure 3 shows the average shares for the pound and yen. These are uniformly low, but the contrast is informative. In the official COFER statistics, both have comparable shares — but in the disaggregated data, the pound appears twice as dominant as the yen. This is suggestive evidence against reserves as a source of fiscal space during recessions, as the yen (not the pound) is the ultimate safe-haven asset.

Finally, Figure 4 shows changes in dollar and euro shares over time, benchmarked to their shares at the start of the sample (2004). The euro has gained some share at the dollar’s expense, but the magnitudes are economically small, at approximately one percentage point. However, these small magnitudes may be a function of overly tight priors; and so in a future version, I will check that these findings are robust to looser priors.
Figure 1: Dollar Shares of Foreign Reserves

Notes: The figure depicts the average dollar share across the foreign currency reserves of countries in a given region, where dollar shares are averaged first across time within country and second across countries. Dollar shares are extremely high and somewhat heterogeneous, with countries in Europe and in the Americas having particularly high dollar shares.

Figure 2: Euro Shares of Foreign Reserves

Notes: The figure depicts the average euro share across the foreign currency reserves of countries in a given region, where euro shares are averaged first across time within country and second across countries. Euro shares are low and somewhat heterogeneous, with countries in the Middle East, Africa, and Asia having particularly high euro shares.
Figure 3: Pound and Yen Shares of Foreign Reserves

(a) Pound Shares

(b) Yen Shares

Notes: The figures depict the average pound and yen shares across the foreign currency reserves of countries in a given region, where shares are averaged first across time within country and second across countries. Pound shares and yen shares are both low and largely homogeneous, although pound shares are surprisingly higher than yen shares across the globe.

Figure 4: Dollar and Euro Shares over Time

Notes: The figure depicts the change, relative to 2004, in the average dollar and euro shares across global foreign currency reserves, where currency shares are averaged across countries for each year. While the euro share has grown at the expense of the dollar share, the growth is small, and the dollar’s dominance in foreign reserve portfolios is economically stable.
4.2 Bank Liabilities

In this section, I explain the heterogeneity in currency shares across countries using the heterogeneity in the currency shares of their financial liabilities. Specifically, I regress the dollar and euro shares in foreign reserves on the dollar and euro shares in banking liabilities, and show this is significant once swap lines — a form of direct lending between central banks that substitutes for official reserves — are taken into account.

Broadly, I regress the the dollar and euro shares of foreign reserves across countries on the dollar and euro shares of their banking systems’ external liabilities, as calculated from the Bank of International Settlement’s Locational Banking Statistics. The BIS data have some known limitations that I address. First, not all countries report their banking systems’ positions. However, fifty countries do, and this includes most developed countries (e.g. the US, UK, Germany, and Japan) and many financial hubs (e.g. Luxembourg, the Cayman Islands, and Jersey) — and the number of reporters has grown steadily over time. Second, a country’s coverage of its own financial system has grown steadily over time, making earlier reports less representative of the financial system at that time than later reports. Thus, I first infer countries’ external liabilities as equal to the assets held on them by reporting countries, to bypass the limited coverage issue. Second, I focus on the latest year the data are available to estimate shares, as this has the widest coverage both in terms of number of reporting countries and number of reporting financial institutions within each country.

This regression on its own yields few significant results, and is not reported. In Table 1, however, I include an indicator for emerging countries, and the interactive term is highly significant. This means that, for emerging markets, higher fractions of banking liabilities in dollars and euros predicts higher dollar and euro shares for foreign reserves.

The distinction between developed and emerging countries may seem arbitrary, but one plausible and consistent explanation involves swap lines, which were extended to many developed countries and to few emerging countries. Specifically, swap lines are channels by which one central bank can temporarily lend its local currency directly to another central bank for liquidity management, and these plausibly crowd out foreign reserves as they function as temporary and “on-demand” foreign reserves. For instance, Aizenman et al. [2011] and Morelli et al. [2015] argue that swap lines empirically and theoretically, respectively, substitute for foreign reserves; and Allen and Moessner [2011] argues that foreign currency banking liabilities directly predict swap lines. (Moreover, Bordo et al. [2014] — who provide a comprehensive history on swap lines — note that William Poole, president of the St. Louis Federal Reserve Bank, objected on extending swap lines to central banks with large dollar reserves on the grounds of redundancy.) Swap lines were particularly popular during the financial crisis, when countries’ financial systems suffered dollar shortages, and McGuire and
von Peter [2009], Fleming and Klagge [2010], and Rose and Spiegel [2012] argue that swap lines alleviated these shortages both in the time series and in the cross-section.

As such, in Table 1, I include an indicator for receiving dollar and euro swap lines during and after the financial crisis. The interactive term remains significant, although with wider confidence levels. Of course, countries that have received swap lines historically may not predict countries that will receive swap lines going forward, and that may partially explain the smaller confidence intervals.

A second explanation directly addresses the divide between emerging and developed markets in the context of supranational entities like the International Monetary Fund or European Central Bank. Developed countries everywhere are more willing to turn to the IMF for historical reasons; and Eurozone countries are of course far more able to turn to the European Central Bank for direct assistance during financial crises. In other words, countries without swap lines or without access to supranational entities have to hold reserves explicitly; countries with swap lines or with access to supranational entities hold reserves implicitly.

5 Model

In this section, I develop a model to explain the empirical patterns — the prevalence of dollar reserves and the correlation between currency shares in reserves and financial liabilities. In the model, a country’s central bank provides liquidity to its private banking system who have taken out excessive dollar debt, in order to protect domestic depositors. During liquidity crises, central banks need to lend dollars, but crucially it faces foreign exchange transaction costs during crises (in addition to general costs of inflation). Thus, printing local currency or holding other currencies and swapping those into dollars during crises is more costly than holding dollars directly \textit{ex ante}. Although this model does not incorporate swap lines, this is equivalent to allowing the central bank to generate dollars during crises directly, removing the need for dollar reserves.

Of course, nominal transaction costs in foreign exchange markets are tiny. For instance, I examine high-frequency exchange rate data for the dollar versus the New Zealand dollar (the least liquid of the major currencies) in August 2011 — a month that included a 7% drop in the S&P 500, a 20% fall in France’s CAC 40, and a downgrade in the US credit rating — and find that the mean and median transaction costs are 2-3 basis points; and even when transaction costs rise, they dissipate within a minute or so. However, I conceptualize implicit foreign exchange transaction costs during crises to be large, particularly when central banks need to swap billions in short intervals. For instance, this might signal bad news to markets, and end up generating market panic and deeper liquidity crunches prematurely.
Table 1: Explaining Reserve Portfolios by Bank Liabilities

<table>
<thead>
<tr>
<th>Specification</th>
<th>Dollar</th>
<th>Euro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Variable: Reserve Share</td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Bank Share</td>
<td>$-0.130$</td>
<td>$-0.085$</td>
</tr>
<tr>
<td></td>
<td>(0.083)</td>
<td>(0.078)</td>
</tr>
<tr>
<td>Emerging (Indicator)</td>
<td>$-0.111^{**}$</td>
<td>$-0.063^*$</td>
</tr>
<tr>
<td></td>
<td>(0.046)</td>
<td>(0.034)</td>
</tr>
<tr>
<td>Bank Share x Emerging</td>
<td>$0.243^{**}$</td>
<td>$0.219^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.099)</td>
<td>(0.079)</td>
</tr>
<tr>
<td>No Swap Lines (Indicator)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bank Share x No Swap Lines</td>
<td></td>
<td>$0.183^*$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.094)</td>
</tr>
<tr>
<td>Constant</td>
<td>$0.895^{***}$</td>
<td>$0.889^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.029)</td>
<td>(0.030)</td>
</tr>
<tr>
<td>Observations</td>
<td>77</td>
<td>77</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.085</td>
<td>0.065</td>
</tr>
</tbody>
</table>

Notes: The table regresses the dollar and euro shares of countries’ foreign reserves on the dollar and euro shares of their banking systems’ liabilities, across the set of seventy-seven countries. Columns (1) and (2) focus on dollars, and Columns (3) and (4) on euros. All specifications include a dummy that is interacted with the banking liabilities variable: for Columns (1) and (3), this dummy is an indicator for emerging countries; for Column (2), this dummy is an indicator for countries that did not receive dollar swap lines; and for Column (4), this dummy is an indicator for countries that did not receive euro swap lines. Significance is assessed at the 10% (*), 5% (**), and 1% (***) level. For all specifications, the interacted term is significant, suggesting that for emerging countries and for countries without swap lines, the currency shares of the financial systems’ liabilities correlate with the currency shares’ of their foreign reserve portfolios in the cross-section.
5.1 Private Banks

The agents in the model are banks, who generate liquidity mismatches with dollar debt. As in the standard Diamond and Dybvig [1983] model, banks borrow and lend across borders to fund long-term assets with short-term liabilities and deposits. Developed markets offer lower-yielding projects and cheaper funding compared to emerging markets, and this assumption — coupled with limited liability on behalf of banks — leads banks to under-hedge dollar debt. Central banks will be introduced later, as trying to protect domestic depositors who have invested in these banks.

The liquidity mismatch is standard. At $t = 0$, banks issue short-term debt (expiring at $t = 1$) and are given long-term deposits (expiring at $t = 2$) to fund long-term projects (paying off at $t = 2$). At $t = 1$, banks issue new short-term debt (expiring at $t = 2$) to pay off expiring short-term debt. At $t = 2$, banks cash in assets and settle all remaining liabilities.

![Diagram showing the flow of deposits and debt over time](image)

Specifically, there are two countries (the US and Thailand), and each country $c$ offers a continuum of projects to banks with gross riskless return $\sim U[1, R^c]$. If projects are liquidated early (at $t = 1$), they yield zero. As such, a bank that invests $x^c$ in a country gets at $t = 2$:

$$\int_{R^c-x^c}^{R^c} rdr = R^c x^c - \frac{1}{2}(x^c)^2$$

Banks also raise financing from risk-neutral lenders in each country, to supplement exogenous deposits $D$. But financial markets have supply constraints, where each marginal dollar borrowed in each market has increasing costs. The costs are governed by a country-specific and time-varying $\alpha^c_t$ for each country $c$:

$$\int_0^X (1 + \alpha^c t)dx = X \left(1 + \frac{\alpha^c}{2} X\right)$$

Note that in this model, each country only offers projects and funding in its local currency, and so raising financing from US investors is equivalent to raising dollar funding.
Finally, exchange rates are assumed to be pegged to unity, and there are no impediments
to moving funding across borders — in other words, foreign exchange markets are frictionless.
As such, the bank’s optimization problem is:

$$\max_{\{x\}_{c},\{X_1\}_{c}} \sum_c \left( R^c x^c - \frac{(x^c)^2}{2} \right) - \sum_c X_1^c \left( 1 + \frac{\alpha^c}{2} X_1^c \right) - D$$

subject to budget constraints at $t = 0$ (in which long-term investments are made) and $t = 1$
(in which short-term debt is refinanced), and various non-negativity constraints:

$$\sum_c X_0^c + D = \sum_c x^c$$

$$\sum_c X_1^c = \sum_c X_0^c \left( 1 + \frac{\alpha^c}{2} X_0^c \right)$$

$$x^c, X_0^c, X_1^c \geq 0 \quad \forall \ c$$

Now, I introduce a second state of the world at $t = 1$: the crisis state. Several things
happen during a crisis. Most importantly, foreign exchange markets develop convex frictions,
paramterized by $f^c$ for country $c$. Suppose a bank wants to move $y$ dollars into a given
country $c$; during a crisis, the bank will only receive the following:

$$\int_0^y (1 - f^c y) dy = y \left( 1 - \frac{f^c}{2} y \right)$$

In addition, during a crisis, short-term borrowing costs shift and exchange rates temporarly deviate from unity. These are not important for the results qualitatively, but they both seem empirically valid and make the quantitative results more stark.

Banks have limited liability, and can default (which changes the cost of borrowing by risk-neutral lenders ex ante, denoted by $\kappa$). Finally, banks can save through $s$, although given the limited liability constraint, they will not do so in practice. Thus, the bank’s optimization problem can be revised.

$$\max_{s,x,X,y} \mathbb{E} \left[ \max \left\{ 0, \sum_c \left( R^c x^c - \frac{(x^c)^2}{2} \right) - \sum_c X_1^{c,s} \left( 1 + \frac{\alpha^{c,s}}{2} X_1^c \right) - D \right\} \right]$$

subject to budget constraints at $t = 0$ (in which long-term investments are made), $t = 1$
(non-crisis state), and $t = 1$ (crisis state), as well as a constraint for transferring wealth in
either state and various non-negativity constraints:

\[ \sum_c X_0^c + D = \sum_c s^c + \sum_c x^c \]

\[ s^c + X_1^c + y^c E^c = X_0^c \left( 1 + \frac{\alpha_0^c}{2} X_0^c \right) \frac{1}{\kappa} \quad \forall c \]

\[ s^c + X_1^c + y^c \left( 1 - \frac{f_c}{2} y^c \right) E^c = X_0^c \left( 1 + \frac{\alpha_0^c}{2} X_0^c \right) \frac{1}{\kappa} \quad \forall c \]

\[ \sum_c y^c = 0 \]

\[ s^c, x^c, X_0^c, X_1^c \geq 0 \quad \forall c \]

To illustrate with a specific parameterization, consider a bank that has license to raise funds and invest in both countries (the US and Thailand). Compared to the US, Thailand has more profitable investments but less developed financial markets. If there is a crisis at \( t = 1 \) (with \( p = 0.01 \)), exchange rate frictions appear. In this scenario, the costs of funding in the US and Thailand switch and there are no exchange rate changes. While I can get more dramatic results when the costs of funding both rise and the exchange rate fluctuates — which is empirically more consistent — this is done to illustrate the importance of foreign exchange frictions, as the overall funding menu offered to the bank is kept the same.

At \( t = 0 \), the bank has two choices. It can take a safe plan, in which it keeps debt low and remains solvent during the crisis; or it can take out a risky plan, in which it takes out high debt and defaults during the crisis. In this example, the risky plan is more profitable, and so a risk-neutral bank will implement this.

## 5.2 Central Banks

When private banks default, the central bank does not sit idle: it wishes to protect depositors, either by bailing out distressed banks or printing the deposits itself. Suppose the cheaper option is to bail out distressed banks. If banks’ short-term liabilities are in foreign currencies, domestic currency is useless — and so the central bank can either incur foreign exchange transaction costs to gather foreign currency, or it can lend out of previously accumulated foreign currency reserves. In this model, central banks accumulate precautionary savings in foreign currencies before turmoil.

Specifically, if a bank is on the verge of defaulting in a crisis, the central bank can choose to bail out the bank by extending loans \( L^c \) at \( t = 1 \) in each currency \( c \). These are not gifts, as banks must repay at \( t = 2 \). However, banks can borrow these loans without encountering the
Table 2: Private Bank Optimization

<table>
<thead>
<tr>
<th>Name</th>
<th>State</th>
<th>Country</th>
<th>Variable</th>
<th>Safe Plan</th>
<th>Risky Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debt</td>
<td>$t = 0$</td>
<td>US</td>
<td>$X^0_1$</td>
<td>1.60</td>
<td>1.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thailand</td>
<td>$X^0_2$</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>$t = 0$</td>
<td>US</td>
<td>$x^1$</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thailand</td>
<td>$x^2$</td>
<td>1.98</td>
<td>2.11</td>
</tr>
<tr>
<td></td>
<td>No Crisis ($t = 1$)</td>
<td>US</td>
<td>$X^{1,1}_1$</td>
<td>4.24</td>
<td>4.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thailand</td>
<td>$X^{2,1}_1$</td>
<td>0.17</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>No Crisis ($t = 1$)</td>
<td>US</td>
<td>$y^{1,1}_1$</td>
<td>-0.08</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thailand</td>
<td>$y^{2,1}_1$</td>
<td>0.08</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Crisis ($t = 1$)</td>
<td>US</td>
<td>$X^{1,2}_1$</td>
<td>4.06</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thailand</td>
<td>$X^{2,2}_1$</td>
<td>0.54</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Crisis ($t = 1$)</td>
<td>US</td>
<td>$X^{1,2}_1$</td>
<td>0.20</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thailand</td>
<td>$X^{2,2}_1$</td>
<td>-0.20</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Expected Profit

| Expected Profit | 69.79 | 73.09 |

The table shows the optimal scenarios under the assumption that a private bank wishes to remain solvent or default in a crisis. Both plans involve taking heavy US debt and investing in Thailand, although the plan under the default assumption involves more leverage. The plan that defaults in a crisis is more profitable, leading to an overly leveraged banking sector in the aggregate.

convex financing costs or foreign exchange costs. Naturally, central banks want to minimize the funds transferred, as long as banks pay off their short-term obligations, and so it does not lend wastefully. I assume that bailouts are unexpected for banks when banks are optimizing. As such, at $t = 1$ in the crisis state, the central bank solves the following optimization problem.

$$\min_{X_1, y, L} \frac{1}{2} \sum_c \beta_c (L^c)^2$$

subject to a solvency constraint for the bank to which it lends at $t = 2$, a constraint to ensure that the bank can remain afloat at $t = 1$, and the usual constraints on internal transfers and non-negativity.

$$\sum_c \left( R^c x^c - \frac{(x^c)^2}{2} \right) \geq \sum_c X^c_1 \left( 1 + \frac{\alpha^c_1}{2} X^c_1 \right) + D + \sum_c L^c$$

$$s^c + L^c + X^c_1 + y^c \left( 1 - \frac{f^c}{2} y^c \right) E^c = X^c_0 \left( 1 + \frac{\alpha^c_0}{2} X^c_0 \right) \frac{1}{K} \forall c$$

$$\sum_c y^c = 0$$

$$X^c_1 \geq 0$$
This optimization yields a “frontier” of lending packages across the two currencies — dollars and Thai baht — depicted in Figure 5. A central bank picks a loan package from the line, as that reflects the minimum transfer needed to bail out the bank.

Figure 5: Central Bank Lending

Notes: The figure depicts the lending frontier for a central bank that chooses to bail out the risky bank in Table 2 during a crisis, across a mixture of dollar and Thai baht lending. The line depicts efficient lending mixtures. A loan package from the upper-right portion of the graph is gratuitous, and a loan package from the lower-left portion is insufficient to bail out a bank.

The next step is determining which loan package to pick (and whether a central bank even wishes to bail out the bank in the first place). The one power that it has is the printing press, and it can print domestic currency — although at the cost of inflation $\pi$. 

Now, consider a central bank that is determining whether to let a failing bank actually fail or not. If the private bank fails, the central bank has to print money to cover depositors. If the bank lends to it, it must hit the support frontier identified earlier, using existing reserves and freshly printed money. The central bank can also use foreign exchange markets, although it is subject to the same frictions during a crisis.

Thus, the central bank solves \textit{ex ante}:

$$\min_{\pi} \mathbb{E} \left[ \pi_0^2 + \pi_1^2 \right]$$

subject to budget constraints at $t = 0$ and $t = 1$ across domestic and foreign currencies, and a bailout function $B(\cdot)$ that checks whether the lending frontier has been reached during a bailout, and returns zero if so.

$$\pi_0 = \sum_c s^c$$
\[
\pi_1 + s^H + y^H \left(1 - \frac{f^H}{2} y^H\right) E^H = \sum_i L^H_i + \sum_j D_j
\]

\[
s^c + y^c \left(1 - \frac{f^c}{2} y^c\right) E^c = \sum_i L^c_i \quad \forall c \neq \text{Home}
\]

\[
B \left(L^H_i, L^c_i\right) = 0 \quad \forall i
\]

For instance, consider the same example. In this example, central banks find it optimal to bail out their risky banks, versus bailing out depositors directly. Note, however, that the domicile of the bank matters greatly — while Thai and American banks perform the same strategies, their supervisors find it differentially difficult to mitigate liquidity shocks. The Federal Reserve, which can print dollars on demand, need not store reserves and can bear inflationary costs if a crisis emerges. The Bank of Thailand, which cannot, stores dollar reserves ahead of time to hedge the possibility of a crisis.

Table 3: Central Bank Optimization

<table>
<thead>
<tr>
<th>Name</th>
<th>State</th>
<th>Variable</th>
<th>Federal Reserve</th>
<th>Bank of Thailand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflation</td>
<td>(t = 0)</td>
<td>(\pi_0)</td>
<td>0.03</td>
<td>2.62</td>
</tr>
<tr>
<td></td>
<td>No Crisis ((t = 1))</td>
<td>(\pi_1)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Crisis ((t = 1))</td>
<td>(\pi_1)</td>
<td>2.70</td>
<td>0.66</td>
</tr>
<tr>
<td>Dollar Savings</td>
<td>(t = 0)</td>
<td>(s^1)</td>
<td>0.03</td>
<td>2.62</td>
</tr>
<tr>
<td>Baht Savings</td>
<td>(t = 0)</td>
<td>(s^2)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Dollar Lending</td>
<td>Crisis ((t = 1))</td>
<td>(L^1)</td>
<td>2.73</td>
<td>2.72</td>
</tr>
<tr>
<td>Baht Lending</td>
<td>Crisis ((t = 1))</td>
<td>(L^2)</td>
<td>0.00</td>
<td>0.36</td>
</tr>
<tr>
<td>Expected Loss</td>
<td></td>
<td></td>
<td>-0.07</td>
<td>-6.89</td>
</tr>
</tbody>
</table>

The table shows the optimal plans for each central bank if the defaulting private bank is their responsibility. Both central banks choose to bail out the defaulting bank, although the Federal Reserve can print dollars as needed and thus stores no reserves. The Bank of Thailand cannot, and thus holds large dollar reserves \textit{ex ante}.

This model thus sheds light on why foreign central banks hold large dollar reserves when their financial systems are heavily dollarized. Failing to do so would be costly for the central bank, which would either have to incur large transaction costs to generate dollars for its financial system or would have to let its financial system collapse.
6 Conclusion

This paper uses a Bayesian dynamic linear model to document a novel empirical fact: dollars are widely prevalent in the foreign reserve portfolios of most countries. This pattern can be explained, both empirically and theoretically, from the dollarization of countries’ financial liabilities. Pragmatic central banks that wish to bypass foreign exchange markets during liquidity crises (and are either unable or unwilling to turn to the IMF or the Fed directly) must hold dollar reserves prior to crises. Alternate explanations, such as ones in which foreign reserves provide fiscal space to governments, seem less consistent with the fact.

Policymakers have recently focused on the global ramifications of countries’ foreign reserves, as Steiner [2014] explains. For instance, the East Asian savings glut — largely by East Asian governments — is blamed for fueling the American mortgage bubble during the 2000s, and the geopolitical consequences of foreign countries holding large quantities of US debt has drawn attention in recent years. This paper both provides new data and plausible explanations to such debates.

In addition, this paper shows another arena in which dollar hegemony reigns. Even as the US’s presence in goods markets shrinks, its presence in financial markets remains endurably dominant — whether in bank loans, trade invoicing patterns, monetary policy, or now sovereign reserves.
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