Dollar Safety and the Global Financial Cycle*

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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". In contrast, shocks in foreign countries have smaller impacts on the U.S. We build a model to rationalize these facts based on 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. U.S. institutions do so against dollar collateral, while foreign institutions do so against foreign currency collateral, taking on exchange rate risk in the process. U.S. monetary shocks impact the supply of dollar safe assets, affecting dollar safe assets' premium and the dollar's value. This impact transmits across the globe and generates a global risk factor. We present evidence from movements in the Treasury basis to support the mechanism underlying our theory.

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

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1 Introduction

U.S. monetary policy appears to have sizable spillover effects on other economies around the world, as documented by a growing empirical literature. Rey (2013) and Miranda-Agrippino and Rey (2015) in particular present 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? Why is the dollar central to this mechanism?

One explanation focuses 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 foreign 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 the dollar. But the data clearly indicate that the dollar is the dominant borrowing currency when firms contract

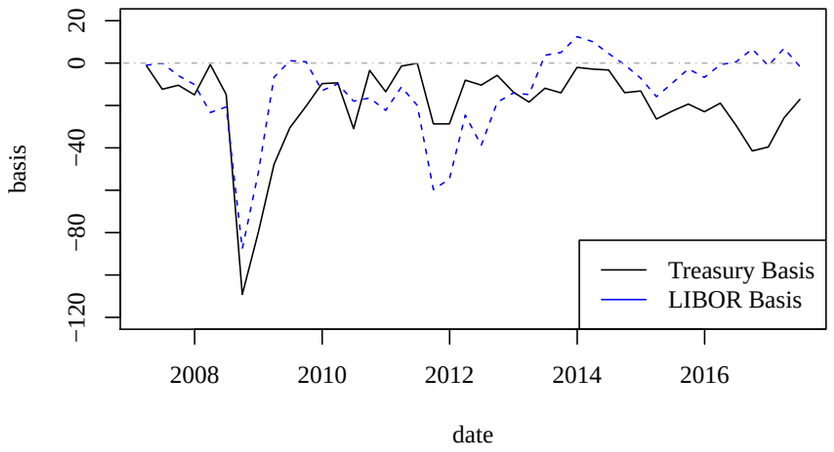
foreign currency debt (see Shin, 2012; Cetorelli and Goldberg, 2012; McCauley, McGuire and Sushko, 2015; Ivashina, Scharfstein and Stein, 2015; Bruno and Shin, 2017). Likewise, if U.S. policy rates drive reach-for-yield and international spillovers, such effects should by driven equally by policy rates in the U.S., Europe, or Japan. 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. This literature assumes that investors around the globe have a special demand for safe dollar claims, which drives up the prices and lowers the yields on such claims. In the language of Jiang, Krishnamurthy and Lustig (2018*a*), investors assign a convenience yield to safe dollar claims. Then, borrowers 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 the U.S. tightens its monetary policy, say for domestic reasons. Then the value of the dollar exchange rate rises for two reasons: (1) its interest rate rises (the standard uncovered interest rate parity channel); and (2) the tightening reduces the supply of dollar bonds through a credit channel. This renders dollar bonds scarcer and raises its convenience yield, further raising the dollar exchange rate. Borrowers around the world with currency mismatch on their balance sheets will suffer losses, and given financial constraints, these losses will impact production and hiring decisions and lead to declines in foreign output. 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 revaluation effect on the stock of their 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.[1] The black line plots

[1]In addition to the empirical support for the safe dollar phenomenon provided by the figures, there are theoretical models that aim to explain the safe-dollar phenomenon. 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.



(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

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 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 plus a currency swap reflects this valuation to a less extent because it is an imperfect substitute for the cash Treasury bond. See Jiang, Krishnamurthy and Lustig (2018*a*) for further details and empirical support for this proposition.

The convenience yield is also reflected in private dollar bonds. Figure 1a also plots the LIBOR basis, defined analogously, reflecting the spread between dollar LIBOR and foreign LIBOR, swapped into the dollar. Note the two bases move together, indicating 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 from Liao (2018). We also plot the Treasury basis for comparison. We again see that the Treasury and the corporate bases move together, but the Treasury basis is typically wider than the corporate basis. These figures provide empirical support for the main assumption of our analysis: Given the premium on issuing dollar bonds, borrowers around the world will tilt their liabilities towards the dollar to collect the convenience yield on safe dollar assets[2].

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 reduce their supply of safe dollar claims, the dollar exchange rate will appreciate. In this way, 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. In other words, our model generates

[2]We 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.

a fundamental asymmetry in shock transmission between the center and periphery. Negative foreign shocks lead to a flight to the dollar which further spreads around the non-dollar world.

These asymmetric spillover effects suggest instability in the international monetary system. Indeed, 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 the 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 is built around four economic relationships.

1. First, in our new model of exchange rate determination, the convenience yield that world investors assign to safe dollar assets enters as a "dividend" on owning the dollar. As a result, an increase in the convenience yield drives up the foreign exchange value of the dollar.

2. Second, we model the convenience yield as dependent on the supply of safe dollar bonds. For example, given a downward sloping convenience-demand curve for safe dollar bonds, an increase in the aggregate supply of safe dollar bonds leads to a reduction in the equilibrium convenience yield, and in turn, a fall in the value of the dollar. Our model has a well-defined concept of the quantity of "dollar liquidity," associated with the quantity outstanding of safe dollar bonds. A dollar shortage is thereby associated with an increase in the value of the dollar exchange rate.

3. The third piece of the model is currency mismatch on the part of dollar bond issuers. This part of the

model is familiar from the literature, and is closest to Bruno and Shin (2014)'s "risk taking channel." A rise in the value of the dollar weakens the balance sheets of currency-mismatched issuers.[3] The real consequences are reduced production and output. The financial consequence is that the aggregate supply of safe dollar bonds falls as there are less credit-worthy firms. An accelerator effect kicks-in: the higher value of dollar exacerbates the dollar shortage, increases the dollar convenience yield, appreciating the dollar, and so on.

4. The last piece of the model is a monetary policy transmission mechanism along the lines of Bernanke and Blinder (1992)'s credit channel. Tighter monetary policy constrains borrowing, production and output. The value of the dollar rises through a direct U.I.P. effect, and indirectly because the supply of safe dollar bonds shrinks. We trace out spillovers through this channels as discussed earlier.

The novelty of our model is the two-way relationship between the value of the dollar and the supply of safe dollar bonds. The monetary policy effects of the model work through this relationship. Our financial market determination of exchange rates is closest to Gabaix and Maggiori (2015) in that the demand and supply of dollars determines exchange rates. However, central to our analysis, we associate "dollars" with safe dollar bonds. Thus, for example, we interpret the increase in the value of the dollar in a crisis as in part due to a reduction in the supply of safe dollar bonds (i.e., because previously safe bonds turn unsafe), creating a dollar shortage. Jiang, Krishnamurthy and Lustig (2018*a*) and Jiang, Krishnamurthy and Lustig (2018*b*) provide evidence for the convenience yield/dollar relationship. In Section 5.2, we present evidence linking the supply of safe dollar bonds and exchange rates based on high frequency responses to Fed quantitative easing and monetary policy announcements.

In our model, the U.S. is a supplier of safe dollar bonds to the rest of the world, consistent with the balance sheet characterization of Gourinchas and Rey (2007). On average, U.S. banks earn a carry trade return by owning foreign bonds and selling dollar bonds. Likewise, in states where the dollar appreciates, the carry trade leads to losses to U.S. banks. The pattern of gains and losses resemble the "exorbitant privilege/exorbitant duty" of Gourinchas, Rey and Govillot (2011). However, there is a nuance associated with the exorbitant duty

[3]Bruno and Shin (2014) describe a model in which a rise in the value of dollar reduces the credit-worthiness of firms that have borrowed in dollars, and in turn tightens the value-at-risk contraint of banks who have extended these dollar loans. Our model describes a combined firm/bank balance sheet whereby a rise in the dollar weakens the balance sheet and tightens credit constraints on this combined firm/bank. This modeling has become standard in the macro-finance literature (e.g., see Brunnermeier and Sannikov (2014)).

in our model. If U.S. losses due to dollar appreciation is associated with an increase in the convenience yield, future carry trade returns are expected to be high, and the present value of bank profits rise. Thus, while the dollar bond holdings of foreign investors rise, and the foreign bond holdings of U.S. banks fall in this event, the future value of the exorbitant privilege rises. This capitalization effect arises because we associate the exorbitant privilege with a convenience yield rather than a risk premium and can lead to a net gain in U.S. wealth.

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 as well as an extension to model international trade.

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 $t = 0, 1, 2, ...$ 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. Households are endowed with $\bar{l}$ units of labor which they supply at date t.

We define utility over date $t + 1$ consumption as:

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

For now, consumption is in terms of the single U.S. good. In Section 3, we embed the U.S. block in an international model, and replace equation (1*) with one that describes utility over both home and foreign goods.

Households can work for firms (F), which we will think of as large corporates/banks. These firms are run by managers 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

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

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,

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

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,

$$\pi_t = \frac{p_{t+1}}{p_t} - 1. \tag{4}$$

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 parametrization 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,

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

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,

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

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,

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

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 $\bar{N}$ units of capital. Then, the law of motion for aggregate net-worth (in real terms) is,

$$N_{t+1} = N_t(1 - \sigma)\frac{A_{t+1}(1 - \theta)}{1 - \frac{\theta A_{t+1}}{1+i_t-\pi_t}} + \bar{N}, \tag{7}$$

where we use the capital letter N_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:

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

It is apparent that profit maximization implies that,

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

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,

$$K_t = N_t.$$

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.[4]

[4]Note 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 $\epsilon \to 0$, we have our specified equilibrium.

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

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

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

$$i_t = \bar{\pi} + \epsilon_t. \tag{11}$$

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

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

We require that $(1-\sigma)\frac{A^{SS}(1-\theta)}{1-\theta A^{SS}} < 1$ and $\bar{N} < N^{SS}$ 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

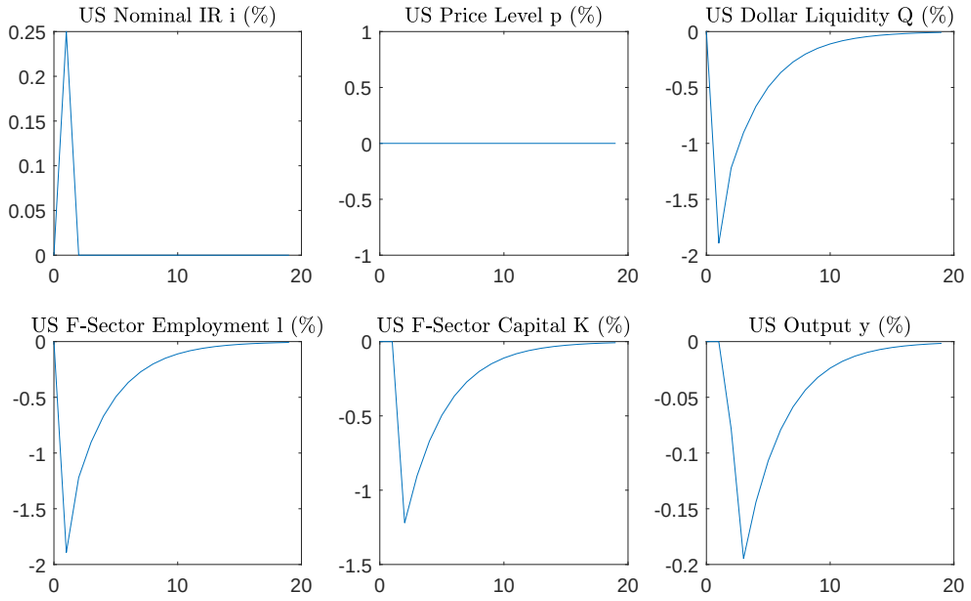


Figure 2: Impulse response to a U.S. monetary policy shock of 0.25%

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

In this section, we embed the U.S. block into a world asset market equilibrium. Building on our earlier work (see Jiang, Krishnamurthy and Lustig, 2018*a*), we consider a representative safe asset investor who determines the exchange rate dynamics.

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 $\mathcal{E}_t = \frac{S_t}{p_t}$ (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*a*). 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:

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

The term $\bar{e} = lim_{t\to\infty} e_t$ 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*a*) presents evidence to support these points, some of which we review in the empirical section.

3.2 Dollar supply, banks, 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:

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

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. We are interested in explaining how the quantity impacts equilibrium exchange rates, carry trade profits, and the dynamics of the current account.

We follow Gabaix and Maggiori (2015) in describing foreign asset trade. We suppose that U.S. households do not participate in world asset markets. Instead, a set of banks intermediate the carry trade into world bonds. Each (young) working 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 private bank deposits at rate i_t^D. The banks that receive deposits use these funds to trade with world safe asset investors in the foreign exchange market.

There is a measure $\chi < 1$ of banks. The banks' equity owners consist of (old) U.S. households as well as world investors. A bank maximizes the value of equity which is equivalent to maximizing the bank's expected profits. We describe ownership of banks further below. Take one of these χ 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 $i_t^D = i_t$.[5]

In raising d_t deposits from the household, the bank receives d_t units of the dollar bonds of this household. The bank then sells these dollar bonds to safe asset investors in return for their world bonds.[6] 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:

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

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

$$b_t^\$ \geq 0. \tag{17}$$

Given that the bank maximizes expected profits, 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 χ of the U.S. safe bonds. Define the (real) dollar liquidity produced by the U.S. as:

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

[5]Note our assumption that χ is strictly less than one is important to pin down the rate on the U.S. dollar bonds at i_t. The fraction $1-\chi > 0$ 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.

[6]Alternatively, and realistically, we can think of the bank as using the dollar bonds as collateral against a repo loan from the safe asset investor.

World investors hold this dollar liquidity, earning a low return on this investment. In turn, banks earn an expected premium on their provision of liquidity. Define bank profits in units of the world good as

$$\mathrm{E}_{t+1} = Q_t \mathcal{E}_t \left(i_t^* - i_t - (s_{t+1} - s_t) \right), \tag{19}$$

where we note that the expected carry profits are proportional to λ_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 bonds is downward sloping in quantity:

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

We note that since B_t falls when i_t rises, the U.S. 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 a reduction in B_t and a corresponding rise in λ_t.

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

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

3.3 Discussion of safe assets

The function $\lambda(Q_t)$ describes world investors' safe asset demand. Here Q_t are the bonds issued by U.S. firms. We comment on some modeling questions.

- *The safe asset literature focuses on convenience yields on U.S. Treasury bonds and financial sector debt*: Plausibly, $\lambda(\cdot)$ takes as argument an aggregate of different safe bonds including Treasuries, repos, bank deposits, AAA corporates, etc. It would be straightforward to add Treasury bonds to the model, issued by the government and funded by taxes on households. Doing so would shed light on how quantitative easing impacts outcomes. Indeed, in Section 5.2 we present evidence for the mechanisms of our analysis from asset price responses to QE announcements. We have set QE aside largely to keep the analysis focused on conventional monetary policy and the dynamics of the private sector.

- *If more U.S. entities could issue safe debt, would not the convenience yield effects disappear?*: 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 and $\lambda_t = 0$). The central mechanism in our model is that dollar safe assets are in short-supply, and in our modeling, are only created by firms. Realistically, banks are also creators of dollar safe-assets, but are limited in doing so by capital constraints, e.g., as described in Du, Tepper and Verdelhan (2017) or Gabaix and Maggiori (2015).[7] Finally, one can think of the bonds of our models as an amalgam of financial sector debt and non-financial sector debt; our firms are a representative producer.

- *If U.S. households or firms could enter international markets, would not the convenience yield disappear?*: The key assumption is not segmentation but rather the short-sale constraint on dollar bonds. If U.S. entities could own foreign bonds and short-sell dollar bonds, then the supply of dollar bonds rises and the convenience yield falls. We introduce U.S. banks, owned by households, and household segmentation primarily to clearly delineate the carry trade profits.

- *Can you talk about safe assets in a model with no risk?*: Our model describes bonds rather than safe or risky bonds. We have not embellished the corporate finance of the modeling. The key economic mechanism of our model is that negative shocks reduce the supply of bonds (Q_t). In a model with risky and safe bonds, negative shocks would turn some safe bonds risky and thereby reduce the supply of safe bonds.

3.4 Current account

We have thus far described how the equilibrium quantity of the carry trade affects the convenience yield and the exchange rate. We next discuss the implications of our model for the dynamics of the current account.

We first adjust our earlier definition of household preferences from equation (1*) to allow for trade in goods

[7] We 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 $b_t^{\$}$ 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.

and thus describe current account dynamics. The generation-t U.S. household maximizes utility,

$$E_{t+1}\left[\ \alpha_H \log c_{t+1,H} + \alpha_T \log c_{t+1,T} + \alpha_W \log w_{t+1}\ \right], \tag{1$^+$}$$

where $c_{t+1,H}$ is consumption of the U.S. home good and $c_{t+1,T}$ is consumption of the world good. We normalize by setting $\alpha_H + \alpha_T + \alpha_W = 1$.

The term w_{t+1} is a bequest of bank equity shares left to generation $t+1$. Recall that the U.S. households own some of the bank equity. At the start of period $t+1$, the old household receives shares in the banking sector worth $w_t\left(\frac{V_{t+1}+E_{t+1}}{V_t}\right)$. Here V_{t+1} is the value of the bank-equity index, in units of the world good, and E_{t+1} are bank earnings, based on the equation (19). At the end of period $t+1$, the household bequeaths shares of bank equity worth w_{t+1} to the next generation. We introduce this bequest term to connect the exorbitant privilege (i.e. carry profits) of the U.S. banks with the U.S. households' consumption decision and current account.

Finally, we acknowledge that although we model the U.S. household's consumption decisions as a function of the exchange rate e_{t+1} and the exorbitant privilege, we do not explicitly model a world consumer who values U.S. goods and accommodates the U.S. trade balance. The world investors in our model impute a convenience yield on US safe assets, in proportion to how much they hold. At the real exchange rate determined by this motive, they are assumed to have infinitely elastic demand for U.S. and foreign goods.

Consider the consumption and saving decision of an old household at date $t+1$. The household maximizes Eq. (1$^+$) subject to the budget constraint,

$$\mathcal{E}_{t+1} c_{t+1,H} + c_{t+1,T} + w_{t+1} = w'_{t+1} \equiv \mathcal{E}_{t+1}(1 + i_t - \pi_t)\bar{l} + w_t\left(\frac{V_{t+1}+E_{t+1}}{V_t}\right). \tag{22}$$

We have written the budget constraint in units of the world good. The left-hand side consists of expenditures on the home good, the world good, and the bequeathed wealth in terms of bank equity. The right-hand side is total resources, denoted as w'_{t+1}, which consists of wage income and the value of bank equity, plus earnings, bequeathed by the previous generation.

When the old household buys or sells bank shares, it trades with world investors (or to be consistent with our segmentation assumptions, the household trades with banks who broker the trade with world investors).

Since world investors are long-lived, we can price bank equity using their discount rate. Then, the equity value of the banking sector (in units of world goods) at time t is,

$$V_t = \sum_{j=1}^{\infty} \frac{E_{t+j}}{(1+r^*)^j}. \tag{23}$$

Note that bank equity is valued at the non-convenience discount rate of r^*. As we will see, bank equity is a risky security whose dollar value fluctuates with the value of the dollar. That is, in keeping with the thrust of our model, bank equity is not a safe dollar claim and thus should not carry a convenience yield.

The first-order conditions for the household are,

$$\begin{aligned} \frac{\alpha_H}{c_{t+1,H}} &= \mu \mathcal{E}_{t+1}, \\ \frac{\alpha_T}{c_{t+1,T}} &= \mu, \\ \frac{\alpha_W}{w_{t+1}} &= \mu, \end{aligned}$$

where μ is the Lagrange multiplier on the budget constraint. Log utility implies that expenditure shares are proportional to the alphas. Combining these equations and using the budget constraint we find that,

$$\mu = \frac{1}{w'_{t+1}}$$

Total imports (in foreign currency value) are,

$$c_{t+1,T} = \alpha_T w'_{t+1}$$

while total exports are,

$$\mathcal{E}_{t+1}(1 + i_t - \pi_t)\bar{l} - \alpha_H w'_{t+1}$$

and the current account (expressed in foreign currency units) is,

$$CA_{t+1} = \left((1 + i_t - \pi_t)\bar{l} - (\alpha_T + \alpha_H) \frac{w'_{t+1}}{\mathcal{E}_{t+1}} \right) \mathcal{E}_{t+1} \tag{24}$$

with wealth,

$$\frac{w'_{t+1}}{\mathcal{E}_{t+1}} = (1 + i_t - \pi_t)\bar{l} + w_t \left(\frac{V_{t+1} + E_{t+1}}{V_t} \right) \frac{1}{\mathcal{E}_{t+1}} \tag{25}$$

The dynamics of the current account are fully described by the dynamics in the dollar value of wealth, $\frac{w'_{t+1}}{\mathcal{E}_{t+1}}$. Note that the standard expenditure switching effect of the exchange rate is absent because of log-utility, whereby expenditure shares are pinned down by the alphas.

Wealth dynamics have two components: first, current carry trade profit enters as E_{t+1}; and second, the present value of future carry trade profits enter as V_{t+1}.

In steady-state, the current account deficit must be matched by a capital account surplus. Steady-state bank profits E^{SS} are positive

$$E^{SS} = Q^{SS}\mathcal{E}^{SS}\lambda^{SS} \tag{26}$$

and proportional to λ^{SS}. The U.S. household owns shares in the banking sector and thus receives a dividend proportional to E^{SS}. To compute how much dividends the U.S. household receives, we need to compute w^{SS}. The F.O.C. for the bequest gives that $\alpha_W w'_{t+1} = w_{t+1}$. Using the expression for w'_{t+1} from the budget constraint, we find that,

$$w^{SS} = \alpha_W \left(\mathcal{E}^{SS}(1 + i^{SS} - \pi^{SS})\bar{l} + w^{SS}(1 + r^*) \right)$$

or,

$$w^{SS} = \frac{\alpha_W}{1 - \alpha_W(1 + r^*)} \mathcal{E}^{SS}(1 + i^{SS} - \pi^{SS})\bar{l}. \tag{27}$$

We require that $\alpha_W(1 + r^*) < 1$ for this wealth to be well-defined (if the bequest parameter α_W is too large, wealth diverges). This expression is strictly positive indicating that the household holds a positive share of bank equity in steady state.[8] The earnings from this ownership of banks is the capital account surplus and finances a current account deficit.[9]

[8]The steady-state value of bank equity is $V^{SS} = \frac{E^{SS}}{r^*}$ and the household owns $\frac{w^{SS}}{V^{SS}}$ fraction of the banking sector. Multiplying this share times the earnings of the banking sector gives that,

$$CA^{SS} = r^* \frac{\alpha_W \mathcal{E}^{SS}(1 + i^{SS} - \pi^{SS})\bar{l}}{1 - \alpha_W(1 + r^*)}.$$

[9]If there is no shock after period $T > 0$, the model will eventually return to the steady state. For $t \gg T$, household income

3.5 Impulse response function

The model with the exchange-rate equilibrium still has a single state variable, N_t. The steady-state capital level is given as before from equation (12).

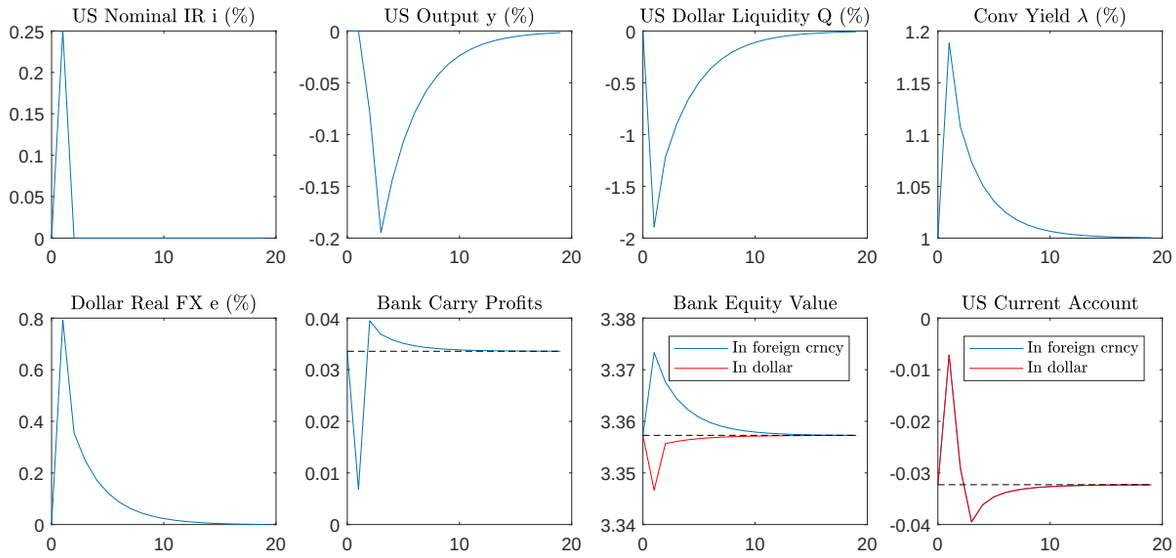


Figure 3: Impulse response to a U.S. monetary policy shock of 0.25%

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 rest of the panel trace out the endogenous variables in our economy. All except for the current account, the carry profits, and the banks' equity value 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 $t+1$. The U.S. output behaves exactly the same as in the U.S.-only model. The new results are in the following panels. The rise in the U.S. interest rate reduces safe asset supply, the U.S. dollar liquidity Q_{t+1}, and hence increases the convenience yield, λ_{t+1}. The dollar appreciates at date $t+1$ both because of the rise in the nominal interest rate i_{t+1} and the increase in the convenience yield λ_{t+1}.

U.S. banks lose money on impact since they are running a carry trade that is long the foreign currency and

$e_{t+1}(1+i_t-\pi_t)\bar{l}$ reverts to its steady-state value, and the realized return on the bank equity is $1+r^*$. Then,

$$w_{t+1} = \alpha_W \mathcal{E}^{SS}(1+i^{SS}-\pi^{SS})\bar{l} + \alpha_W(1+r^*)\cdot w_t.$$

Since $0 < \alpha_W(1+r^*) < 1$, starting from any initial value of w_t, $\lim_{s\to\infty} w_{t+s} = w^{SS}$.

short the dollar, but they subsequently make money as the convenience yield λ_{t+k} rises. This pattern of losses and gains is reflected in the panel of the banks' carry profits. The value of bank equity, measured in foreign currency, rises on impact because the present value of bank profits is increasing in the expected convenience yield λ_{t+k}. In this parameterization, bank equity value declines in dollar terms because the dollar appreciates more than the foreign-currency value of bank equity. As a result U.S. wealth falls and the U.S. household reduces consumption causing the current account (last panel) to improve.

3.6 Discussion: international financial equilibrium

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, earning an "exorbitant privilege." 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.

However, note that the steady-state net-foreign-asset (NFA) position of the U.S. is zero in our model. The U.S. is simply long foreign bonds and short dollar bonds. Our model does not speak to the trends in the NFA which are evident in the data.

- 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 our 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.

Lastly it is useful to contrast our convenience yield mechanism for the exorbitant privilege with the risk-sharing mechanism of Gourinchas, Rey and Govillot (2010) and Maggiori (2017). In their models, the U.S. provides safe assets to the rest of the world as part of a risk-sharing arrangement. Gourinchas, Rey and Govillot (2010) rationalizes the U.S. balance sheet as due to the U.S. being less risk averse than foreign, as a result of which the U.S. shorts bonds to the rest of the world and holds a levered claim on the world endowment. Foreign holds the safe claim issued by the U.S., and effectively holds a less risky claim on the world endowment. Maggiori (2017) derives this portfolio preferences from differences in financial development, rather than differences in risk aversion. But in both models, the mechanism of exorbitant privilege is in terms of a risk premium: the U.S. earns a risk premium on its levered risk portfolio most of the time, but in the event of a world downturn, such as a global financial crisis, the U.S. pays out on the insurance to the rest of the world and transfers wealth to the rest of the world. A key implication of this risk-sharing model is that the U.S. runs a current account deficit, equal to the risk premium, on average, but in a crisis runs a current account surplus as it pays out on the insurance it provides to the rest of the world. There is a further twist that is studied by Maggiori (2017). If the U.S. transfers wealth to the rest of the world in a crisis, then foreign demand for U.S. goods would rise in a crisis, and as a result the value of foreign currency relative to the dollar would have to rise. But as Maggiori (2017) notes, these crisis predictions regarding surplus and the dollar depreciation appear at odds with the patterns in the 2007-2009 global financial crisis. Maggiori (2017) suggests a resolution by introducing higher trade costs in crisis states.

In our model, the world pays a convenience yield to own dollar assets. Because it is a convenience yield, as opposed to a risk premium, the U.S. earns a seigniorage from providing safe dollar claims without incurring the crisis liability. Moreover, the convenience yield may rise in a crisis, leading to higher present and future profits from this seignorage. This last implication of our model highlights the new mechanism at work in our model.

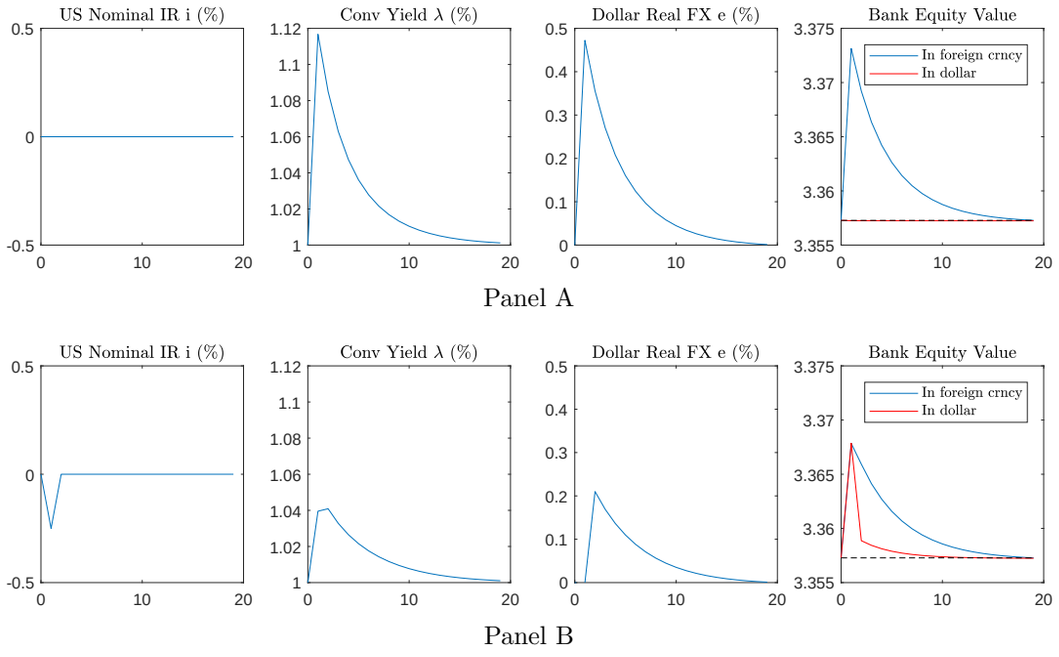


Figure 4: Effect of a flight-to-dollar shock on capitalized carry trade profits

Capitalized carry trade profits are measured by bank equity value in the right-most figures. The shocks in both panels dissipate with an autocorrelation of 0.8. In Panel A we plot the impulse response to a safe asset demand shock of 10 basis points. In Panel B we plot the impulse response to a safe asset demand shock of 10 basis points and a US nominal interest rate shock of -25 basis points. See Table 5 for parameter values.

Figure 4 illustrates this point in the context of a simulated flight-to-dollar episode. In Panel A, we trace the impulse response to a safe asset demand shock. We increase the convenience yield (λ_{t+1}) in period $t+1$ unexpectedly by setting $\epsilon^{\lambda}_{t+1} = 0.1\%$, which gradually dissipates with an autocorrelation of 0.8. The shock increases the convenience yield and the value of the dollar. The shock also has no impact on U.S. output or dollar liquidity, which are determined entirely by U.S. productivity and monetary policy. The last figure in the panel traces the impact of bank equity value. We note that bank equity value rises in foreign currency reflecting higher

future carry trade profits. However, when converted back to dollars, the rise in the dollar value almost perfectly offsets the rise in the value of these profits. This should be expected in our model. To a first order, the value of bank profits is, $V_t \approx \mathbb{E}_t \sum_{j=1}^{\infty} Q_{t+j-1} \frac{\lambda_{t+j-1}}{(1+i^*)^j}$, while the exchange rate is $s_t = \mathbb{E}_t \sum_{j=0}^{\infty} \lambda_{t+j} + \mathbb{E}_t \sum_{j=0}^{\infty} (i_{t+j} - i^*_{t+j})$. Both reflect a common $\mathbb{E}_t \sum_{j=0}^{\infty} \lambda_{t+j}$ term which to a first-order offset each other.

In Panel A, we fix U.S. response to the flight-to-dollar. In Panel B we suppose that the Fed lowers interest rates, partially offsetting the flight-to-dollar as well as inducing an expansion in Q_t. In this case, we see that the convenience yield does not rise as much (because Q_t rises), and the dollar appreciation is also smaller (since i_t falls and the convenience yield rise is more muted). The rise in Q_t allows banks to expand carry trade operations and induces higher future profits. The smaller rise in the dollar works to eliminate the offset effect we describe above. We can see in the last panel that bank equity value now rises both in dollar and foreign currency terms.

As this discussion makes clear, the novelty of our analysis is that a convenience yield is capitalized into wealth in terms of the future value of carry trade profits. In our analysis, we have associated this profit with U.S. banks. It is plausible that the banks are global banks rather than just U.S. banks and the profits flow to the foreign owners of these banks as well as to the U.S. owners. Indeed in our setup, the equity of the banks are owned by both U.S. and foreign agents. It is also plausible that some of the convenience yield profits flow to firms and is capitalized into the value of corporate equity.

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,

$$\frac{1}{1+i_t^*}c_{t+1}^* - l_t^* \tag{28}$$

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:

$$f(l_t^*, k_t^*) = A_{t+1}^*(l_t^* + k_t^*) \qquad A_{t+1}^* > i_t^* \tag{29}$$

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,

$$\sum_{t=1}^{\infty} (\sigma^*)^{t-1}(1-\sigma^*)w_t^* \tag{30}$$

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,

$$w_t^* + k_t^* + l_t^* = \frac{\theta^* A_{t+1}^*}{1+i_t^*}(k_t^* + l_t^*) \Rightarrow k_t^* + l_t^* = w_t^* \frac{\theta^* A_{t+1}^*}{(1+i_t^*) - \theta^* A_{t+1}^*} \tag{31}$$

and firm profits are:

$$A^*_{t+1}(l^*_t + k^*_t) - \theta^* A^*_{t+1}(l^*_t + k^*_t) = w^*_t A^*_{t+1} \frac{1-\theta^*}{1 - \frac{\theta^* A^*_{t+1}}{1+i^*_t}}. \tag{32}$$

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":

$$i_t + (E_t s_{t+1} - s_t) < i^*_t \tag{33}$$

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 (33). 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, $\beta^* << 1$, 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,

$$Q_t^*(1+i_t)E_t S_{t+1} \leq \theta^* A_{t+1}^*(k_t^* + Q_t^* S_t) \tag{34}$$

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 (34) binding, we find that:

$$Q_t^* S_t = w_t^* \frac{\theta^* A_{t+1}^*}{1 + i_t^* - \lambda_t - \theta A_{t+1}^*}. \tag{35}$$

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

$$\begin{aligned}
\Pi_t^*(s_{t+1}) &= A_{t+1}^*(w_t^* + Q_t^* S_t) - Q_t^*(1 + i_t) S_{t+1} \\
&= A_{t+1}^* w_t^* + A_{t+1}^* Q_t^* S_t - Q_t^* S_t (1 + i_t + s_{t+1} - s_t) \\
&= A_{t+1}^* w_t^* + w_t^* \frac{\theta^* A_{t+1}^*}{1 + i_t^* - \lambda_t - \theta^* A_{t+1}^*} \left(A_{t+1}^* - (1 + i_t + s_{t+1} - s_t) \right) \\
&= A_{t+1}^* w_t^* \left(\frac{(1 - \theta^*) - \theta^* (s_{t+1} - E_t[s_{t+1}])}{1 - \frac{\theta^* A_{t+1}^*}{1 + i_t^* - \lambda_t}} \right)
\end{aligned} \tag{36}$$

We can compare this last expression for profits to that in (32). 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 (32). 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.[10] 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 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.

[10] We 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 (32) and (36). 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.

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

$$Y^*_{t+1} = A^*_{t+1}N^*_t\left((1-\gamma)\left(1+\frac{\theta^* A^*_{t+1}}{1+i^*_t-\theta^* A^*_{t+1}}\right)+\gamma\left(1+\frac{\theta^* A^*_{t+1}}{1+i^*_t-\lambda_t-\theta^* A^*_{t+1}}-\frac{\theta^*(s_{t+1}-E_t[s_{t+1}])}{1+i^*_t-\lambda_t-\theta A^*_{t+1}}\right)\right) \tag{37}$$

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:

$$\lambda_t = \lambda(Q_t + Q^*_t). \tag{38}$$

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

$$N^*_{t+1} = N^*_t(1-\gamma)(1-\sigma^*)\frac{A^*_{t+1}(1-\theta)}{1-\frac{\theta A^*_{t+1}}{1+i^*_t}}+\gamma(1-\sigma^*)\Pi^*_t + N^{N*} \tag{39}$$

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, (N_t, N^*_t). The non-stochastic steady state satisfies (12) and

$$N^*_{SS} = N^*_{SS}(1-\gamma)(1-\sigma^*)\frac{A^*_{SS}(1-\theta^*)}{1-\frac{\theta^* A^*_{SS}}{1+i^*_{SS}}}+\gamma(1-\sigma^*)\Pi^*_{SS} + N^{N*}. \tag{40}$$

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 (N_t, N^*_t), and the dynamics of N^*_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 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.

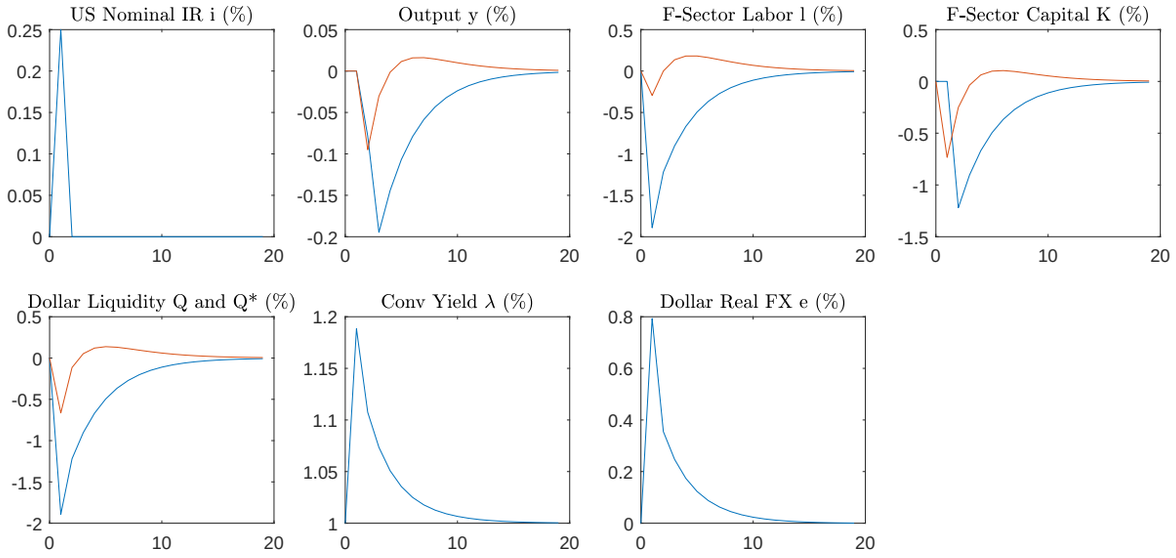


Figure 5: Impulse response to a U.S. monetary policy shock of 0.25%

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.

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 firms' 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.

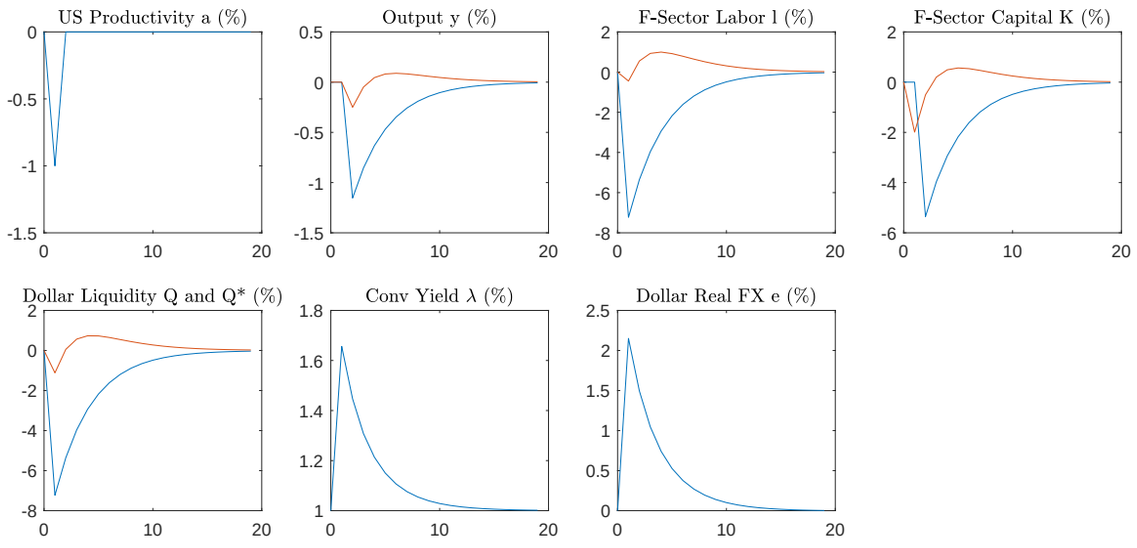


Figure 6: Impulse Responses to U.S Productivity Shock.

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.

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.

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 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 pledgeability 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

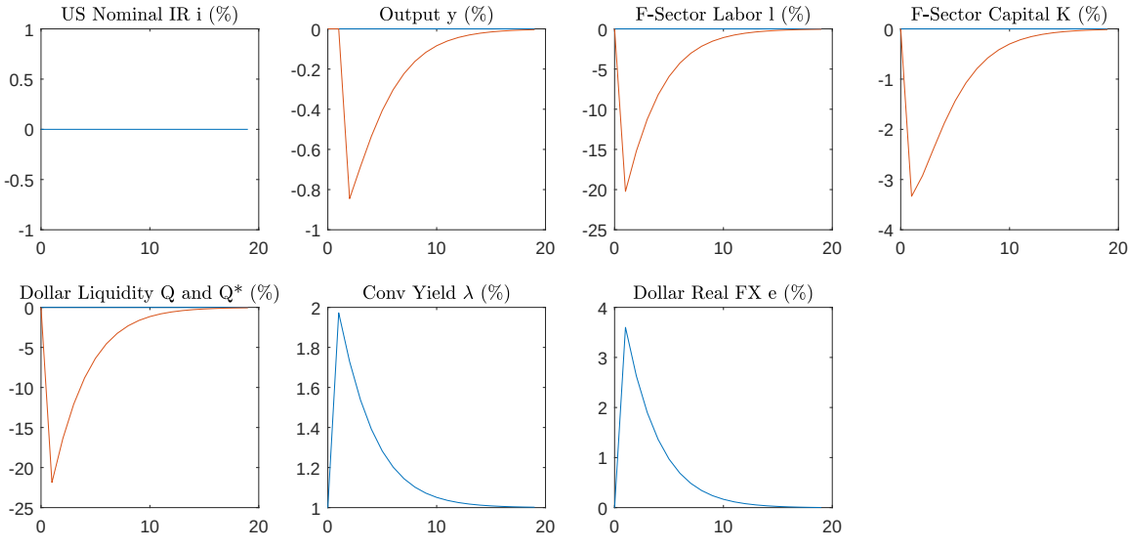


Figure 7: Impulse Responses to Foreign Pledgability Shock

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.

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 parametrization, 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 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

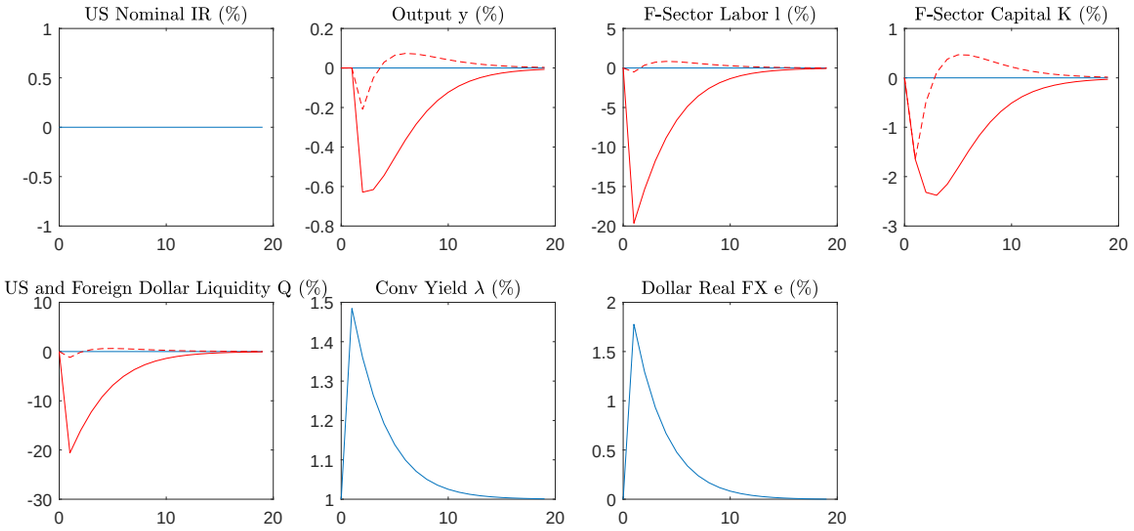


Figure 8: Impulse Responses to Foreign Pledgability Shock and Foreign Contagion

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.

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.[11]

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.[12] 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 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.

[11]There 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.

[12]Farhi, 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.

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 λs, 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 parametrization. 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. In our view, the most compelling evidence for the channel of this paper is the QE and exchange rate evidence we present below.

5.1 Exchange rates and λ

In Jiang, Krishnamurthy and Lustig (2018*a*), 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*a*), 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:

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

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."

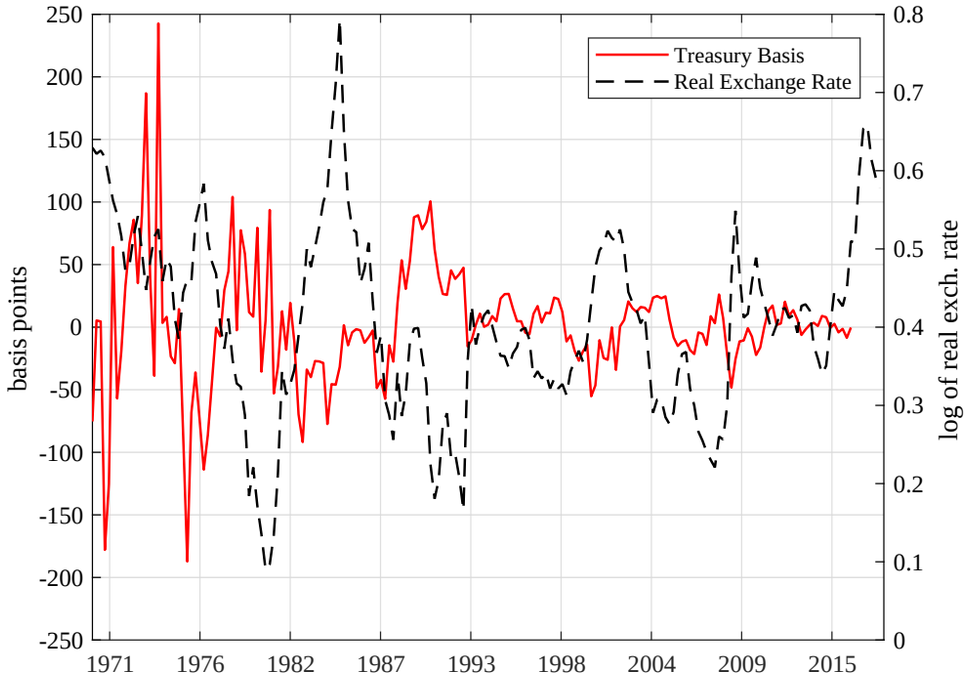


Figure 9: U.S./U.K. Treasury Basis and Real Exchange Rate

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*a*).*

Figure 9 presents one of the graphs from Jiang, Krishnamurthy and Lustig (2018a). 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.

5.2 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, 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 Treasurys. 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.

	Dependent variable:						
	basis						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Fed Funds Rate	-3.50^{***}	-2.79^{***}				-3.15^{***}	-1.79
	(1.22)	(0.78)				(0.92)	(1.12)
Inflation	6.42^{*}		-1.93			8.01^{**}	6.48^{**}
	(3.45)		(2.75)			(3.20)	(3.24)
GDP Gap	-1.45			-3.93^{***}			-2.84^{**}
	(1.54)			(1.27)			(1.38)
VIX Index					-78.21^{***}	-64.77^{**}	-78.63^{***}
					(27.24)	(26.92)	(27.36)
Constant	-28.99^{***}	-15.67^{***}	-20.93^{***}	-30.62^{***}	-7.64	-17.03^{*}	-19.56^{**}
	(6.72)	(3.37)	(6.27)	(2.80)	(5.69)	(8.76)	(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.

We can better identify monetary policy's effects on the Treasury basis by inspecting the change in the Treasury basis around FOMC announcements. Following Kuttner (2001), 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. 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 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 as in Kuttner (2001). We also use the Policy News Shock measure of Nakamura and Steinsson (2018), 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. This shock can proxy for shifts in the path of monetary policy, along the lines of forward guidance (see Gürkaynak, Sack and Swanson, 2005).

Results are in Table 2. High-frequency exchange rate data are only available from 2007-09-18. Our data on the monetary policy shock is obtained from Nakamura and Steinsson (2018), whose 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.

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

	Dependent variable:			
	Change in 2-Year US/Germany Treasury Basis		Change in USD/EUR	
	(1)	(2)	(3)	(4)
Fed Funds Future Shock	-27.01^{***}		-0.05^{***}	
	(6.95)		(0.02)	
Policy News Shock		-41.76^{***}		-0.08^{***}
		(8.06)		(0.02)
Constant	-0.12	0.12	0.0004	0.001
	(0.31)	(0.28)	(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

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%).

We next turn to QE actions of the Fed. Given that the timing of QE announcements vary, we shift away from intraday analysis to a daily event window around the announcement days. When the Fed purchases long-term assets, it is effectively changing the supply of USD denominated safe assets. When the Fed purchases Treasurys, this reduces the effective supply of Treasurys available to investors and could result in a widening of the U.S. Treasury basis. However, when the Fed purchases other assets, such as MBS, and substitutes these for reserves, this could increase the supply of USD denominated safe assets and narrow the basis.

We include the following QE event dates: 25-Nov-08, 1-Dec-08, 28-Jan-09, 18-Mar-09, 12-Aug-09, 23-Sep-09, 4-Nov-09, 3-Nov-10, 21-Sep-11, 13-Sep-12, 22-May-13, 19-Jun-13, and 18-Dec-13, for a total of 14 observations. The first FOMC statement, which kicked off quantitative easing, triggered substantial widening of the U.S. Treasury basis by 21 bps, while the third event narrowed the 10Y basis by 18 bps, presumably because the

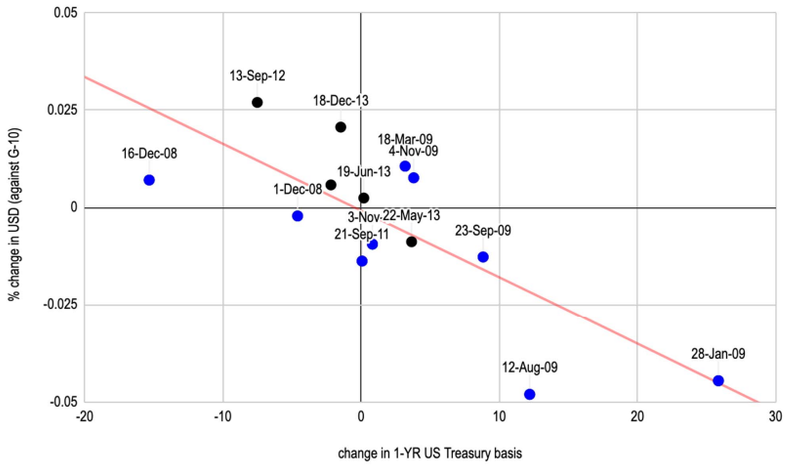


Figure 10: G-10 Dollar appreciation against change in basis around QE event dates. Sample of 14 QE event dates. 2-day window after QE-event dates. We include the event day and define the change in the basis (Δ Basis) and the change in the dollar from the close of trading on the day prior to the event day to the close of trading 2 days later.

FOMC statement emphasized a commitment to buying agency-debt and mortgage backed securities. The statement also mentioned that the FOMC was still evaluating the benefits of purchasing longer term Treasury securities. We run regressions of changes in the dollar on changes in the basis. We exclude the event day and define the change from close of trading on the event day to the close of trading N days later, because European and Asian bond markets are closed when the announcement occurs. In addition, the exchange rate fix occurs at 4.00 PM GMT before the announcement.

Figure 10 illustrates the relation. The basis widens on some days and narrows on others, depending on the nature of QE and expectations going into the event. There is a strong relation between basis changes and exchange rate changes on these dates. Our regression estimate for this line is:

$$\Delta \text{ G10/Dollar}_t = const. + \overbrace{\beta_{\text{Basis}}}^{-0.166 \ (0.057)} \Delta\text{Basis}_t + \overbrace{\beta_{\text{Y}}}^{31.38 \ (8.03)} \Delta\text{Y}_t + \epsilon_t,$$

with coefficient and standard error in parentheses. We include the change in 1-year government bond yield differentials as a control for other channels that monetary policy may impact exchange rates. We measure the basis from 1-year bond yield differentials and forward and spot exchange rates. There is a clear negative relation between the QE induced shifts in the basis and exchange rate changes. The R^2 of the regression is 82.8%.

The QE evidence is perhaps the strongest for the channel we describe connecting the supply of safe dollar bonds and the exchange rate. In this event-study, we are able to control for interest rate changes, which is the standard channel through which monetary policy impacts exchange rates.

5.3 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 consider 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.

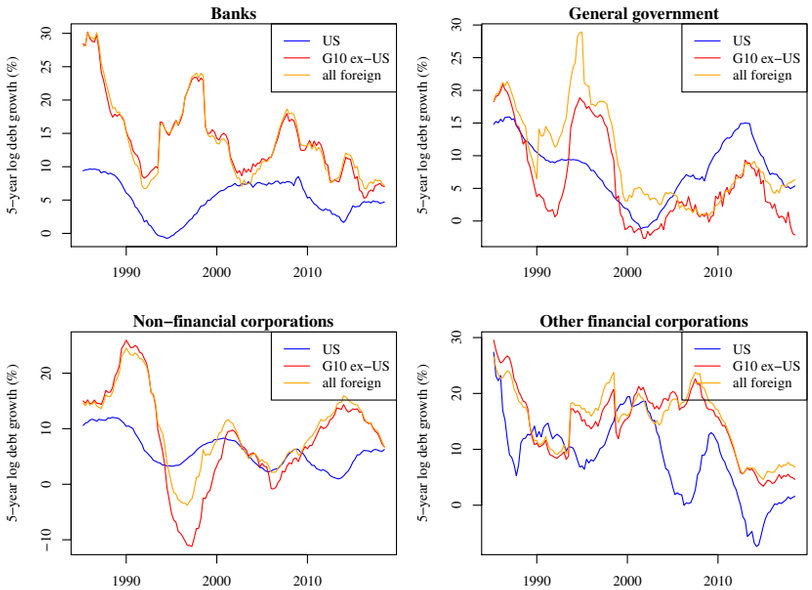


Figure 11: 5-Year Log Growth Rates of Dollar Debt Securities Issued by US and Foreign Sectors. The log growth rate is per annum.

Figure 11 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,

	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)

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, currrency 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	
Firms' Exit Rate	σ	0.48	
Productivity	$\bar{A}$	1.055	
Share of Global Banks	χ	0.5	Foreign/US holdings of US Treasury
Aggregate Labor	$\bar{\ell}$	7.5	
Steady-State Interest Rate	$\bar{i}$	0.00	
Steady-State F-Sector Capital	k^{SS}	1	
Global Safe Asset Investors			
Steady-State Convenience Yield	$\bar{\lambda}$	0.01	
Convenience Yield Per Dollar Liquidity	β_λ	0.025	
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	
Steady-State F-Sector Capital	$k^{SS,*}$	1	
Implied Parameters			
Steady-State US F-Sector Labor	ℓ^{SS}	6.71	
Steady-State 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	
Steady-State US Dollar Liquidity	Q^{SS}	3.36	
Steady-State Foreign Dollar Liquidity	$Q^{SS,*}$	1.78	Foreign/US net dollar debt issuance
Steady-State US Bank Profits	E^{SS}	0.03	
Steady-State US Current Account	CA^{SS}	-0.03	

Table 5: **Parameter Values.**