

Dollar Safety and the Global Financial Cycle*

FIRST DRAFT

Zhengyang Jiang[†], Arvind Krishnamurthy[‡], and Hanno Lustig[§]

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Abstract

U.S. monetary policy shocks have an outsized impact on the world economy, a phenomenon that is described by Rey's (2013) global financial cycle. On other hand, shocks in foreign countries have smaller impacts on the U.S. We build a model to rationalize these facts stemming from the special demand for dollar safe assets. In the model, dollar safe assets trade at a premium: that is, they offer especially low returns. Banks and firms that have the collateral to issue dollar safe assets can collect this premium. Institutions in the U.S. do so against dollar collateral, while institutions in foreign countries do so against local currency collateral, but in the process take on exchange rate risk. Changes in U.S. monetary policy impact the supply of dollar safe assets, but do not offset shocks to safe asset demand. Shocks to U.S. monetary policy and shocks to the value of the dollar transmit across the globe and are a global risk factor. We present evidence from movements in the Treasury basis that support the mechanism underlying our theory.

Keywords: Covered interest rate parity, exchange rates, safe asset demand, convenience yields.

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[†]Kellogg School of Management, Northwestern University. Email: zhengyang.jiang@kellogg.northwestern.edu.

[‡]Stanford University, Graduate School of Business, and NBER. Email: a-krishnamurthy@stanford.edu.

[§]Stanford University, Graduate School of Business, and NBER. Address: 655 Knight Way Stanford, CA 94305; Email: hlustig@stanford.edu.

1 Introduction

U.S. monetary policy appears to have sizable spillover effects on other economies around the world, as has been documented by a growing empirical literature. Rey (2013) and Miranda-Agrippino and Rey (2015) in particular have presented compelling evidence for the existence of a “global financial cycle” in which asset prices and financial variables such as bank leverage comove across the globe. Moreover, U.S. monetary policy appear to drive some of this comovement. Conversely, the monetary policy of other large economies does not appear to be as important to the global cycle (see Gerko and Rey, 2017). The issues this work raises are of first-order importance for emerging markets and international policymakers. While more time and research is needed to resolve measurement issues, it is equally important to understand the mechanisms behind these dollar spillovers. Indeed, in standard open economy macroeconomic models, if countries adopt flexible exchange rates with free movement of capital then domestic monetary policy is free to insulate domestic output against any spillovers. This result leads to some skepticism regarding the interpretation of the empirical results (see Bernanke, 2017). What mechanisms are behind these spillovers and why is the dollar central to this mechanism?

One set of explanations focus on yields, particular the spread between dollar and foreign yields. The borrower version is that firms around the world, particularly in emerging markets, choose to issue dollar denominated debt because it is cheaper than issuing home currency debt. The rationale behind “cheaper” here is that either bailout or risk-shifting incentives lead borrowers to contract lower interest rate foreign currency debt and ignore the currency risk involved. Periods of easy U.S monetary policy, when the yield spreads are highest, encourage such debt growth. But given the currency mismatch of the borrowers, a tightening of U.S. monetary policy raises the value of the dollar, triggering losses and defaults on these foreign currency borrowers, hence creating spillovers. The lender explanation revolves around an international version of “reach for yield.” When dollar rates fall, investors in the U.S. reach for yield by investing in high-yield foreign debt, triggering a debt build-up and vulnerability in an emerging market that can implode when dollar rates rise.

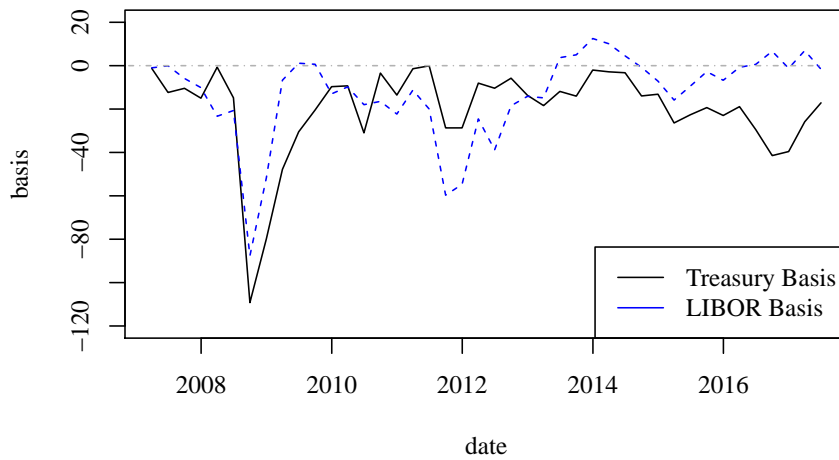
These yield based explanations find support in the data and are common wisdom among emerging market central bankers. See Carstens (2015). But from a theoretical point-of-view they fail in a significant way: they are not particularly about the dollar. If foreigners firms are after cheap low interest rate borrowing, they would borrow in the globally lowest interest rate currency such as Swiss Francs or Japanese Yen, rather than dollars. But the data clearly indicate that the dollar is the dominant borrowing currency when firms contract foreign

currency debt (see Shin, 2012; Cetorelli and Goldberg, 2012; McCauley, McGuire and Sushko, 2015; Ivashina, Scharfstein and Stein, 2015; Bruno and Shin, 2017). Likewise, if U.S. policy rates drives reach-for-yield and international spillovers, such effects should be driven equally by policy rates in the U.S., Europe, or Japan. But Gerko and Rey (2017) suggests that is not the case.

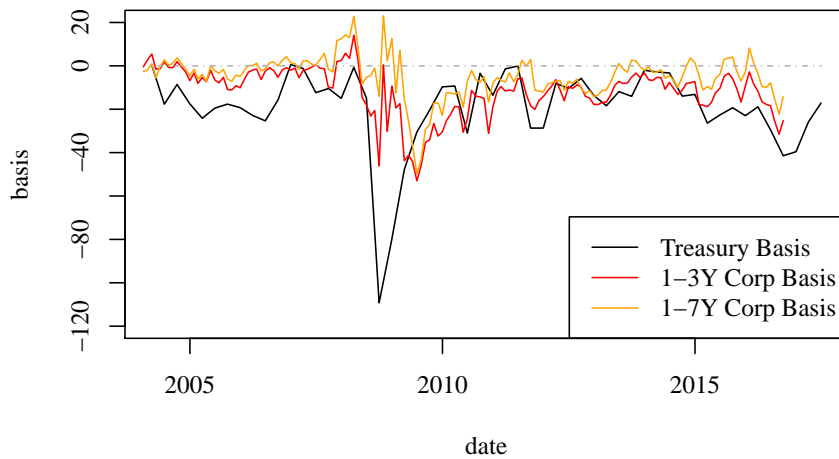
This paper takes a different tack, drawing from the recent literature on safe assets and global imbalances. Suppose that investors around the globe have a special demand for safe dollar claims, driving up the prices and lowering the yields on such claims. In the language of Jiang, Krishnamurthy and Lustig (2018), suppose investors assign a convenience yield to safe dollar claims. Then, borrowers will have incentive to tilt their liabilities towards issuing dollar claims to satisfy the convenience demand of investors. A multi-national in Brazil may issue some local currency Real bonds but will also have an incentive to tilt its liabilities towards dollar bonds. The same applies to firms in every country around the globe, with the tilt always being towards dollars where there is a convenience yield and not to some third currency (say Yen) without a convenience yield. U.S. borrowers will also issue dollar claims, but crucially such claims will be backed largely by dollar revenues. Now suppose that the U.S. tightens monetary policy, say for domestic reasons. Then the value of the dollar exchange rate rises for two reasons: (1) the standard uncovered interest rate parity condition; and, (2) the tightening will reduce the supply of dollar bonds through a credit channel, and this will render dollar bonds scarcer and further raise the dollar exchange rate. Borrowers around the world with dollar balance sheet mismatch will suffer losses, and given financial constraints, these losses will impact production and hiring decisions and lead to declines in output in the countries where these borrowers are domiciled. U.S. output will also fall, but the effect on dollar firms will be an increase in the flow cost of credit, while for foreign firms the impact will be through a valuation effect on the stock of dollar debt. This latter effect can plausibly be as large if not larger than the impact on U.S. firms so that U.S. monetary policy can generate significant financial spillovers for other countries.

Figure 1a illustrates the safe dollar phenomenon that is at the heart of our analysis. The black line plots the “Treasury basis”, which is the spread between 1-year U.S. Treasury bonds and foreign government bond yields, swapped into dollars. The swap ensures that both bonds are in dollars and yet we see that dollar Treasury bonds have a lower yield than the foreign bonds.

Why is the basis negative? We argue that the basis reflects the high valuation that investors place on cash



(a) The Treasury basis is the spread between 1-year U.S. Treasury bonds and foreign government bond yields, swapped into dollars. The LIBOR basis is the same spread but using dollar LIBOR and foreign LIBOR. Data is from 2005 to 2017. Foreign in both cases refers to the average across a sample of developed economies.



(b) The Treasury basis is the spread between 1-year U.S. Treasury bonds and foreign government bond yields, swapped into dollars. The corporate basis is constructed from a sample of corporate bonds issuing in dollars and foreign currencies, as described by Liao (2018). The 1-3Y corporate basis is the average corporate basis of companies with credit ratings from AA- to AAA and maturities of 1 to 3 years. The 1-7Y basis is an average for companies with credit ratings from BBB- to AAA and across maturities from 1 to 7 years. Foreign in both cases is a sample of developed economies.

Figure 1: Treasury, LIBOR, and Corporate Basis

dollar safe assets, i.e., the convenience yield on dollar safe assets. The short-term U.S. Treasury bond being the par-excellence of world safe assets especially reflects this valuation and hence the figure reveals a time-varying valuation of dollar safe bonds. The foreign bond less reflects this valuation because it is a synthetic security and the package of a bond and swap is an imperfect substitute for the cash Treasury bond. See Jiang, Krishnamurthy and Lustig (2018) for further details and empirical support for this proposition.

The convenience yield is also reflected in private dollar bonds. Figure 1a plots the LIBOR basis, defined analogously, reflecting the spread between dollar LIBOR and foreign LIBOR, swapped into dollars. Note that the two bases move together indicating that the convenience yield on dollar safe assets is also reflected in private bank deposit rates. When investors demand more safe dollar bonds, they drive down the yield on both dollar Treasury bonds and dollar bank deposit rates, relative to their swapped foreign counterparts. Figure 1b plots the basis for safe corporate issuers, and is from Liao (2018). We also plot the Treasury basis for comparison. We again see that the spreads move together, but that the Treasury basis is typically wider than the corporate basis. These figures provide empirical support the main assumption of our analysis: Given the premium on issuing dollar bonds, borrowers around the world will tilt liabilities towards dollars, satisfying this dollar bond demand.¹

Our analysis also highlights channels of contagion. Shocks to foreign countries will impact other foreign countries but will have limited spillovers to the U.S. Suppose that a shock tightens financial constraints in foreign countries. Then, this shock will lead to a reduction in foreign-country output as is standard in financial accelerator models. But furthermore to the extent that these countries supply dollar claims to satisfy safe asset investors and the supply of these dollar claims falls, the dollar exchange rate will appreciate. Then a shock in one foreign country will lead to contagion, through the dollar balance sheet mismatch, to other foreign countries. Impact on the U.S. will be limited to trade and expenditure switching channels (which are absent in our model). That is, there is a fundamental asymmetry in shock transmission between the center and periphery and from periphery to center. Negative world shocks lead to a flight-to-the-dollar which further spreads around the non-dollar world.

These asymmetric spillover effects are suggestive of instability in the international monetary system. Indeed,

¹We also note that the negative basis illustrated in these figures cuts against pure reach-for-yield explanations. If U.S. investors reached for foreign yield during the last decade, eschewing U.S. dollar bonds in favor of foreign bonds, we would expect that the basis will be positive not negative.

our model identifies a new Triffin dilemma (Triffin, 1960). In the context of the Bretton-Woods system where the dollar was the *de-jure* center country, Triffin foresaw an emerging imbalance. He argued that as world demand for dollar reserve assets grew with the world economy, the U.S. will inevitably be in the position of supplying such assets, but their backing is limited by the supply of U.S.-held gold. The erosion of backing will eventually lead to a run on the dollar and the collapse of the international monetary system. Today, we live in a world where backing is not provided by gold and is instead provided by revenue streams of firms and governments.

But in a world with a *de-facto* dollar standard, there is a version of the Triffin dilemma that reappears. Dollar assets are provided by both U.S. firms and foreign firms. But crucially, foreign firms do so by taking on currency mismatch. As world demand for dollars grows, the incentive for both U.S. and foreign firms to supply dollar assets will grow. In particular, if world demand growth exceeds the growth in U.S. produced asset supply, the result will be growth in currency-mismatched balance sheets around the world. The conclusion is that financial spillovers and the global financial cycle may grow in importance.

Our model has three blocks: U.S., world safe asset investors, and foreign country. The U.S. and foreign blocks are built around a standard macro model where firms face financial constraints and monetary policy affects borrowing, hiring, and investment. The key object of interest in the model is the supply of dollar bonds; or equivalently, the quantity of safe dollar debt that firms in the U.S. and foreign countries choose to issue. These bonds are valued by the world safe asset investors who pay a premium to own these bonds. We show that the premium depends on the supplies of bonds; that exchange rates depend on the premium; and that monetary policy as well as real economic shocks impact bond supplies, the premium, and exchange rates. In addition, to the results mentioned above, our model replicates a number of the aspects of the current world dollar standard. We show that the U.S. earns an exorbitant privilege on its provision of safe dollar assets to the rest of the world, which it uses in part to cover its trade deficit (see Gourinchas and Rey, 2007). We also show that convenience yield on dollar assets lowers the equilibrium safe real interest rates in the U.S. relative to the rest of the world, consistent with safe assets hypothesis (see Caballero, Farhi and Gourinchas, 2008). Finally, we show that the dollar convenience yield comoves with strength of the dollar, consistent with the results in Jiang, Krishnamurthy and Lustig (2018).

Our results rest on one key assumption: world investors have a special demand for safe U.S. dollar securities.

Figures 1a and 1b provide empirical support for this proposition. Moreover, there are theoretical models that aim to explain this fact and why it is about the dollar. See He, Krishnamurthy and Milbradt (2018) for an explanation that revolves around the depth of the U.S. Treasury market and the relative fiscal strength of the U.S. government. See Maggiori (2017) for an explanation based on the better financial system of the U.S. See Gopinath and Stein (2018) and Chahrour and Valchev (2017) for an explanation that ties together the role of the dollar in trade invoicing and the demand for dollar safe assets. We take the assumption as given and explore its implications for other aspects of the international monetary system. The contribution of our paper then is that we identify the essential element of the reserve currency paradigm that drives the global financial cycle.

This paper is laid out as follows. The next section lays out the U.S. block of the model. We explain the international asset market equilibrium and exchange rate determination in Section 3. We consider the foreign country and spillovers and present our main results in Section 4. We present empirical evidence consistent with the model’s mechanisms in Section 5. The conclusion and an appendix detailing the calibration of the model follow.

2 U.S. Model

The model has three blocks: U.S., Foreign, and World Safe Asset Investors. We begin with the U.S. block, highlighting the monetary transmission mechanism and the supply of U.S. safe assets (“dollar liquidity”).

We consider an infinite horizon, discrete time, economy. Time is indexed as $t = 0, 1, 2, \dots$. U.S. households are modeled as living in overlapping-generations (OLG). They are born and work at date t , save their wages until date $t + 1$ at which time they consume. Utility over date $t + 1$ consumption is:

$$E_t[c_{t+1}] \tag{1}$$

where c_{t+1} is (non-traded) consumption at date $t + 1$. Households are endowed with \bar{l} units of labor which they supply at date t .

Households can work for firms (F), which we will think of as large corporates or banks. These firms are run by managers/entrepreneurs subject to a standard agency problem that limits borrowing (more on this below).

A manager at time t has capital of k_t . The manager can liquidate the capital for k_t goods at time t . The manager can also freely convert any goods into new capital. Thus the price of capital relative to goods will be one in equilibrium. The manager can also hire labor and produce goods at time $t + 1$. Given l_t labor and k_t capital, the production technology gives output at date $t + 1$ of

$$f(l_t, k_t) = A_{t+1}(l_t + k_t), \quad A_{t+1} > 1. \quad (2)$$

A_{t+1} is productivity which is known at time t .

The production technology in (2) is linear. Furthermore, capital and labor are perfect substitutes. The modeling has two implications that help simplify the analysis. First, the price of capital and wages will be equal in any interior equilibrium. Furthermore, since capital can be liquidated for goods, the price of capital and goods will also be equal in an interior equilibrium. We don't think much is at stake in making these simplifications rather than adopting say a more standard Cobb-Douglas form.

We denote the price level (in terms of the non-traded good) at date t as p_t . Firms hire workers at date t and pay them for their labor. As noted, in equilibrium the wage rate has to be equal to the price of the good. Thus we will denote the nominal wage as p_t as well. The price of capital is also p_t .

Firms are run by managers. These managers have wealth at date t of w_t , in real terms. They die with probability $1 - \sigma$ at the end of each period, and at death, consume their wealth. A manager maximizes,

$$\sum_{t=1}^{\infty} \sigma^{t-1} (1 - \sigma) w_t. \quad (3)$$

2.1 Borrowing constraint

To raise money to pay wages, firms issue nominal one period bonds at the nominal interest rate i_t . At date $t + 1$, firms produce the output good and sell this good at price p_{t+1} . Denote the inflation rate as,

$$\pi_t = \frac{p_{t+1}}{p_t} - 1. \quad (4)$$

We assume that firms face financial constraints. A firm has debt capacity equal to a fraction $\theta < 1$ of next period's expected output. We focus on a parameterization under which $A_{t+1} \geq 1 + i_t - \pi_t$ always, i.e. the

marginal product of investment exceeds the real interest rate so that firms borrow and produce at maximum scale. Then, firms raise total funding in dollars of,

$$\frac{p_{t+1}\theta A_{t+1}(l_t + k_t)}{1 + i_t}. \quad (5)$$

The budget constraint for a firm at date t is:

$$p_t w_t + p_{t+1} \frac{\theta A_{t+1}(l_t + k_t)}{1 + i_t} = p_t(l_t + k_t),$$

i.e., the manager's wealth plus proceeds from the debt sale is used to purchase capital and hire workers. Solving,

$$l_t + k_t \approx w_t \frac{\theta A_{t+1}}{(1 + i_t - \pi_t) - \theta A_{t+1}}. \quad (6)$$

So that employment and capital are decreasing in the interest rate, increasing in productivity (A_{t+1}), and increasing in the manager's net worth. We require that $(1 + i_t - \pi_t) - \theta A_{t+1} > 0$ so that this ratio is well defined.

Profits of a given firm at $t + 1$ are,

$$p_{t+1}A_{t+1}(l_t + k_t) - p_{t+1}\theta A_{t+1}(l_t + k_t) = p_{t+1} w_t \frac{A_{t+1}(1 - \theta)}{1 - \frac{\theta A_{t+1}}{1 + i_t - \pi_t}}.$$

In aggregate, a fraction σ of managers die and consume their wealth each period. To facilitate the steady state analysis, we also assume that managers are born each period with W^N units of capital. Then, the law of motion for aggregate net-worth (in real terms) is,

$$W_{t+1} = W_t(1 - \sigma) \frac{A_{t+1}(1 - \theta)}{1 - \frac{\theta A_{t+1}}{1 + i_t - \pi_t}} + W^N, \quad (7)$$

where we use the capital letter W_t to denote the aggregate net-worth of the firm sector.

2.2 Monetary policy and price setting

We introduce monetary policy along with sticky prices and wages so that monetary policy affects the real interest rate $i_t - \pi_t$. First we suppose that the central bank sets the nominal interest rate i_t . This could be either via setting the interest on reserves or setting the growth rate of money; our model does not depend on these particulars.

Second, we assume that at beginning of period t , firms choose the prices for hiring p_t as well as the prices for the output good p_{t+1} . These prices are held constant until date $t + 1$. The monetary authority sets the one-period interest rate i_t after prices are set; that is, at the end of period t . Thus π_t is set before i_t is chosen and hence policy controls the real interest rate.

To complete the model, we describe optimal price setting. We assume that workers have an alternative sector in which to work; call this an informal (I) sector. The I-sector has productivity of one at all times, is owned by households, and faces no debt-capacity constraints. Loosely, think of this as an endeavor where people work for their neighbors. The firm also sets prices and wages at date t and holds them constant for one period. The profits of an I-firm as function of the firm's pricing and hiring decision is:

$$p'_{t+1}l'_t - p'_t(1 + E_t[i_t])l'_t \quad (8)$$

It is apparent that profit maximization implies that,

$$\frac{p'_{t+1}}{p'_t} = 1 + E_t[i_t] \quad (9)$$

The firm sets prices so that the real interest is zero, thus equating the cost of capital and the marginal rate of transformation of labor into goods.

An F-sector firm faces a similar profit maximization problem when setting prices, but with productivity $A_{t+1} > 1$. But since this sector faces financial constraints in hiring labor, profit maximization only gives the inequality:

$$\frac{p_{t+1}}{p_t} A_{t+1} - (1 + E_t[i_t]) \geq 0.$$

Next, note that since the labor and goods market are competitive it follows that:

$$p_t = p'_t \quad \text{and} \quad p_{t+1} = p'_{t+1}.$$

That is prices and wages are set based on the optimality condition for the I-sector (equation (8)). It should be apparent that the I-sector is introduced primarily as a modeling device to describe optimal price-setting.

2.3 Market clearing, output, and debt supply

There are two market clearing conditions. Labor market clearing is that,

$$L_t + L'_t = \bar{l},$$

where we again use capital letters to denote aggregate quantities. We assume parameters such that $L'_t > 0$ always. This guarantees that the I-sector is active and its optimality condition determines the expected inflation rate. Capital market clearing is that,

$$K_t = W_t.$$

All of the manager's wealth is invested in capital. Note that this condition means that wealth and capital are always equal. With some abuse of terminology, when describing the equilibrium, we use wealth and capital interchangeably.

Output across both sectors at date $t + 1$ is,

$$\begin{aligned} Y_{t+1} &= A_{t+1}(L_t + K_t) + \bar{l} - L_t \\ &= A_{t+1}K_t \left(1 + \frac{\theta(A_{t+1} - 1)}{(1 + i_t - \pi_t) - \theta A_{t+1}} \right) + \bar{l} \end{aligned}$$

Output is increasing in capital and productivity and decreasing in the real interest rate.²

²Note that workers are indifferent between the I-sector and the F-sector since wages are the same in both sectors. In writing equation (10), we have specified an equilibrium where labor is allocated to the F-sector up to their capacity to pay, and the rest to the I-sector. We can construct the equilibrium as follows. Suppose that the F-sector, which is more profitable, offers a wage of $p_t + \epsilon$, so that workers strictly prefer working in the F-sector. As $\epsilon \rightarrow 0$, we have our specified equilibrium.

For future reference we also define the “safe private debt supply” of the U.S. as,

$$B_t = \frac{\theta A_{t+1}(L_t + K_t)}{1 + i_t - \pi_t} \quad (10)$$

This quantity is the dollar value of debt issued by firms. The asset supply is decreasing in the interest rate, and increasing in capital and productivity. We will see that it plays an important role in the international safe asset equilibrium.

2.4 Impulse response to a monetary policy shock

We suppose that the central bank has an inflation target of $\bar{\pi}$. Then, the central bank is expected to set $E_t[i_t] = \bar{\pi}$. We evaluate the impact of the monetary policy shock, ϵ_t , where

$$i_t = \bar{\pi} + \epsilon_t. \quad (11)$$

This completes the description of the U.S. block of the model. The model has one state variable, W_t . The steady state level of net worth solves,

$$W^{SS} = W^{SS}(1 - \sigma) \frac{A^{SS}(1 - \theta)}{1 - \theta A^{SS}} + W^N. \quad (12)$$

We require that $(1 - \sigma) \frac{A^{SS}(1 - \theta)}{1 - \theta A^{SS}} < 1$ and $W^N < W^{SS}$ to ensure stable dynamics around the steady state.

To illustrate the impact of monetary policy we consider the impulse response to a one-time shock ϵ_t . We trace out the impact of this shock beginning from the steady-state of the model. Figure 2 illustrates.

A surprise tightening of monetary policy at $t + 1$ reduces the debt capacity of firms on impact. As a result, the F-sector hires less labor (bottom-left panel) in $t + 1$. Firms make less profits both because of the reduction in margins ($A_{t+2} - i_{t+1}$) and because their debt capacity, hiring, and production levels fall. The lower profits leads to a fall in K in the following period, i.e. $t + 2$. Output falls in period $t + 2$ with the initial shock as labor is allocated to the less productive I-sector, and further at $t + 3$, as the shock leads to a fall in K_{t+2} . The dollar debt supply, B_t , which is equal to debt capacity, also falls on impact as illustrated in the bottom-right panel. The effect of the initial shock persists even after the shock disappears through a propagation mechanism via

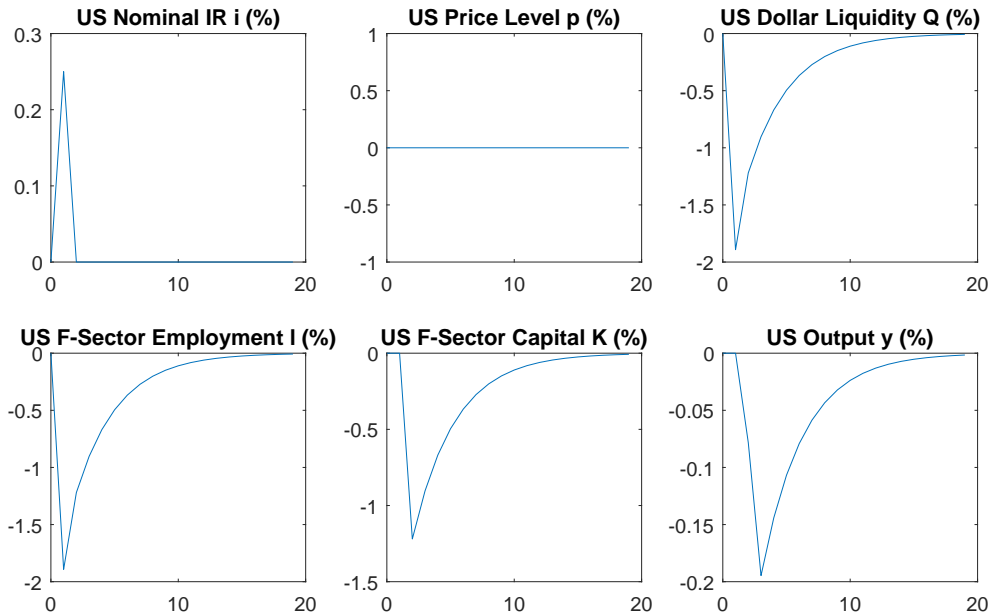


Figure 2: Impulse response to a U.S. monetary policy shock of 0.25%

We consider a 0.25% shock to the US quarterly nominal interest rate i_t in period $t + 1$ of the model. The top-left panel plots i_t , with the x -axis in periods. The top-middle panel plots the price level. The top-right panel plots output as a percent deviation from the steady-state value. The bottom panels plot hiring (l_t) and capital (K_t) in the F-sector, as well as dollar liquidity (Q_t), all as percentage deviations from their steady-state values. See Table 5 for parameter values.

K_t , as in financial accelerator models (see Bernanke, Gertler and Gilchrist, 1996). Capital returns gradually to its steady-state level as profits accumulate and new firms enter. Output, labor, and debt supply are below steady-state through this entire path.

3 International Equilibrium and Dollar Liquidity

We embed the U.S. block into a world asset market equilibrium to solve for exchange rates and dollar liquidity. We then model a representative foreign country borrower and trace out the impact of U.S. monetary policy on this country.

3.1 Safe asset investors

There are risk-neutral world investors who own world bonds paying interest rate i_t^* . We assume these bonds pay in a world good that is consumed by these world investors. We also set the price of this good to be one at all dates, without loss of generality. The world investors do not value the non-tradable good produced by U.S. firms. So any investments in dollars must be converted back to world currency for consumption. Denote the nominal exchange rate in world-per-dollar as S_t (the log rate is denoted s_t). The real exchange rate is $E_t = \frac{S_t}{p_t}$ (the log rate is denoted e_t). Our sign convention means that a stronger dollar is associated with a higher value of S_t .

We suppose that world safe asset investors place an extra convenience yield of λ_t to own dollar liquidity. Dollar liquidity in the model is the bonds issued by U.S. firms. Let us consider an equilibrium in which Q_t dollars of the bonds are purchased by world investors. We construct such an equilibrium in the next section. For now, we note that optimality for the world safe asset investor requires that

$$i_t + E_t s_{t+1} - s_t = i_t^* - \lambda_t.$$

The return to owning dollar bonds less the convenience yield must equal the return to owning world bonds, accounting for the expected appreciation of the exchange rate.

Rewriting, this uncovered interest parity (U.I.P.) condition becomes:

$$E_t s_{t+1} - s_t = i_t^* - i_t - \lambda_t. \tag{13}$$

If world safe asset demand rises (high λ_t), then the dollar appreciates today and gives an expected depreciation. This is the condition we derive in our other work (see Jiang, Krishnamurthy and Lustig, 2018). The condition in (13) is derived for risk-neutral world investors. In our other work, we consider the case of risk-averse world investors so that the U.I.P. condition also reflects a risk premium. We set this aside as it is not central to our present analysis.

For the real exchange rate, the U.I.P. condition is,

$$E_t e_{t+1} - e_t = r_t^* - r_t - \lambda_t \tag{14}$$

where r_t^* and r_t are the real interest rates; i.e. the nominal rate minus expected inflation.

We iterate on this equation and find:

$$e_t = E_t \sum_{j=t}^{\infty} \lambda_j + E_t \sum_{j=t}^{\infty} (r_j - r_j^*) + \bar{e} \quad (15)$$

The term $\bar{e} = \lim_{t \rightarrow \infty} e_t$ is a constant because we assume that the real exchange rate is stationary. From (15) we see that the dollar exchange rate moves both because of shocks to safe asset demand (λ_t) and shocks to the real interest rate differential. Jiang, Krishnamurthy and Lustig (2018) presents evidence to support these points, some of which we review below.

3.2 Dollar liquidity and the U.S. carry trade

A U.S. bond holder can earn a “carry trade” profit by selling U.S. bonds and investing in foreign bonds since:

$$\dot{i}_t^* - \dot{i}_t - (E_t s_{t+1} - s_t) = \lambda_t > 0.$$

We next describe the equilibrium in which U.S. investors do this carry trade while world safe asset investors purchase dollar bonds. This quantity dimension has been a central focus of the empirical and theoretical literature on safe assets.

For technical reasons we introduce a set of “global banks” that intermediate this carry trade, as in Gabaix and Maggiori (2015). Households are assumed to not participate in the foreign bond market, so that these global banks trade with U.S. households and foreign safe asset investors, thereby earning the carry-trade profit from this intermediation service. An alternative modeling would be to allow the U.S. households to directly participate in foreign bond markets, but in doing so, we would also have to specify U.S. household preferences over the foreign good (they need to consume the fruits of their carry trade profits) and ensure that the exchange rate also clears the home/foreign goods market, which adds considerable overhead to the model (see Itskhoki and Mukhin, 2017). We go in a different direction by adding global banks who intermediate the carry trade and consume their profits in the foreign good.

We suppose that each U.S. household receives its wages of $p_t l_t$ and either invests in U.S. dollar bonds issued by firms at interest rate i_t , central bank deposits at rate i_t , or with a bank at deposit rate i_t^D .

There is a measure $\alpha < 1$ of banks. The banks are run by owner-managers that are risk neutral profit maximizers. At the end of each period, the bank owner consumes any profits, settled in the world good. We also allow the bank to consume negative quantities of the world good (or more palatably, we can provide them with a large endowment of the world good that absorbs any realized losses).

Take one of these α measure of banks. We assume that this bank can contact exactly one household and offer to take a deposit of d_t from this household. The bank is assumed to have monopoly power over the depositor (as in Drechsler, Savov and Schnabl (2017) and Duffie and Krishnamurthy (2016)) and can dictate the deposit rate. Given depositors' outside option to invest in dollar bonds and central bank deposits it follows that $i_t^D = i_t$.³

In raising d_t deposits from the household, the bank receives d_t of the dollar bonds of this household. The bank then sells these dollar bonds to safe asset investors in return for their world bonds. Consider a representative bank that raises d_t of dollar deposits and invests these funds in U.S. firm bonds ($b_t^\$$) and world bonds (b_t^w). The budget constraint for a bank is,

$$b_t^w + b_t^\$ = d_t.$$

The expected profit to the bank from this portfolio choice is:

$$b_t^w (i_t^* - i_t - (E_t s_{t+1} - s_t)) + (b_t^w + b_t^\$) i_t. \quad (16)$$

The bank maximizes (16) subject to the short-sale constraint,

$$b_t^\$ \geq 0. \quad (17)$$

The short-sale constraint, (17), is an important one. Without this constraint we would expect that banks sell all of their dollar bonds to satisfy foreign safe-asset demand and short-sell more bonds as long as $\lambda_t > 0$ (presumably, selling enough quantity to the point that safe-asset investors' demand for safe dollar bonds is satiated). The central mechanism in our model is that dollar safe assets are in short-supply, and in our

³Note our assumption that $\alpha < 1$ is important to pin down the rate on the U.S. dollar bonds at i_t . The fraction $1 - \alpha$ of U.S. households invest their wages in central bank deposits and U.S. dollar bonds issued by firms. Since central bank deposits pay i_t , and since some firms bonds are held in equilibrium by these households, it follows that the firm bonds must also pay i_t .

modeling, are only created by firms. Realistically, banks are also creators of dollar safe-assets, but are limited in doing so capital constraints, e.g., as described in Du, Tepper and Verdelhan (2017) or Gabaix and Maggiori (2015).⁴

Given that the bank is risk-neutral, it is apparent that the solution is at the corner where the short-sale constraint binds. That is, note that the first term in (16) is the return on running the “carry” trade of investing in the world bond:

$$i_t^* - i_t - (E_t s_{t+1} - s_t) = \lambda_t > 0.$$

The bank thus holds no U.S. dollar bonds and invests only in world bonds.

In equilibrium, world investors purchase a fraction α of the U.S. safe bonds. Define the (real) dollar liquidity produced by the U.S. as:

$$Q_t = \alpha B_t. \tag{18}$$

World investors hold this dollar liquidity, earning a low return on this investment. In turn, global banks earn an expected premium, proportional to λ_t , on their provision of liquidity. In our model, the bankers use these profits to purchase goods from abroad. Define the dollar value of carry profits as,

$$\text{Carry Profits}_{t+1} = Q_t (i_t^* - i_t - (s_{t+1} - s_t)), \tag{19}$$

and we note that $E_t[\text{Carry Profits}_{t+1}] = \lambda_t$. The positive return on the carry trade stems from the “exorbitant” privilege of the U.S in producing safe dollar assets, consistent with the analysis of Gourinchas and Rey (2007).

Last suppose that the world investor’s convenience yield for dollar liquidity is downwards sloping in quantity:

$$\lambda_t = \lambda(Q_t) \text{ with } \lambda'(Q_t) < 0. \tag{20}$$

We note that since B_t falls when i_t rises, monetary policy impacts the exchange rate through two channels: a rise in i_t increases e_t directly through the U.I.P. relation, and indirectly through the reduction in B_t and corresponding rise in λ_t .

⁴We could enrich the model by introducing financial frictions into the bank’s carry trade operations as in Gabaix and Maggiori (2015). In this case, the friction may result in an interior optimum where both b_t^w and b_t^s are positive and affect equilibrium exchange rates, as Gabaix and Maggiori (2015) show. We can see this most clearly by noting that in (18), the quantity Q_t will fall, and as a result λ_t will rise, and the equilibrium exchange rate will be affected by the financial friction.

In our simulations below, we parameterize the convenience yield function as:

$$\lambda_t = \bar{\lambda} - \beta^\lambda(Q_t - Q^{SS}) + \epsilon_t^\lambda. \quad (21)$$

3.3 International financial equilibrium

The model with the exchange-rate equilibrium still has a single state variable, W_t . The steady-state capital level is given as before from equation (12). Before turning to the impulse response functions we note that our model of the international financial equilibrium captures important features of the world economy post-Bretton Woods.

- Steady-state interest rates in the U.S. satisfy:

$$r^* - r = \lambda.$$

We can understand this relation by inspecting equation (15). To maintain a constant e_t , the real interest in the U.S. must be lower than the real interest rate abroad by exactly λ_t . The result is consistent with observations linking safe asset demand to the low steady-state real interest rate (“R-star”) in the U.S (see Caballero, Farhi and Gourinchas, 2008).

- Changes in the demand for safe dollar assets impact the dollar exchange rate. That is, there is a financial demand component to exchange rate determination, which is strongly supported by the data as we explain in Section 5.
- The U.S. is a world financial intermediary. It provides safe dollar assets to the world and recycles these flows into a carry trade return, which then partly finances the trade deficit (see Gourinchas and Rey, 2007). The position of the U.S. is not an artifact of the exchange rate system, as argued by Despres, Kindleberger and Salant (1966) in their well-known “minority view.” This view, which was written in response to Triffin (1960)’s critique of the Bretton-Woods system, posited that the U.S., having the deepest and most liquid financial markets in the world, will naturally be in a position of providing liquid assets to the world and earning a premium from this financial service.

Additionally, through the lens of the model, some arguments about the international monetary system

appear invalid. Triffin (1960) and Dooley and Garber (2005) argue that in order for non-U.S. countries to obtain their desired dollar assets, these countries have to run a current account surplus vis-a-vis the U.S. to gain dollars. In the model, the rest-of-the-world trades their assets to the U.S. to source dollar assets; the trade account does not have to enter as the source for dollar assets. This point is also made by Despres, Kindleberger and Salant (1966). Nevertheless it is the case that if there is a dollar premium, then the U.S. will earn a return on this trade and will use it to cover imports from the rest-of-the-world.

3.4 Impulse response function

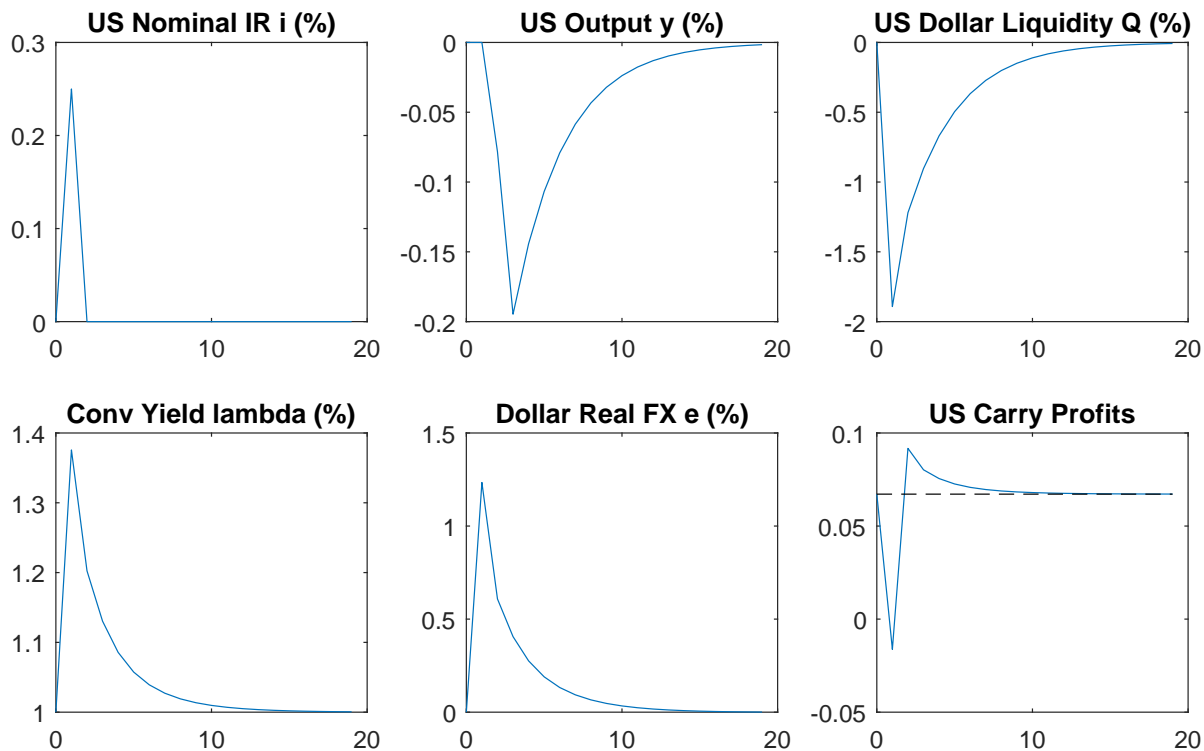


Figure 3: Impulse response to a U.S. monetary policy shock of 0.25%

We consider a 0.25% shock to i_t in period $t + 1$ of the model. The top-left panel plots i_t , with the x -axis in periods. The top-middle panel plots output, as a percentage deviation from steady-state. The top-right panel plots the the quantity of dollar liquidity (Q_t). The bottom panels plot the convenience yield, real dollar exchange rate, US bank carry profits. All, except for the profits, are expressed as percentage deviations from their steady-state values. See Table 5 for parameter values.

Figure 3 plots the impulse response to a 0.25% shock to the nominal interest rate in period $t + 1$. US output

(top row, middle panel) behaves exactly as in the U.S.-only model. The new results are in the next panels. The rise in the U.S. interest rate reduces safe asset supply and hence increases the convenience yield, λ . The dollar appreciates at date $t + 1$ both because of the rise in i_{t+1} and the increase in λ_{t+1} . U.S. banks lose money on impact since they are running a carry trade that has them long foreign currency/short dollars. But they subsequently make money as λ_t rises. This pattern of losses and gains is reflected in the panel for U.S. carry profits.

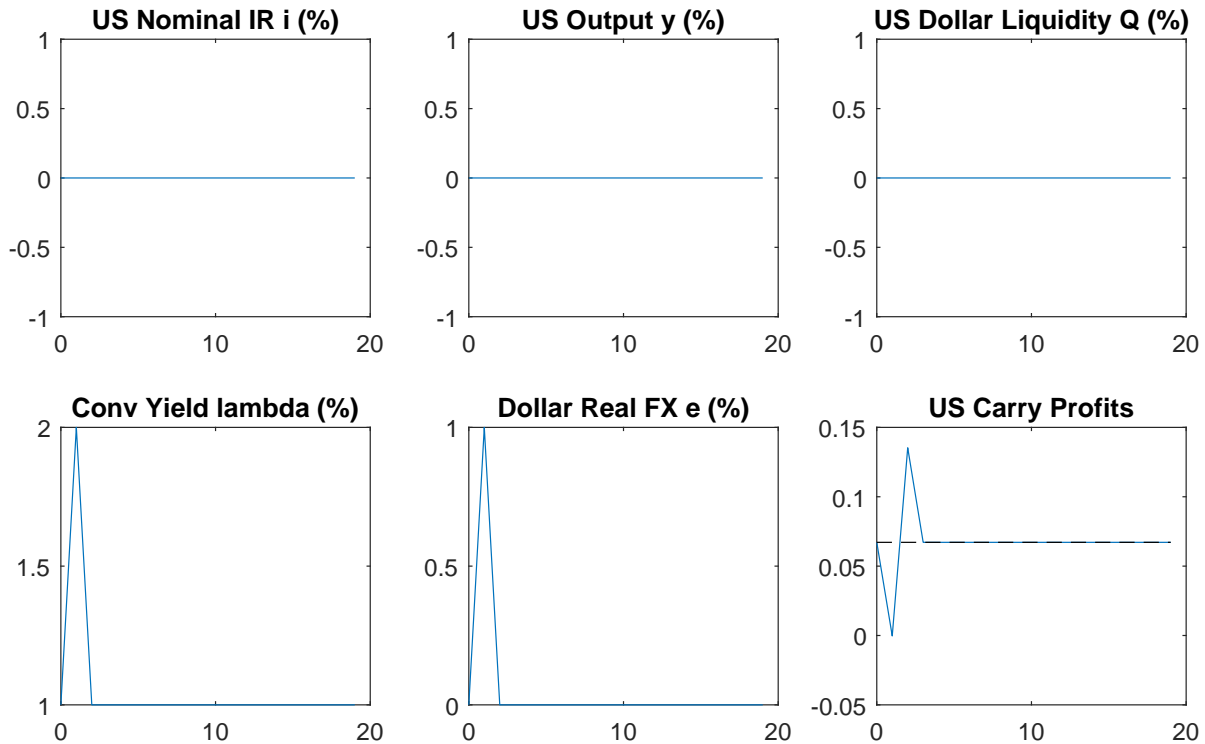


Figure 4: Impulse response to a safe asset demand shock of 1%

We consider a 1% one-time shock to λ_t in period $t + 1$ of the model, as in the top-right panel. The top-left panel plots i_t , with the x -axis in periods. The top-second panel plots output as a percent deviation from the steady-state value. The top-third panel plots dollar liquidity (Q_t). The bottom panels plot the convenience yield, the real dollar exchange rate, US carry profits. All except the last are expressed as the percentage deviation from that variable's steady-state value. See Table 5 for parameter values.

Figure 4 illustrates the impact of a temporary shock that increases safe-asset demand. We increase the convenience yield (λ_t) in period $t + 1$ unexpectedly by setting $\epsilon_{t+1}^\lambda = 1\%$ (doubling the convenience yield relative to its steady-state value in our parameterization). This shock appreciates the dollar and leads to a

pattern of bank carry losses and then gains. The shock has no impact on U.S. output which is determined entirely by U.S. productivity and monetary policy. In a richer model where U.S. households consume both home and foreign goods, the dollar appreciation may drive an expenditure-switching effect which increases demand for the foreign good by U.S. households and has implications for the trade balance. We have set this effect aside.

Suppose the Federal Reserve places weight on smoothing bank carry profits and chooses to stabilize the exchange rate in response to the safe asset demand shock. In this case, the Fed would lower interest rates, depreciating the dollar and as in Figure 3 would boost U.S. output and firms' dollar borrowing. This effect of world safe asset demand on the U.S. market equilibrium is plausibly one of the factors driving the boom in housing and bank borrowing in the U.S. in the pre-crisis period from 2002 to 2007, as argued by Caballero and Krishnamurthy (2009). Our analysis shows that it is the monetary authority's decision to accommodate these inflows by lowering rates that creates the domestic effect. We also note that the lowering of the policy rate by itself does not make the U.S. a less attractive safe asset haven. Holding λ_t fixed and given U.I.P., the expected return to a safe asset investor of buying dollar assets relative to world assets is still $-\lambda_t$. But lower rates does have an impact on λ_t . As evident in Figure 3, lowering rates boosts U.S. safe asset supply (by inducing firms to take on more debt) which in turn increases Q_t and reduces the equilibrium value of λ_t . It is the increase in "liquidity" which offsets the safe asset demand shock. Of course such an increase in liquidity also leads to a build-up in U.S. leverage which can leave the U.S. firms vulnerable to firms, as argued by Caballero and Krishnamurthy (2009).

4 Dollar Spillovers

We next introduce a representative foreign country to trace the impact of U.S. monetary policy and dollar safe asset demand on the rest of the world. This country has households and firms who provide labor, produce, and consume. The foreign model is more streamlined than the U.S. model because we set aside sticky prices and focus on the monetary transmission mechanism.

4.1 Foreign households and firms

The foreign country produces and consumes a world tradable good. The law of one price holds: the price of the domestic tradable good and the world tradable good are equal. Prices are not sticky. The world interest rate is $i_t^* > 0$ which the country takes as given; i.e., we make the “small open economy” assumption.

Households in the country are OLG. Their utility function is,

$$\frac{1}{1 + i_t^*} c_{t+1}^* - l_t^* \quad (22)$$

c_{t+1}^* is consumption of the world traded good. Note that labor enters as a linear disutility cost and there is no bound on l_t (as we had assumed in the U.S. model). The discount factor is chosen to match the world interest rate. Other than these aspects, the rest of the model mirrors the U.S. model.

Suppose that the goods price at date $t + 1$ is p_{t+1}^* and wages at t are p_t^* . A household is willing to supply a unit of labor at disutility cost of one to receive p_t^* goods which is then saved at interest rate i_t^* and used to purchase $\frac{1}{p_{t+1}^*}$ of goods at $t + 1$. Given the linear household utility function it follows that,

$$-1 + \frac{1}{1 + i_t^*} (1 + i_t^*) \frac{p_t^*}{p_{t+1}^*} = 0 \Rightarrow p_t^* = p_{t+1}^*$$

We furthermore set these prices to be one for simplicity.

Firms in the foreign country produce the traded output good using labor and input of traded goods using the production technology:

$$f(l_t^*, k_t^*) = A_{t+1}^* (l_t^* + k_t^*) \quad A_{t+1}^* > i_t^* \quad (23)$$

Firms are run by managers. These managers have wealth at date t of w_t^* units of the good. They die with probability $1 - \sigma^*$ at the end of each period, and at death, consume their wealth. Thus they maximize,

$$\sum_{t=1}^{\infty} (\sigma^*)^{t-1} (1 - \sigma^*) w_t^* \quad (24)$$

Foreign firms may choose to borrow in foreign currency or dollars. Suppose first that the firm only borrows in foreign currency. This case follows readily from our U.S. analysis. The firm can promise repayments up to $A_{t+1}^* (l_t^* + k_t^*)$. The firm raises foreign currency debt at the interest rate of i_t^* up to this maximum amount and

uses the proceeds to hire labor l_t^* . The firm budget constraint gives,

$$w_t^* + k_t^* + l_t^* = \frac{\theta^* A_{t+1}^*}{1 + i_t^*} (k_t^* + l_t^*) \Rightarrow k_t^* + l_t^* = w_t^* \frac{\theta^* A_{t+1}^*}{(1 + i_t^*) - \theta^* A_{t+1}^*} \quad (25)$$

and firm profits are:

$$A_{t+1}^* (l_t^* + k_t^*) - \theta^* A_{t+1}^* (l_t^* + k_t^*) = w_t^* A_{t+1}^* \frac{1 - \theta^*}{1 - \frac{\theta^* A_{t+1}^*}{1 + i_t^*}}. \quad (26)$$

Households that work for this firm receive their wages of l_t^* and invest these funds at the world interest rate of i_t^* until date $t + 1$ when they consume.

Next take the case where foreign firms choose to borrow in dollars from world investors rather than in foreign currency. Why would they do this? It is because borrowing in dollars and taking the exchange rate risk is “cheap”:

$$i_t + (E_t s_{t+1} - s_t) < i_t^* \quad (27)$$

i.e. because of the convenience yield on dollar claims. Indeed a firm that chooses this dollar option will raise strictly higher resources at date t from the bond issue, hire more labor, and make more profits at $t + 1$ compared to the case of foreign currency borrowing.

It is worth pausing and noting the mechanism behind “cheap.” Informally, observers often make the argument that emerging market firms borrow in dollars because the interest rate in dollars, i_t , is lower than that of home, i_t^* . Without a convenience yield on dollar claims, i.e. if $i_t + (E_t s_{t+1} - s_t) = i_t^*$, the argument needs further assumptions. That is, in the case that U.I.P. holds the lower dollar interest rate is matched by a high expected dollar appreciation so that a borrower should expect a greater future debt burden when contracting dollar liabilities. A typical further assumption is that due to risk-shifting or bailout possibilities the borrower does not internalize the cost of this future debt burden. For example, the borrower discounts the future debt burden at $\beta^* < 1$, so that the effective borrowing cost as perceived by the borrower is $i_t + \beta^* (E_t s_{t+1} - s_t) < i_t^*$. But this argument suggests that emerging market firms should all be borrowing in the globally lowest interest rate currency – say Yen or Swiss Francs rather than Dollars. The convenience yield hypothesis is specifically about the dollar. Dollar borrowing is cheaper because demand for dollar safe assets generates a wedge in the U.I.P condition, as in (27). We could imagine a richer model where the risk-shifting and the convenience yield

explanation are both present. In this case, for a borrower with discount factor β^* , the perceived cost of dollar borrowing is,

$$i_t + \beta^*(E_t s_{t+1} - s_t) = i_t^* - \beta^* \lambda_t - (1 - \beta^*)(i_t^* - i_t)$$

The attraction of dollar borrowing relative to local currency borrowing at i_t^* stems from both $\lambda_t > 0$ and the lower dollar borrowing rate, $i_t^* - i_t > 0$. Countries with high local interest rates, i_t^* , and high risk-shifting problems, $\beta^* \ll 1$, will opt for the globally lowest interest rate borrowing (e.g., Yen). The dollar borrowing countries will be those with intermediate interest rates and risk-shifting problems. This is a testable implication of the model, although we are unaware of research pursuing this implication.

The foreign-firm dollar borrowing of the model captures the non-US dollar borrowing market, including the Eurodollar market. Shin (2012) documents that European banks' dollar assets and liabilities are of the same order of magnitude as U.S. banks' dollar assets and liabilities. Shin reports numbers of about \$10 trillion in 2010, indicating the relevance of these entities in the world dollar market. Shin also makes the point that a substantial amount of this activity reflects European banking activities where both borrowers and lenders are in dollars – that is, these are truly global dollar banks. Moving from the bank to country perspective, Lane and Shambaugh (2010) document the large net dollar liabilities of non-US countries. McCauley, McGuire and Sushko (2015) puts this number at \$8 trillion in 2014. These numbers underscore the importance of the non-U.S. dollar borrowing and lending markets.

Suppose that the firm sells Q_t^* dollars of bonds this way and raises $Q_t^* S_t$ units of goods in this way. We impose the financial constraint that the maximum number of dollar bonds issued by this firm is,

$$Q_t^*(1 + i_t)E_t S_{t+1} \leq \theta^* A_{t+1}^*(k_t^* + Q_t^* S_t) \quad (28)$$

On the left is the expected repayment on the bonds in units of foreign currency. As before the financial constraint places a limit on the maximum face value of bonds issued, parameterized by θ^* . Also note that since the payment is in dollars and involves exchange rate risk, we have used $E_t S_{t+1}$ in the constraint. We will assume shocks are small enough that there is no default in equilibrium (e.g., wealth w_t^* is large enough that the firm-owners can absorb losses).

We note that dollar safe asset demand implies the U.I.P violation:

$$(1 + i_t)E_t \frac{S_{t+1}}{S_t} \approx 1 + i_t^* - \lambda_t.$$

Then, solving for Q_t^* , with equation (28) binding, we find that:

$$Q_t^* S_t = w_t^* \frac{\theta^* A_{t+1}^*}{1 + i_t^* - \lambda_t - \theta^* A_{t+1}^*}. \quad (29)$$

And profits, based on the realization of s_{t+1} are,

$$\begin{aligned} \Pi_t^*(s_{t+1}) &= A_{t+1}^*(w_t^* + Q_t^* S_t) - Q_t^*(1 + i_t)S_{t+1} \\ &= A_{t+1}^* w_t^* + A_{t+1}^* Q_t^* S_t - Q_t^* S_t (1 + i_t + s_{t+1} - s_t) \\ &= A_{t+1}^* w_t^* + w_t^* \frac{\theta^* A_{t+1}^*}{1 + i_t^* - \lambda_t - \theta^* A_{t+1}^*} (A_{t+1}^* - (1 + i_t + s_{t+1} - s_t)) \\ &= A_{t+1}^* w_t^* \left(\frac{(1 - \theta^*) - \theta^* (s_{t+1} - E_t[s_{t+1}])}{1 - \frac{\theta^* A_{t+1}^*}{1 + i_t^* - \lambda_t}} \right) \end{aligned} \quad (30)$$

We can compare this last expression for profits to that in (26). Note the dependence of profits on $s_{t+1} - E_t[s_{t+1}]$. If the dollar unexpectedly appreciates, then net worth falls because of currency mismatch. The effect is also increasing in leverage, θ^* . That is, more dollar debt relative to local currency assets exacerbates this risk. Also notice that when $\lambda_t > 0$, the effective interest rate on borrowing is lowered to $i_t^* - \lambda_t$, resulting in higher profits compared to (26). The benefit of dollar borrowing is cheaper financing, driven by the positive convenience yield, while the cost is exposure to exchange rate risk.

To close the foreign block of the model, we suppose that every firm in the economy is a conglomerate composed of two divisions. One division, in fraction γ , is the “multi-national” that can raise dollar financing and does so to reduce costs.⁵ The other part $(1 - \gamma)$ is the local business that only can raise local financing. The conglomerate pools its capital at the end of every period and splits it equally between its two divisions in

⁵We are making a parametric assumption here that the multinational’s borrowing choice is at the corner where dollar borrowing is preferred. Although firms are risk neutral, the financial constraint of our model induces a benefit from hedging. In states of the world with high λ_t , the marginal value of unit of net-worth (k_t^*) is high. We can see this by comparing equations (26) and (30). In high λ_t states, the dollar will be appreciated so that a firm will want to have more resources in this state. As a result, dollar borrowing is riskier in a meaningful way than local currency borrowing. We discuss the issue further in Section 4.6.

the next period. This conglomerate modeling means that k_t^* is the only foreign state variable; i.e., we do not need to keep track of the capital in each type of firm when solving for equilibrium.

Output at date $t+1$ is the sum of output from the two divisions of the conglomerate net of debt repayments:

$$Y_{t+1}^* = A_{t+1}^* W_t^* \left((1 - \gamma) \left(1 + \frac{\theta^* A_{t+1}^*}{1 + i_t^* - \theta^* A_{t+1}^*} \right) + \gamma \left(1 + \frac{\theta^* A_{t+1}^*}{1 + i_t^* - \lambda_t - \theta^* A_{t+1}^*} - \frac{\theta^* (s_{t+1} - E_t[s_{t+1}])}{1 + i_t^* - \lambda_t - \theta^* A_{t+1}^*} \right) \right) \quad (31)$$

Note that since $\lambda_t > 0$, the multi-national finances itself more cheaply and produces more output than the local business. The cost is currency mismatch which may lead to larger debt repayments than expected.

Foreign firms also produce dollar liquidity. Define global liquidity as $Q_t + Q_t^*$. We thus alter the international market equilibrium to take global liquidity as the argument:

$$\lambda_t = \lambda(Q_t + Q_t^*). \quad (32)$$

We assume that new firms are born each period with capital of W^{N*} . Then the dynamics of net worth are:

$$W_{t+1}^* = W_t^* (1 - \gamma) (1 - \sigma^*) \frac{A_{t+1}^* (1 - \theta)}{1 - \frac{\theta A_{t+1}^*}{1 + i_t^*}} + \gamma (1 - \sigma^*) \Pi_t^* + W^{N*} \quad (33)$$

where we have noted that Π_t^* depends on the realized exchange rate at date $t + 1$.

4.2 Equilibrium and steady state

The equilibrium has two state variables, (W_t, W_t^*) . The non-stochastic steady state satisfies (12) and

$$W_{SS}^* = W_{SS}^* (1 - \gamma) (1 - \sigma^*) \frac{A_{SS}^* (1 - \theta^*)}{1 - \frac{\theta^* A_{SS}^*}{1 + i_{SS}^*}} + \gamma (1 - \sigma^*) \Pi_{SS}^* + W^{N*}. \quad (34)$$

In order to compute impulse response paths, we need to tackle a more complex problem than in previous sections. The equilibrium convenience yield and exchange rate are functions of (W_t, W_t^*) , and the dynamics of W_t^* is a function of the equilibrium convenience yield and exchange rate. We solve this fixed-point problem iteratively: for a given shock at $t + 1$, we compute the path of the state variables and convenience yield given an initial guess of the linear map between the state variables and convenience yield. Then given the path of the

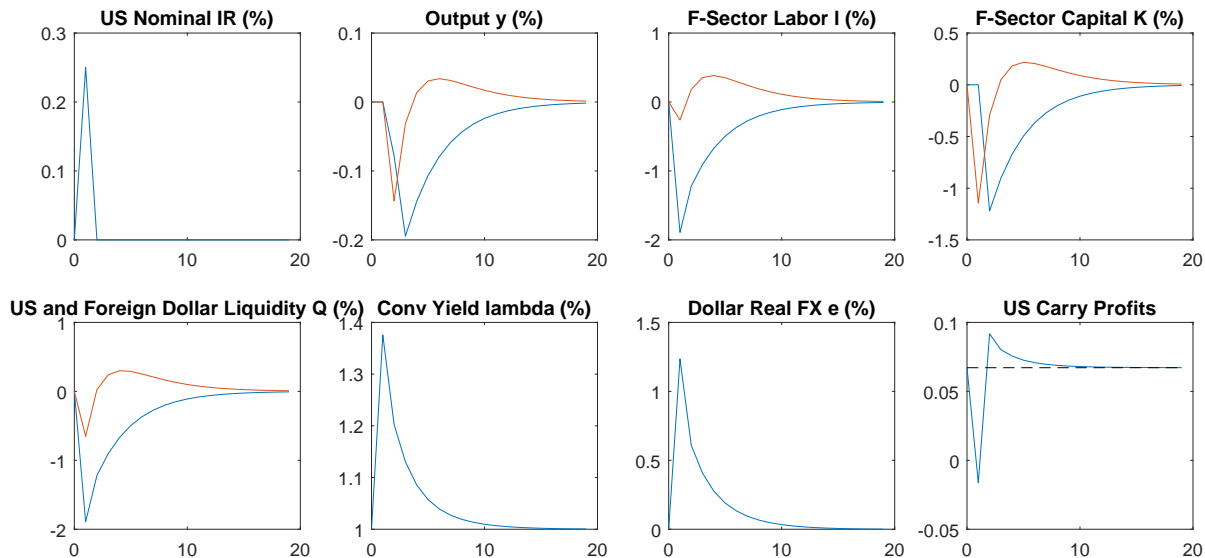


Figure 5: Impulse response to a U.S. monetary policy shock of 0.25%

We consider a 0.25% shock to i_t in period $t + 1$ of the model. In blue we plot the response of U.S. variables while in red we plot foreign variables. The top-left panel plots i_t , with the x -axis in periods. The top-second panel plots output, as a percentage deviation from steady-state. The top-right panels plot F-sector labor and capital, as percentage deviation from their steady-state values. The bottom panels plot dollar liquidity, the convenience yield, real dollar exchange rate, US bank carry profits, all except the last as percentage deviations from their steady-state values. See Table 5 for parameter values.

convenience yield we compute the exchange rate at $t + 1$ and the implied path of the state variables, etc. We iterate until convergence. Given that the model has only a single shock at $t + 1$, this problem is fairly tractable.

4.3 Monetary policy spillovers

Figure 5 presents the effects of monetary policy tightening in the U.S. on the foreign country and shows the spillover of U.S. monetary policy to the rest-of-the-world, which is a central result of our analysis. We also present the effects on the U.S. for comparison. Blue corresponds to the U.S., and red to the foreign country. Tightening at $t + 1$ leads to an appreciation in the dollar, s_{t+1} rises, inducing losses to the multinationals. As a result, K^* , foreign output, and Q^* fall at date $t + 1$. Note that the fall in Q^* further amplifies the shock since it tightens safe asset supply, increases λ , and adds to the dollar appreciation.

Capital and output rise sharply in $t + 2$. This is because the losses are reversed in period $t + 2$ as the high

convenience yield lowers the cost of borrowing dollars for foreign firms and hence leads to high profits and fast capital growth. In the figure, they overshoot the steady-state levels, but this result is parameter dependent. With other parameters, the model produces a fall and then recovery in output.

One aspect of transmission that may not be obvious on first glance is that monetary policy tightening changes the expected flow cost of borrowing indirectly through λ and not through a direct i channel. Consider a hypothetical new foreign firm with a clean balance sheet that borrows in dollars at time $t + 1$ after i_{t+1} is raised 25 basis points. One may think that as the firm borrows in dollars and dollar rates are higher, this firm's expected cost of borrowing is increased by 25 basis points. But this is not correct. The expected borrowing cost, in local currency, is:

$$i_{t+1} - (E_{t+1}s_{t+2} - s_{t+1}) = i_{t+1}^* - \lambda_{t+1}.$$

Holding λ_{t+1} constant, we can see that the firms' borrowing cost only depends on i_{t+1}^* . The exchange rate movements offset the 25 basis point change in i_{t+1} . However, as noted, λ_{t+1} rises when i_{t+1} is increased which results in a decrease in the dollar borrowing cost for the foreign firm (and not an increase). Of course the net effect on foreign firms depends both on the balance sheet effect via K_t^* and this flow cost effect.

Figure 6 presents a different experiment. We lower A_{t+1} for the U.S. unexpectedly at date $t + 1$. The impact on the U.S. (blue) is as expected: borrowing, F-capital, F-labor, and output all fall. The effect is persistent through the financial accelerator effects of the model. The effects on foreign are novel. The U.S. recession leads to a decline in dollar liquidity, an increase in the convenience yield and an appreciation in the U.S. dollar. As a result of the currency mismatch, foreign firms suffer temporarily. The economics here are exactly as in the case of the U.S. monetary policy tightening.

The effects documented in Figure 6 reveal a financial spillover. The U.S. recession leads to a recession abroad, but the channel is not via reduced demand for foreign goods (as we have left this channel out of the model) but rather through the impact on dollar liquidity and the exchange rate.

In practice, the emergence of this spillover will depend on the response of U.S. monetary policy. If the U.S. lowers interest rates, there is an offsetting force that weakens the dollar, and the net effect depends on the shock and the U.S. response. Our analysis of this section highlights the channels through which U.S. shocks spillover to foreign firms.

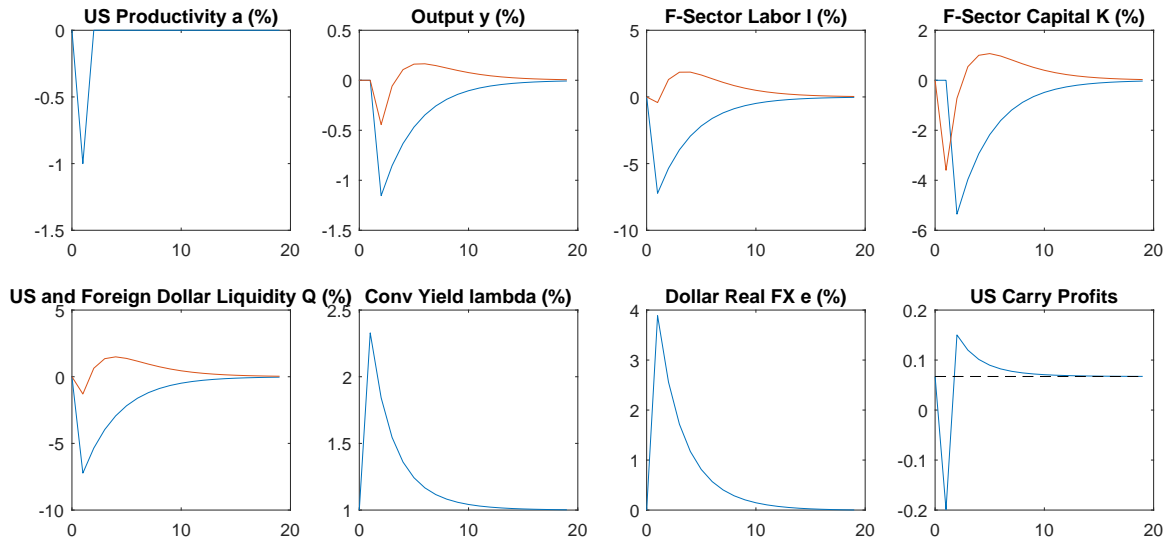


Figure 6: Impulse Responses to U.S. Productivity Shock.

We consider a -1% shock to A_{t+1} in period $t + 1$ of the model. In blue we plot the response of U.S. variables while in red we plot foreign variables. The top-left panel plots i_t , with the x -axis in periods. The top-second panel plots output, as a percentage deviation from steady-state. The top-right panels plot F-sector labor and capital, as percentage deviation from their steady-state values. The bottom panels plot dollar liquidity, the convenience yield, real dollar exchange rate, US bank carry profits, all except the last as percentage deviations from their steady-state values. See Table 5 for parameter values.

4.4 Foreign financial shock

We next consider shocks to foreign firms and show that such shocks affect foreign countries, as expected, but have a limited impact on the U.S. In conjunction with the results of the previous section, this result shows a fundamental asymmetry in the way shocks transmit across the globe.

Figure 7 plots the impulse response to a shock that reduces θ_t^* unexpectedly by 5% . We assume that the shock dissipates with autocorrelation of 0.7 . The reduction in θ^* tightens the financing constraint on foreign firms. As a result, borrowing, output, and hiring fall. The effect is magnified through the impact on the exchange rate. There is effectively a flight-to-dollar as the global dollar liquidity shrinks. The convenience yield rises and the dollar appreciates, which then amplifies the shock through the impact on foreign firms' balance sheets.

Finally, this pledgability shock creates contagion across foreign countries. Figure 8 illustrates. We consider

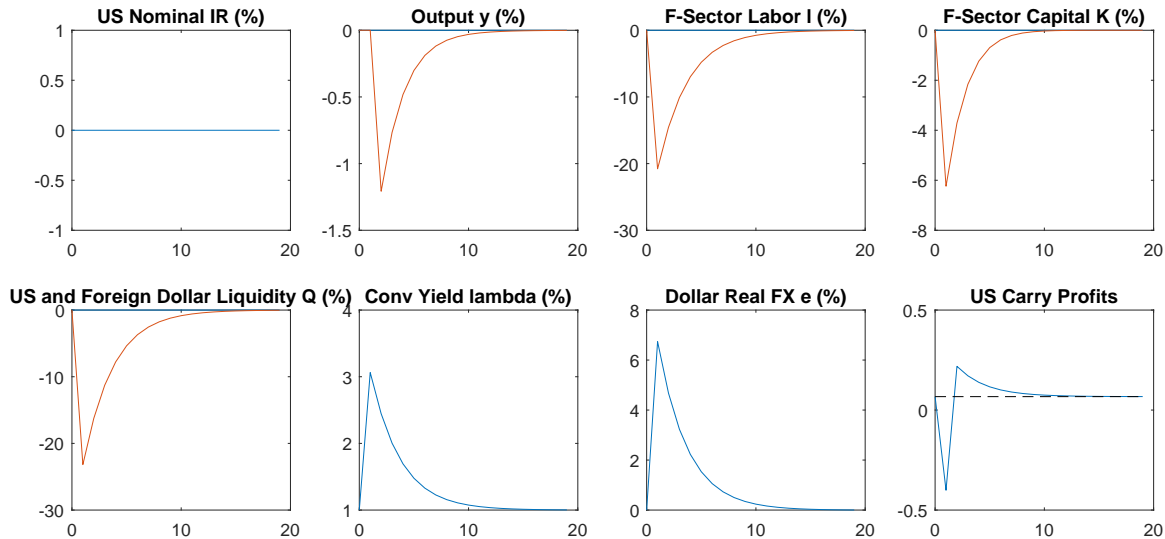


Figure 7: Impulse Responses to Foreign Pledgability Shock

At time t we reduce θ_t^* unexpectedly by 5%. The shock dissipates with autocorrelation of 0.7. In blue we plot the response of U.S. variables while in red we plot foreign variables. The top-left panel plots i_t , with the x -axis in periods. The top-second panel plots output, as a percentage deviation from steady-state. The top-right panels plot F-sector labor and capital, as percentage deviation from their steady-state values. The bottom panels plot dollar liquidity, the convenience yield, real dollar exchange rate, US bank carry profits, all except the last as percentage deviations from their steady-state values. See Table 5 for parameter values.

an extension of our model in which there are two foreign countries, each of measure one-half (i.e. 50% of the size of the foreign block of the prior setup). When the pledgability shock hits the first foreign country in period $t + 1$, global dollar liquidity drops. As a result, the convenience yield rises and the dollar appreciates. This then feeds back to both foreign countries by deteriorating the balance sheets of all foreign dollar borrowers. After period $t + 1$, both foreign countries' capital recovers, but the shocked foreign country's recovery is slower as the pledgability shock is persistent. In our parameterization, the second foreign country bounces back and overshoots steady-state output. This is because the convenience yield remains low due to the shock to the first country and hence financing terms are actually better for the second country.

4.5 A new Triffin dilemma

The patterns described by our model rationalize many patterns in the world. The importance of U.S. shocks for the world help explain the global financial cycle of Rey (2013). The asymmetry that foreign shocks have

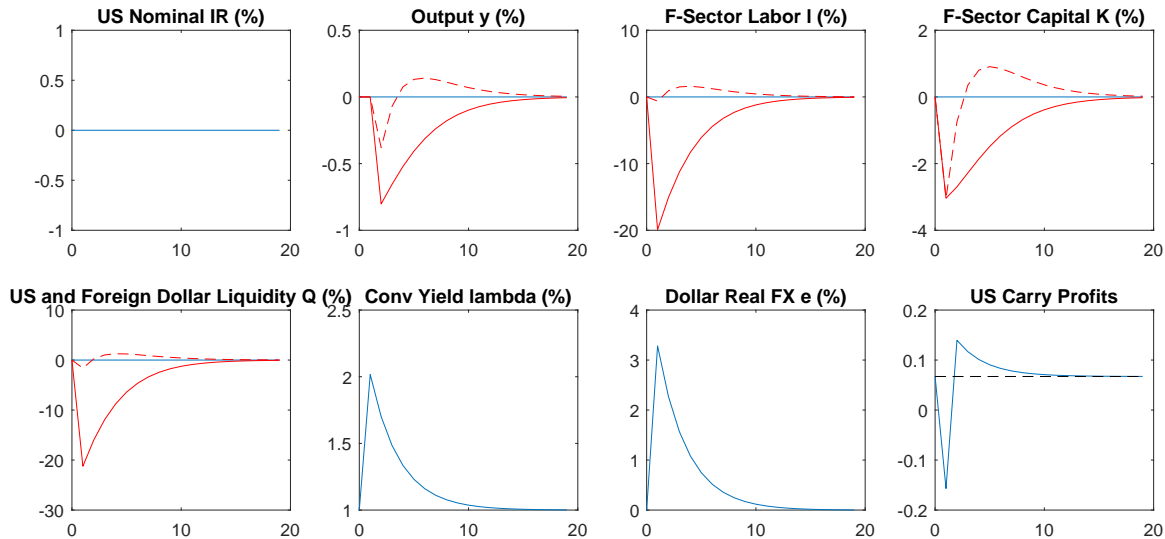


Figure 8: Impulse Responses to Foreign Pledgability Shock and Foreign Contagion

We consider two foreign countries. At time t we reduce the first foreign country's θ_t^* unexpectedly by 5%. The shock dissipates with autocorrelation of 0.7. In blue we plot the response of U.S. variables, in solid red we plot that of the first foreign country's variables, and in dashed-red we plot that of the second foreign country's variables. See Table 5 for parameter values.

limited impact on the U.S., but not other foreign countries, also squares with experience (“spillovers but limited spillbacks”) of many emerging markets (see Mishra and Rajan, 2016). Finally, the importance of the dollar as a risk factor for foreign countries is also apparent from the model. Papers such Lustig, Roussanov and Verdelhan (2014) and Wiriadinata (2018) present compelling evidence that the dollar is a priced risk factor.

In traditional open-economy macroeconomic models, these patterns would not arise. A country with free capital mobility and floating exchange rates would be able to use domestic monetary policy to largely insulate themselves from foreign shocks. Moreover, there should be no inherent asymmetry between U.S. and foreign. See Bernanke (2017).

Indeed the patterns of our model are more consistent with the pre-floating Bretton-Woods period where the dollar was the *de-jure* center country of the world monetary system. Our analysis shows that as long as there is dollar safe asset demand, the world economy even with floating exchange rates and free capital mobility will operate under a *de-facto* dollar standard. In the context of the earlier Bretton-Woods system, Triffin (1960) famously argued that as the rest of the world needs dollar assets, and as such demand scales with world growth,

the U.S. will inevitably produce dollar assets whose backing will erode with time. He foresaw a collapse where he hypothesized a run from dollar assets into gold, which in 1970 proved prescient.

In the post-Bretton Woods system as well as our model, dollar assets are produced by both the U.S. and firms in foreign countries. A U.S. dollar asset is just a claim whereby the writer of the claim agrees to pay back one-dollar of value. Whether this claim is written by a U.S. firm or a foreign firm matters only for the currency mismatch created on the issuer's balance sheet. U.S. firms have dollar revenues and can issue such claims with less mismatch; foreign firms will take on mismatch when making dollar promises. Thus in the context of the model, Triffin's logic turns on the balance between the growth in demand for dollar assets (i.e., global GDP growth), and the capacity of asset supply to keep up with this demand. But, unlike in Triffin's analysis, this supply need not be tied to U.S. growth; it can just as well arise from foreign GDP growth.⁶

There is a new version of the Triffin dilemma that arises from our analysis. As demand for dollar assets rises, currency mismatch around the world will inevitably rise. That is, the problem of the dollar for the rest of the world will only grow larger over time. The core issue that the current dollar standard poses for the world economy is not one of instability of the reserve currency but rather one of asymmetric financial spillovers.⁷ Indeed in many respects, the *de-facto* dollar standard poses a greater problem for the world than the *de-jure* standard of Bretton-Woods. In that standard, the center country acknowledged its centrality explicitly and bound itself to a set of rules to stabilize the international monetary system. In the current *de-facto* standard, the international monetary system lacks such rules.

What can foreign countries do to respond to the shocks we have considered? Foreign monetary policy is a weak instrument to deal with the problem of dollarized borrowing as has been emphasized by many scholars. Lowering interest rates stimulates some sectors in the local economy, but also depreciates the exchange rate and hence contracts the dollarized sectors of the economy. Thus, effectively foreign countries have blunt ex-post instruments to deal with shocks. Their only option is to use ex-ante instruments such as capital controls and hoarding of foreign reserves. The basic fact of the international equilibrium is that when the dollar is the safe-asset currency of choice and only the U.S. has the structure to cheaply create dollars, privately via claims

⁶There is an additional argument that undercuts the Triffin conjecture. There is not enough gold out there to support the liquidation of dollar assets into gold. (See He, Krishnamurthy and Milbradt, 2018) for this size argument.

⁷Farhi, Gourinchas and Rey (2011) make a related point on the modern version of the Triffin dilemma. They argue that the core issue is one of the U.S. government running out of the fiscal capacity needed to generate the dollar assets that the world needs. Our analysis broadens this point, since safe dollar assets can be provided by both the U.S. government and the private sector.

backed by dollar-revenue firms as in our model and publicly via central bank and fiscal policy, volatility in foreign countries via the flight-to-safety loops are unavoidable.

4.6 Hedging considerations

We have side-stepped a nuance involving the risk associated with currency mismatch in our main analysis. This section explains the issue in further detail. Although all agents have linear utility, the financial constraint creates an incentive to hedge which affects financing choices. The hedging results of this section are not novel. Although the model is somewhat different, the substance of our results are quite close to that of Caballero and Krishnamurthy (2003).

Suppose that, as in our analysis, shocks are realized at time $t + 1$, and there are no further shocks. Define the value of wealth to a manager as,

$$V(w_{t+1}^*, \lambda_{t+1}) = \sum_{k=t+1}^{\infty} (\sigma^*)^{k-(t+1)} (1 - \sigma^*) w_s^*.$$

Next suppose that γ is a choice variable of the manager. That is, we dispense with the exogenous multi-national/local split. Given that $\lambda > 0$ for date $t + 1$ and beyond, managers will always set $\gamma = 1$. Thus the wealth accumulation equation is,

$$\frac{w_{t+1}^*}{w_t^*} = \frac{A^*(1 - \theta^*)}{1 - \frac{\theta^* A^*}{1+i^*-\lambda_t}}$$

and we find that,

$$V(w_{t+1}^*, \lambda_{t+1}^*) = w_{t+1}^* (1 - \sigma^*) \sum_{k=t+1}^{\infty} \left((\sigma^* A^* (1 - \theta^*))^{k-(t+1)} \prod_{j=t+1}^{k-1} \frac{1}{1 - \frac{\theta^* A^*}{1+i^*-\lambda_j}} \right)$$

This value function is linear in wealth because the firm is risk neutral. However, the term in the sum depends on the state at time $t + 1$. Define the marginal value of wealth in the state at date $t + 1$ where the convenience yield is λ_{t+1} as,

$$m(\lambda_{t+1}) = \sum_{k=t+1}^{\infty} \left((\sigma^* A^* (1 - \theta^*))^{k-(t+1)} \prod_{j=t+1}^{k-1} \frac{1}{1 - \frac{\theta^* A^*}{1+i^*-\lambda_j}} \right)$$

The key property of this marginal value is that it is increasing in λ_j (for each j). In states of the world with

higher λ s, a firm can lever up and make more profits, for any level of wealth. As a result, the marginal value of wealth is higher in high λ states.

Next consider the choice of dollar and local currency borrowing at date t . The firm solves:

$$\max_{\gamma} E_t[\sigma^* w_{t+1}^* + (1 - \sigma^*) w_{t+1}^* m(\lambda_{t+1})] \Rightarrow \max_{\gamma} E_t[w_{t+1}^*] E_t[\sigma^* + (1 - \sigma^*) m(\lambda_{t+1})] + cov_t[w_{t+1}^*, (1 - \sigma^*) m(\lambda_{t+1})]$$

where,

$$w_{t+1}^* = A_{t+1}^* w_t^* \left\{ (1 - \gamma) \frac{1 - \theta^*}{1 - \frac{\theta^* A_{t+1}^*}{1+i_t^*}} + \gamma \left(\frac{(1 - \theta^*) - \theta^* (s_{t+1} - E_t[s_{t+1}])}{1 - \frac{\theta^* A_{t+1}^*}{1+i_t^* - \lambda_t}} \right) \right\}$$

$m(\lambda_{t+1})$ is like a stochastic discount factor in this optimization problem and drives hedging considerations.

The term $E_t[w_{t+1}^*]$ is increasing in γ when $\lambda_t > 0$. On average, increasing dollar borrowing leads to greater profits. But the covariance term $cov_t < 0$ and decreasing in γ . First, we note that $\frac{dw_{t+1}^*}{ds_{t+1}}$ is negative and linear in γ . Higher dollar debt means that wealth is more sensitive to changes in the value of the dollar. Next, note that high λ_{t+1} states are also high s_{t+1} states. Thus, the covariance term is negative and proportional to γ .

We then have a simple risk-return tradeoff. If λ_t is sufficiently high, then the cost savings on taking on dollar debt is high enough that the solution is at the corner where $\gamma = 1$. We can think of the case we have analyzed earlier as corresponding to such a parameterization. For lower values of λ_t , risk considerations enter the picture and the solution is at an interior where $\gamma < 1$. If risk is high enough, then it is possible that the solution sets $\gamma = 0$.

Finally, we note that these hedging considerations will also make the private choice of γ too high relative to the choice of a planner of the foreign country. This is due to a pecuniary externality of the model that is familiar from Caballero and Krishnamurthy (2003). Given that the result is not novel, we only mention it in passing. As γ rises, currency mismatch rises. If a shock arises (such as tightening of U.S. monetary policy) which appreciates the dollar, then firms will suffer losses and as a result the equilibrium Q^* will fall. But this will lead to a higher value of λ_{t+1} and feedback to a higher value of s_{t+1} . The planner takes this feedback into account when choosing γ and will set a lower value of γ than the private sector. In our model, as in Caballero and Krishnamurthy (2003), firms will undervalue the hedging benefit of local currency debt and overexpose themselves to currency mismatch. The new insight of our paper relative to Caballero and Krishnamurthy (2003) is that this the currency mismatch externality is particularly a problem when it comes to dollar borrowing.

5 Empirical evidence

This section discusses empirical evidence consistent with the mechanisms of the model. The results should be interpreted as a consistency check rather than a formal test of the model.

5.1 Global banks

The existing literature has interpreted the evidence on monetary policy spillovers in terms of a credit supply channel via the operation of global banks (see Cetorelli and Goldberg, 2012; Rey, 2013; Bruno and Shin, 2014; Miranda-Agrippino and Rey, 2015; Bräuning and Ivashina, 2017). When the Fed tightens monetary policy, global banks' leverage constraints tighten and as a result credit to the rest of the world contracts.

We offer a different mechanism, via safe asset demand and borrowers' financial constraints, but the patterns generated by our mechanism can also be interpreted in terms of the actions of global banks. Indeed, while the global banks are passthroughs in our model, one could enrich our model to include financial constraints on their operations which can amplify the effects we model.

Consider the global bank we introduced earlier. We described an equilibrium in which the global bank sells its dollar bonds to world safe asset investors to satisfy their safe asset demand. Here is another, economically equivalent, description of the equilibrium. The global bank offers dollar deposits to safe asset investors and holds the firm-issued dollar bonds as loans on its portfolio. It uses some of the dollar deposits to run the carry trade of buying world bonds and earning the convenience yield. Moreover, the global bank also lends in dollars to foreign firms, accepting dollar deposits from safe asset investors. This latter set of transactions can be interpreted as the Eurodollar market. That is, consistent with the data, the global bank provides dollar deposits and intermediates flows into dollar bonds and world bonds.

Now suppose that U.S. monetary policy tightens. We have seen that Q_t and Q_t^* will fall. That is bank dollar credit will fall both in the U.S. and abroad. Moreover, bank dollar liabilities will also contract, reducing the dollar safe asset supply. These are the patterns documented by empirical work on financial spillovers.

Next consider an increase in safe-asset demand as in a period of global turmoil. We would also expect that VIX will rise in this period. The effects are broadly similar to the monetary policy tightening: bank dollar credit falls, and bank liabilities contract. These are the patterns documented by Rey (2013) and Miranda-Agrippino and Rey (2015).

5.2 Search for yield

Another common explanation for dollar spillovers is via a search for yield (see Mishra and Rajan (2016)). Under this hypothesis, when the US lowers interest rates, as in the decade after the global financial crisis, US investors search for foreign yield triggering capital flows to high interest rate emerging markets. This leads to a debt build-up in the emerging market and possible financial instability.

Our model provides a different view of this chain. First, we note that over the last decade, the dollar basis has been consistently negative (see Figures 1a and 1b). If the driver of flows was US investors eschewing low-yield dollar debt and searching out high-yielding foreign debt, we would expect that foreign rates would be bid down by these flows driving the basis *positive*. The negative basis thus indicates that demand worldwide, perhaps driven by crisis-induced uncertainties, has been towards safe dollar denominated debt. From this standpoint, the “search for yield” of US investors is a natural equilibrium outcome. US investors sell highly valued dollar debt to foreign investors and run a carry trade to invest abroad.

But note that our explanation also involves foreign firms issuing the highly valued dollar debt and hence running a currency mismatch. In the search for yield explanation, the spillover would drive an increase in local currency borrowing of foreign firms. Our explanation is that firms borrow in dollars and as a result currency mismatch rises. Events of the last year in many EMs suggest that this currency mismatch problem has now come back to hurt EM performance.

5.3 Exchange rates and λ

In Jiang, Krishnamurthy and Lustig (2018), we present empirical evidence in support of equation (15) that relates the real exchange rate, e_t , to the convenience yield, λ_t . Key to our empirical work is a measure of λ_t . We explain this measurement in the context of our model in this section.

Suppose that world safe asset investors value safe dollar claims differentially. In particular, suppose that dollar claims issued by firms carry a convenience yield of λ_t but dollar claims issued by the U.S. government, safer and more liquid, carry a convenience yield of $(1 + \phi)\lambda_t$ where $\phi > 0$. What are these government bonds? Suppose that the government imposes a tax on the I-sector of τ_t . The tax is used to back a government bond. We take the limit as τ_t goes to zero so that the equilibrium is exactly as in the model we have analyzed, but can also price this almost zero supply of the government bond.

For firm dollar bonds we had posited,

$$i_t + E_t s_{t+1} - s_t = i_t^* - \lambda_t,$$

and used this equation to derive the U.I.P. condition in (13). For government bonds, we posit that,

$$i_t^T + E_t s_{t+1} - s_t = i_t^* - (1 + \phi)\lambda_t,$$

where i_t^T is the interest rate on the one-period U.S. Treasury bond. We subtract these two expressions to find that,

$$i_t - i_t^T = \phi\lambda_t.$$

So that the spread on the left is proportional to the convenience yield. In Jiang, Krishnamurthy and Lustig (2018), we consider the case where there may be a convenience yield on both U.S. and world bonds, but with a larger convenience yield on U.S. bonds. In this case, the appropriate measure of λ_t is proportional to:

$$(i_t - i_t^T) - (i_t^* - i_t^{T,*}).$$

We construct this difference (or more accurately, the negative of this difference) using Treasury bond rates and forward exchange rates, and denote the resulting measure as the “Treasury basis.”

Figure 9 presents one of the graphs from Jiang, Krishnamurthy and Lustig (2018). We plot the US/UK real exchange rate and the Treasury basis using quarterly data from 1970 to 2017. The Treasury basis is proportional to the negative of λ_t . It is apparent that there is a strong negative correlation between the basis and the exchange rate, indicating that when the basis falls (λ rises), the dollar appreciates relative to the pound. We interpret this evidence as saying that safe asset demands are a significant driver of the value of the dollar.

5.4 Monetary policy and the Treasury basis

In our model, a tightening of U.S. monetary policy leads to a widening of the basis. We present evidence consistent with this mechanism.

In Table 1, we regress the Treasury basis on contemporaneous variables including the fed funds rate, inflation,

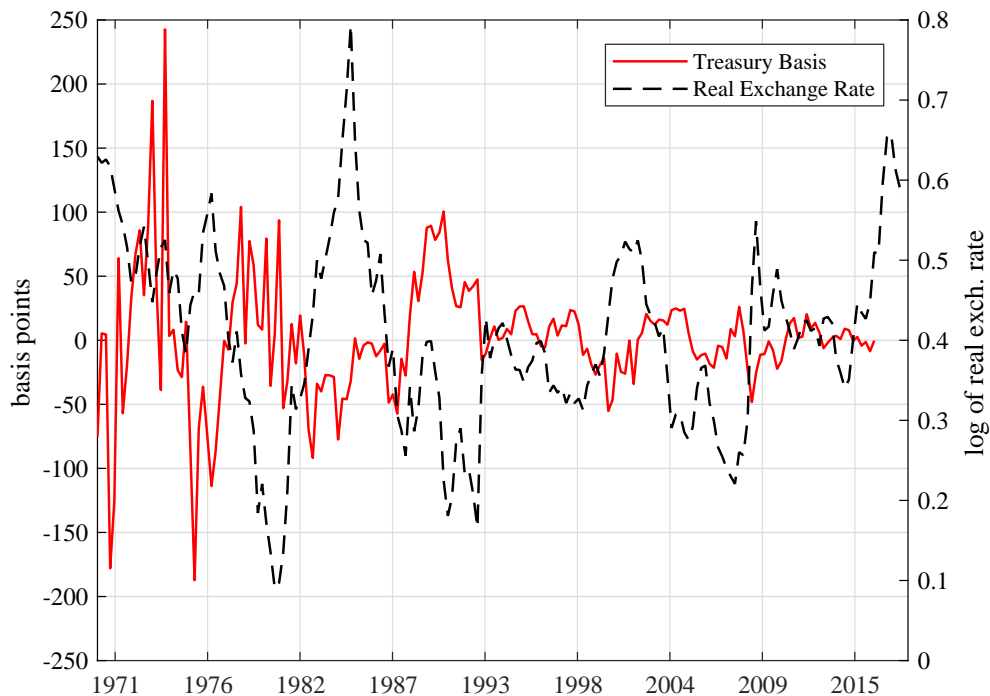


Figure 9: U.S./U.K. Treasury Basis and Real Exchange Rate

One-year maturity Treasury basis from 1970Q1 to 2017Q2 for US/UK, in basis points, and the log real US/UK exchange rate. *Note: From Jiang, Krishnamurthy and Lustig (2018).*

GDP gap and the VIX index. In univariate regressions, we find a higher fed funds rate and a higher VIX index are correlated with a more negative Treasury basis. Note that a negative Treasury basis means a higher convenience yield on US Treasuries. Thus, consistent with our model's prediction, monetary tightening raises the convenience yield. We also see that increases in the VIX correlate with a widening of the Treasury basis, consistent with a global flight-to-quality episode and safe asset demand increases. Rey (2013) finds that movements in the VIX largely characterize the global financial cycle.

We can better identify monetary policy's effects on the Treasury basis by inspecting the change in the Treasury basis around FOMC announcements. From Gorodnichenko and Weber (2016) and Nakamura and Steinsson (2018), we obtain the changes in the 30-day fed funds future's rate in 30-minute windows bracketing the FOMC press releases, from 1994 to 2014. Following Kuttner (2001), this shock can be interpreted as a US monetary policy surprise. We only consider scheduled meetings.

We obtain exchange rate movements and forward rate movements from 2pm to 3pm from Bloomberg. To

	<i>Dependent variable:</i>						
	basis						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Fed Funds Rate	-3.50*** (1.22)	-2.79*** (0.78)				-3.15*** (0.92)	-1.79 (1.12)
Inflation	6.42* (3.45)		-1.93 (2.75)			8.01** (3.20)	6.48** (3.24)
GDP Gap	-1.45 (1.54)			-3.93*** (1.27)			-2.84** (1.38)
VIX Index					-78.21*** (27.24)	-64.77** (26.92)	-78.63*** (27.36)
Constant	-28.99*** (6.72)	-15.67*** (3.37)	-20.93*** (6.27)	-30.62*** (2.80)	-7.64 (5.69)	-17.03* (8.76)	-19.56** (8.71)
Observations	118	118	118	118	110	110	110
R ²	0.14	0.10	0.004	0.08	0.07	0.17	0.20
Adjusted R ²	0.12	0.09	-0.004	0.07	0.06	0.14	0.17

Note:

*p<0.1; **p<0.05; ***p<0.01

Table 1: Explaining Treasury basis. We regress Treasury basis on fed funds rate, inflation in GDP deflator, GDP as a fraction of potential GDP, and the VIX index. 1988 to 2017.

find proxies for the changes in Treasury yields in this time window, we obtain tick-level trade prices of the US 2-year Treasury Note future and the Euro-Schatz 2-year German Government Bond future. We obtain the raw data from TickData. We use the most active contracts, and convert bond prices to yields on a semi-annual basis for the US Treasury note and on an annual basis for the German Bund.

We assume the movements in the prices of these bond futures, which expire in 3 to 9 months, proxy for the movements in actual bond yields. Then we can calculate the change in the 2-year Treasury basis by combining the futures on 2-year US and German bonds with the 2-year forward premium of USD/EUR.

We regress the change in this Treasury basis from 2pm to 3pm on two measures of monetary shock. The Fed Funds Future Shock is the unanticipated change over the 30-minute windows in the Fed Funds future. Nakamura and Steinsson (2018) also provides the Policy News Shock, which is the first principle component of the unanticipated change over the 30-minute windows in the following five interest rates: the federal funds rate immediately following the FOMC meeting, the expected federal funds rate immediately following the next FOMC meeting, and expected 3-month eurodollar interest rates at horizons of two, three and four quarters.

The news shock is rescaled such that its effect on the 1-year nominal Treasury yield is equal to one.

Results are in Table 2. High-frequency exchange rate data are only available from 2007-09-18. Nakamura and Steinsson (2018)'s data stop at 2014-03-19. We have 52 observations in total. Consistent with our model's prediction, a positive 1% monetary shock widens the Treasury basis by 27 to 42 basis points, and causes the US dollar to appreciate by 5 to 8 percent.

	<i>Dependent variable:</i>			
	Change in 2-Year US/Germany Treasury Basis		Change in USD/EUR	
	(1)	(2)	(3)	(4)
Fed Funds Future Shock	-27.01*** (6.95)		-0.05*** (0.02)	
Policy News Shock		-41.76*** (8.06)		-0.08*** (0.02)
Constant	-0.12 (0.31)	0.12 (0.28)	0.0004 (0.001)	0.001 (0.001)
Observations	52	52	52	52
R ²	0.23	0.35	0.14	0.24
Adjusted R ²	0.22	0.34	0.12	0.23

Note:

*p<0.1; **p<0.05; ***p<0.01

Table 2: High-Frequency Identification of Monetary Shock. Sep 2007 to March 2014

These high-frequency monetary shocks explain large fractions of the variation in the Treasury basis and in the exchange rate during the hour surrounding FOMC announcements. In addition, we also find

- Exchange rate movements in the hour surrounding FOMC announcements are 5 times as volatile as exchange rate movements during the same hour in other days (standard deviations are 0.52% vs. 0.12%). Exchange rate movements in the day surrounding FOMC announcements are twice as volatile as exchange rate movements in other days (standard deviations are 1.17% vs. 0.66%).
- We also calculate the exchange rate movement from 2pm in one FOMC announcement day to 2pm in the next FOMC announcement day, roughly six weeks later. The exchange rate movement over this 6-week period is not explained by the monetary shock or by the Treasury basis movement around the first FOMC announcement (R^2 is below 1%).

5.5 Secular Growth of Dollar-Denominated Debt

We examine the new version of the Triffin dilemma. As the world economy grows and the demand for dollar safe assets rises, entities around the world will produce more dollar debt to exploit the convenience yield. Foreign entities will incur currency mismatch as their incomes are in foreign currency units. We construct the time series of dollar-denominated debt in each sector of US and of foreign countries.

For US, we obtain data from Flow of Funds. For US banks, we use the total liabilities of U.S.-chartered depository institutions (FL764190005) minus their total miscellaneous liabilities (FL763190005). For US government, we use the Federal government’s Treasury securities (FL313161105). For US non-financial corporations, we use nonfinancial corporate businesses’ debt securities (FL104122005) plus their loans (FL104123005). For other financial corporations, we use money market funds’ total financial assets (FL634090005).

For foreign countries, banks’ loans are the volume of non-US banks’ Eurodollar deposits, which are the on-balance sheet dollar funding of non-US banks from deposits outside US. The data are obtained from Aldasoro et al. (2017), as of 2016. Banks’ bonds and governments’ bonds are from the international debt securities (IDS) database of the BIS, which only contain debt securities issued outside the local market of the country where the borrower resides. Non-financial corporations’ and other financial corporations bank loans and bonds are from McCauley, McGuire and Sushko (2015); data are as of 2014.

Table 3 reports the outstanding quantities of dollar-denominated debt as of the latest data. The US government is still the predominant source of dollar-denominated government debt, but in other sectors the amount of dollar-denominated liabilities borrowed by foreign issuers is comparable to their US counterparts.

From the IDS database, we also obtain the time-series of dollar-denominated international debt securities owed by banks, governments, non-financial corporations, and other non-bank financial corporations. We con-

	US	Foreign		
	Total	Total	Loans	Bonds
Banks	13.07	7.1	4.5	2.58
General Government	17.09	0.84		0.84
Non-Financial Corporations	9.42	9	4.8	3.2
Other Financial Corporations	2.82			1

Table 3: Outstanding Quantities of Dollar-Denominated Liabilities (Trillions of Dollars)

sider two samples of foreign countries. The first sample is the G10 countries excluding US (Australia, Belgium, Canada, France, Germany, Italy, Japan, Netherlands, Spain, Sweden, Switzerland, United Kingdom). The second sample includes top 50 countries ranked by GDP (purchasing power parity), G20 countries, and 28 EU countries. The second sample has 66 countries in total.

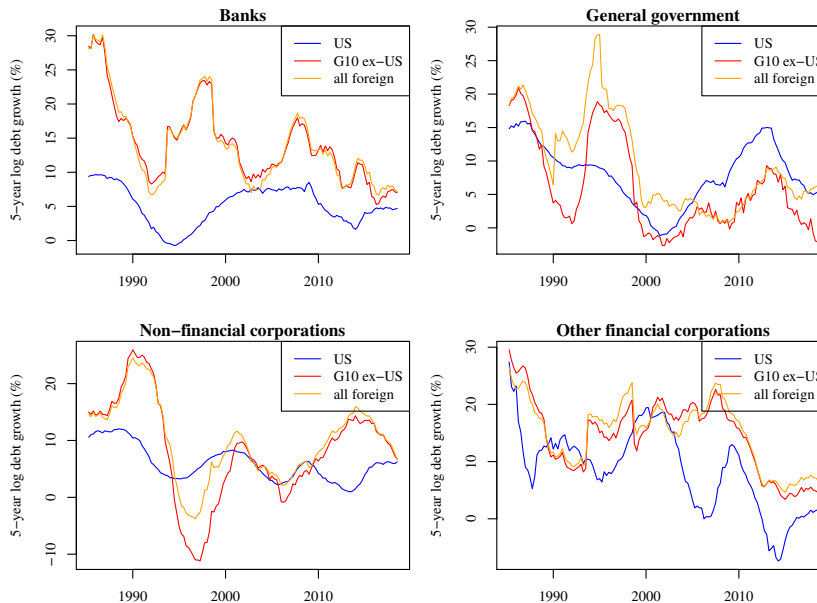


Figure 10: 5-Year Log Growth Rates of Dollar Debt Securities Issued by US and Foreign Sectors. The log growth rate is per annum.

Figure 10 plots the 5-year log growth rates of the dollar-denominated liabilities of US sectors (from Flow of Funds) and the dollar-denominated debt securities of foreign sectors (from IDS). We note that in recent years, foreign banks, foreign non-bank financial corporations, and foreign non-financial firms issue dollar-denominated debt at higher rates than their US counterparts. That is, currency mismatch has grown around the world.

The figure also suggests that foreign dollar debt issuance is more volatile than US entities' dollar debt issuance. Table 4 reports the standard deviations of 1-quarter log growth rates of these quantities. It is apparent that the growth rates in foreign sectors are also more volatile than their US counterparts.

Sector	US	G10 ex-US	all foreign countries
Banks	1.30	4.33	4.24
General government	1.94	4.62	4.64
Non-financial corporations	1.23	3.76	3.17
Other financial corporations	4.21	4.58	4.34

Table 4: Standard Deviations of 1-Quarter Log Growth Rates of Dollar Debt Securities Issued by US and Foreign Sectors. Data are from 1980 to 2018.

6 Conclusion

We have presented a model and some evidence to explain why US monetary policy has spillover effects to the rest of the world. The central ingredient in our explanation is that there exists a world-wide demand for safe dollar assets. Our model, with this ingredient, is able to rationalize a number of important patterns of the world financial system from dollar borrowing/currency mismatch, the structure of the US balance sheet, low safe US interest rates and the exorbitant privilege, spillovers of monetary policy, and that the dollar is a global risk factor.

Our analysis has left out an important piece that has been the primary subject of the literature on currency mismatch: frictions in emerging markets leads them to undervalue the hedging benefits of local currency borrowing and choose to take on currency mismatch by borrowing in low-interest rate foreign currencies. These frictions may be risk-shifting incentives due to agency conflicts or the prospect of government bailouts, or externalities whereby private borrowers do not internalize the systemic risk consequences of currency mismatch. We have omitted this ingredient to focus on our new mechanism and not because we do not find them important. A full analysis would include these frictions. It is likely moreover that our mechanism and the current literatures' mechanisms interact. That is, in the cross-section of countries, those where the undervaluation of the hedging benefits of local currency debt are highest are those that choose dollar borrowing. Moreover, periods where dollar borrowing is most attractive are periods where these countries also accumulate the most debt. We leave these issues for future research.

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A Appendix

Parameter	Notation	Estimate	Calibration Target
US			
Pledgibility	θ	0.825	Foreign/US holdings of US Treasury
Firms' Exit Rate	σ	0.48	
Productivity	\bar{A}	1.055	
Share of Global Banks	α	0.5	
Aggregate Labor	$\bar{\ell}$	7.5	
SS Interest Rate	\bar{i}	0.00	
SS F-Sector Capital	k^{SS}	1	
Global Safe Asset Investors			
SS Convenience Yield	λ	0.01	
Convenience Yield Per Dollar Liquidity	β_λ	0.05	
Foreign			
Pledgibility	θ^*	0.74	
Firms' Exit Rate	σ^*	0.48	
Productivity	\bar{A}^*	1.055	
Share of Firms that Can Borrow Dollar	γ	0.5	
Aggregate Labor	$\bar{\ell}^*$	7.5	
Interest Rate	\bar{i}^*	0.01	
SS F-Sector Capital	$k^{SS,*}$	1	
Implied Parameters			
SS US F-Sector Labor	ℓ^{SS}	6.71	Foreign/US net dollar debt issuance
SS Foreign F-Sector Labor	$\ell^{SS,*}$	3.48	
New US F-Sector Capital	k^N	0.54	
New Foreign F-Sector Capital	$k^{N,*}$	0.75	
SS US Dollar Liquidity	Q^{SS}	3.36	
SS Foreign Dollar Liquidity	$Q^{SS,*}$	1.78	

Table 5: **Parameter Values.**