

Dollar Safety and the Global Financial Cycle

PRELIMINARY AND INCOMPLETE

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Abstract

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

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

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1 Introduction

U.S. monetary policy appears to have sizeable spillover effects on other economies around the world, as has been documented by a growing empirical literature. Rey (2013) and Miranda-Agrippino and Rey (2015) in particular have presented compelling evidence for the existence of a “global financial cycle” in which asset prices and financial variables such as bank leverage comove across the globe. Moreover, U.S. monetary policy appear to drive some of this comovement, and 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, so that 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, leading to some skepticism regarding the interpretation of the empirical results (see Bernanke, 2017). What mechanisms are behind these spillovers and why is the dollar central to this mechanism?

One explanation 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. Then, given the currency mismatch of these 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.

This explanation fails deeper scrutiny, however. It is 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 dollars. But the data clearly indicate that the dollar is the dominant borrowing currency when firms contract foreign currency debt (see Shin, 2012; Cetorelli and Goldberg, 2012; McCauley, McGuire and Sushko, 2015; Ivashina, Scharfstein and Stein, 2015; Bruno and Shin, 2017).

This paper takes a different tack drawing from the recent literature on safe assets and global imbalances. Suppose that investors around the globe have a special demand for safe dollar claims, driving up the prices and lowering the yields, on such claims. In the language of Jiang, Krishnamurthy and Lustig (2018), suppose investors assign a convenience yield to safe dollar claims. Then, borrowers will have incentive to tilt their

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

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

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

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

Our results rest on one key assumption: world investors have a special demand for safe U.S. dollar securities. While we do not micro-found this assumption, there are theoretical models that aim to explain this fact and why it is about the dollar. See He, Krishnamurthy and Milbradt (2018) for an explanation that revolves around the depth of the U.S. Treasury market and the relative fiscal strength of the U.S. government. See Maggiori (2017) for an explanation based on the better financial system of the U.S. See Gopinath and Stein (2017) 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.

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

2 U.S. Model

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

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

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

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

Households can work for firms (F), which we will think of as large corporates or banks. These firms are run by manager/entrepreneurs subject to a standard agency problem that limits borrowing (more on this below). A manager at time t has capital of k_t . The manager can liquidate the capital for k_t goods at time t . The manager can also freely convert any goods into new capital. Thus the price of capital relative to goods will be one in equilibrium. The manager can also hire labor and produce goods at time $t + 1$. Given l_t labor and k_t capital, the production technology gives output at date $t + 1$ of

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

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 w_t as well. The price of capital is also p_t .

Firms are run by managers. These managers have wealth at date t of k_t units of capital, or equivalently, k_t units of the non-traded consumption good (since a unit of capital can be converted into a unit of goods). They die with probability $1 - \sigma$ at the end of each period, and at death, liquidate their capital and consume their wealth. A manager maximizes,

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

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

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

We assume that firms face financial constraints. A firm has debt capacity equal to a fraction $\theta < 1$ of next period's expected output. We focus on a parameterization under which $A_{t+1} \geq 1 + i_t - \pi_t$ always, i.e. the marginal product of investment exceeds the real interest rate so that firms hire as much labor as possible. Then, firms raise total funding in dollars of,

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

The budget constraint for a firm at date t is:

$$p_{t+1} \frac{\theta A_{t+1} (l_t + k_t)}{1 + i_t} - p_t l_t = 0,$$

i.e., the money raised pays the wage bill. Solving,

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

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

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

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

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

$$K_{t+1} = K_t (1 - \sigma) \frac{A_{t+1} (1 - \theta)}{1 - \frac{\theta A_{t+1}}{1 + i_t - \pi_t}} + K^N, \quad (7)$$

where we use the capital letter K_t to denote the aggregate capital of the firm sector.

2.1 Monetary policy, output, and asset supply

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

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

To complete the model, we describe optimal price setting. We assume that workers have an alternative sector in which to work; call this an informal (I) sector. The I-sector has productivity of one at all times, is owned by households, and faces no debt-capacity constraints. Loosely, think of this as an endeavor where

people work for their neighbors. The firm also sets prices and wages at date t and holds them constant for one period. The profits of an I-firm as function of the firm's pricing and hiring decision is:

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

It is apparent that profit maximization implies that,

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

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

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

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

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

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

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

Given these prices, households decide on how to allocate their labor. Labor market clearing is that,

$$l_t + l'_t = \bar{l}.$$

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.

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.¹

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

$$B_t = \frac{p_{t+1}\theta A_{t+1}(l_t + K_t)}{1 + i_t} \quad (10)$$

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

2.2 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 policy shocks, ϵ_t , where

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

This completes the description of the U.S. block of the model. The model has one state variable, K_t . The steady state level of capital solves,

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

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

¹Note 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 upto their capacity to pay, and the rest to the I-sector. We can construct the equilibrium as follows. Suppose that the F-sector, which is more profitable, offers a wage of $p_t + \epsilon$, so that workers strictly prefer working in the F-sector. As $\epsilon \rightarrow 0$, we have our specified equilibrium.

trace out the impact of this shock beginning from the steady-state of the model. Figure 1 illustrates.

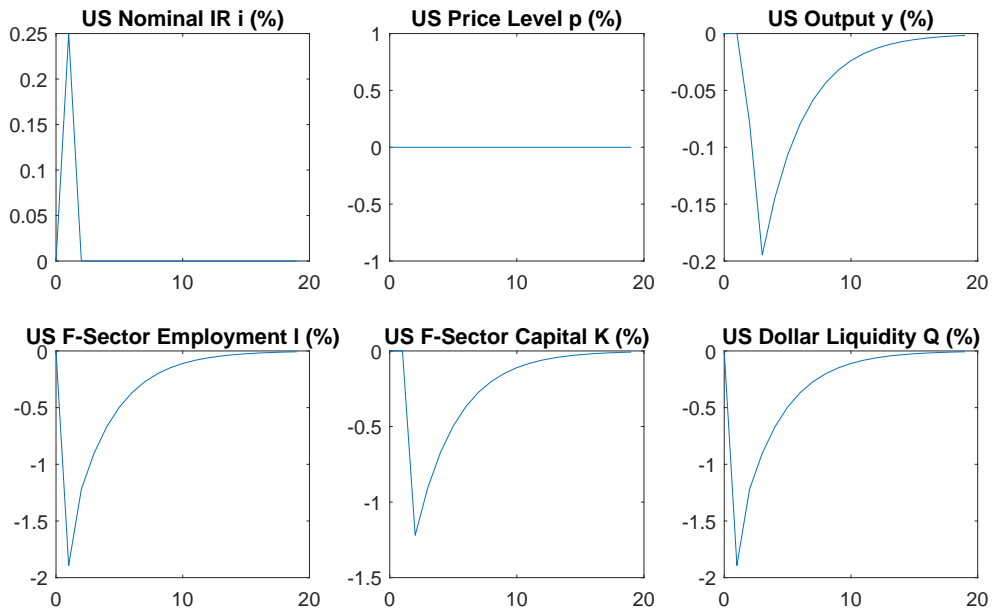


Figure 1: Impulse response to a U.S. monetary policy shock of 0.25%

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 safe-asset supply (B_t), all as percentage deviations from their steady-state values.

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

3 International Equilibrium and Dollar Liquidity

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

3.1 Safe asset investors

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

Let us start with a simple benchmark. U.S. households own dollar bonds paying rate i_t . To begin, suppose that these households are happy to own world bonds and world investors are happy to own U.S. bonds, then the usual uncovered interest-rate parity (U.I.P.) condition holds:

$$i_t + E_t s_{t+1} - s_t = i_t^*. \quad (13)$$

Owning either U.S. or world bonds must give the same return when expressed in the same currency. This expression says that if the U.S. interest rate rises, then the dollar appreciates today and gives an expected depreciation.

3.2 Safe asset demand and no capital mobility

We alter condition (13) to include safe asset demand. We suppose that world safe asset investors place an extra convenience yield of λ_t to own dollar liquidity (the bonds issued by U.S. firms). Moreover, we suppose that U.S. investors have no ability or desire to own world bonds. That is there is no capital mobility from the U.S. investor side.

World investors attempt to sell their world bonds to U.S. investors in exchange for dollar bonds. In equilibrium, the dollar exchange rate appreciates to the point where the return to this trade falls: the world investor's return to holding U.S. bonds falls relative to his return to holding world bonds until the point where:

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

and no trade occurs. Rewriting, the U.I.P. condition becomes:

$$E_t s_{t+1} - s_t = i_t^* - i_t - \lambda_t. \quad (14)$$

If world safe asset demand rises (high λ_t), then the dollar appreciates today and gives an expected depreciation. This is the condition we derive in our other work (see Jiang, Krishnamurthy and Lustig, 2018). The condition in (14) 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,

$$E_t e_{t+1} - e_t = r_t^* - r_t - \lambda_t \quad (15)$$

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

We iterate on this equation and find:

$$e_t = E_t \sum_{j=t}^{\infty} \lambda_j + E_t \sum_{j=t}^{\infty} (r_j - r_j^*) + \bar{e} \quad (16)$$

The term $\bar{e} = \lim_{t \rightarrow \infty} e_t$ is a constant because the real exchange rate is stationary in our model. This is because foreign inflation is zero and the U.S. central bank targets a constant inflation rate of $\bar{\pi}$. From (16) we see that the dollar exchange rate moves both because of shocks to safe asset demand (λ_t) and shocks to the real interest rate differential. Jiang, Krishnamurthy and Lustig (2018) presents evidence to support these points, some of which we review below.

3.3 Dollar liquidity and global banks

We next allow for partial capital mobility so that world safe asset investors in equilibrium own some of the B_t of U.S. dollar safe bonds. This quantity dimension has been a central focus of the empirical and theoretical literature on safe assets. We will see that the impact of safe asset demand for exchange rates goes through almost exactly as in the previous section, with additional implications for quantities and the impact of monetary policy on safe asset demand.

To allow foreign holdings of U.S. dollar assets, asset trade must happen in equilibrium: U.S. holders of safe dollar bonds need to trade their bonds to world investors in return for foreign bonds. Our assumption so far is that U.S. households do not participate in foreign bond markets, ruling out such trade. We could relax this assumption, but in doing so, we would also have to specify U.S. household preferences over the foreign good (they need to consume the fruits of their carry trade profits), which adds considerable overhead to the model. We go in a different direction by adding U.S. banks who intermediate the carry trade and consume their profits in the foreign good. The modeling is simple and also realistic.

We suppose that each U.S. household receives its wages of $p_t l_t$ and either invests in U.S. dollar bonds at interest rate i_t or deposits the funds in a local bank at the deposit interest rate of i_t^D . The bank is local in the sense that it has 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 bonds at rate i_t it follows that $i_t^D = i_t$.

A fraction α of the banks ("Global Banks") can invest internationally. That is, they take dollar deposits from U.S. households and invest in a portfolio of U.S. bonds and world bonds. Note for the remaining $1 - \alpha$ of banks, the equilibrium is as we have previously described: the banks are a pass-through (like a money market fund) and U.S. households effectively own the U.S. bonds. With an active portfolio choice, global banks will own world bonds and world investors will own U.S. bonds.

We suppose that banks are run by owner-managers that are risk neutral profit maximizers and live one period. At the end of the period, the bank owner consumes any profits, settled in the world good. We also allow the bank to consume negative quantities of the good (or more palatably, we can provide them with a large endowment of the world good that absorbs any realized losses).

Consider a representative global bank that raises d_t of dollar deposits and invests these funds in U.S. firm

bonds ($b_t^{\$}$), world bonds (b_t^w) and reserves at the central bank paying interest rate i_t . In equilibrium, the quantity of reserves will be zero and hence we suppress this term in the equations that follows. The reserves rate simply serves as the policy instrument that sets i_t . The budget constraint for a bank is,

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

We impose a no-short-sale constraint, $b_t^{\$} \geq 0$. The expected profit to the bank from this portfolio choice is:

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

The first term here is the expected excess return on running the “carry” trade of investing in the world bond:

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

That is, given the U.I.P. violation that is driven by safe asset demanders it is profitable for the bank to tilt its portfolio towards the world bond. Given that the bank is risk-neutral, it is apparent that the solution is at the corner where the short-sale constraint binds. The bank holds no U.S. dollar bonds.

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

$$Q_t = \alpha B_t. \tag{17}$$

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

$$\text{Import}_{t+1} = Q_t (i_t^* - i_t - (s_{t+1} - s_t)), \tag{18}$$

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

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

$$\lambda_t = \lambda(Q_t) \quad \text{with} \quad \lambda'(Q_t) < 0. \quad (19)$$

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

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

$$\lambda_t = \bar{\lambda} - \gamma(Q_t - Q^{SS}) + \epsilon_t^\lambda. \quad (20)$$

3.4 International financial equilibrium

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

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

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

We can understand this relation by inspecting equation (16). To maintain a constant e_t , the real interest in the U.S. must be lower than the real interest rate abroad by exactly λ_t . The result is consistent with observations linking safe asset demand to the low steady-state real interest rate (“R-star”) in the U.S (see Caballero, Farhi and Gourinchas, 2008).

- Changes in the demand for safe dollar assets impact the dollar exchange rate. That is, there is a financial demand component to exchange rate determination, which is strongly supported by the data as we explain in Section 5.
- The U.S. is a world financial intermediary. It provides safe dollar assets to the world and recycles these

flows into a carry trade return, which then partly finances the trade deficit (see Gourinchas and Rey, 2007). The position of the U.S. is not an artifact of the exchange rate system, as argued by Despres, Kindleberger and Salant (1966) in their well-known “minority view.” This view, which was written in response to Triffin (1960)’s critique of the Bretton-Woods system, posited that the U.S., having the deepest and most liquid financial markets in the world, will naturally be in a position of providing liquid assets to the world and earning a premium from this financial service.

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

3.5 Impulse response function

Figure 2 plots the impulse response to a 0.25% shock to the nominal interest rate in period $t + 1$. US output (top row, third panel) behaves exactly as in the U.S.-only model. The new results are in the next panels. The rise in the U.S. interest rate reduces safe asset supply and hence increases the convenience yield, λ . The dollar appreciates at date $t + 1$ both because of the rise in i_{t+1} and the increase in λ_{t+1} . U.S. banks lose money on impact since they are running a carry trade that has them long foreign currency/short dollars. But they subsequently make money as λ_t rises. This pattern of losses and gains is reflected in the panel for U.S. imports.

Figure 3 illustrates the impact of a temporary shock that increases safe-asset demand. We increase the convenience yield (λ_t) in period $t + 1$ unexpectedly by setting $\epsilon_{t+1}^\lambda = 1\%$ (doubling the convenience yield relative to its steady-state value in our parameterization). This shock appreciates the dollar and leads to a pattern of bank losses and then gains. These losses and gains are mirrored by movements in imports since the bankers are assumed to consume only the world good. The shock has no impact on U.S. output which is determined entirely by U.S. productivity and monetary policy. In a richer model where U.S. households consume both home and foreign goods, the dollar appreciation may drive an expenditure-switching effect which

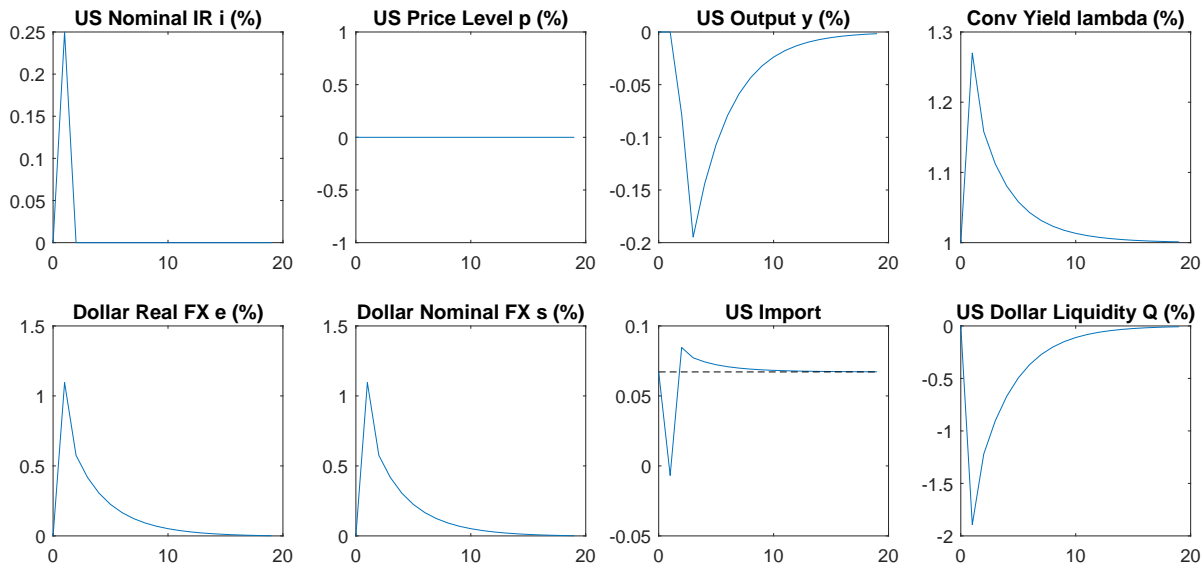


Figure 2: Impulse response to a U.S. monetary policy shock of 0.25%

We consider a 0.25% shock to i_t in period $t + 1$ of the model. The top-left panel plots i_t , with the x -axis in periods. The top-middle panel plots output, as a percentage deviation from steady-state. The top-right panel plots the convenience yield. The bottom panels plot the real dollar exchange rate, US imports, and safe-asset supply (B_t), all as percentage deviations from their steady-state values.

increases demand for the foreign good by U.S. households and add a further dynamic to the trade balance. We have set this effect aside.

Suppose the Federal Reserve places weight on smoothing bank profits and chose to stabilize the exchange rate in response to the safe asset demand shock. In this case, the Fed would lower interest rates, depreciating the dollar and as in Figure 2 would boost U.S. output and firms' dollar borrowing. This effect of world safe asset demand on the U.S. market equilibrium is plausibly one of the factors driving the boom in housing and bank borrowing in the U.S. in the pre-crisis period from 2002 to 2007, as argued by Caballero and Krishnamurthy (2009). Our analysis shows that it is the monetary authority's decision to accommodate these inflows by lowering rates that creates the domestic effect. We also note that the lowering of the policy rate by itself does not make the U.S. a less attractive safe asset haven. Holding λ_t fixed and given U.I.P., the expected return to a safe asset investor of buying dollar assets relative to world assets is still $-\lambda_t$. But lower rates does have an impact on λ_t . As evident in Figure 2, lowering rates boosts U.S. safe asset supply (by inducing firms to take on

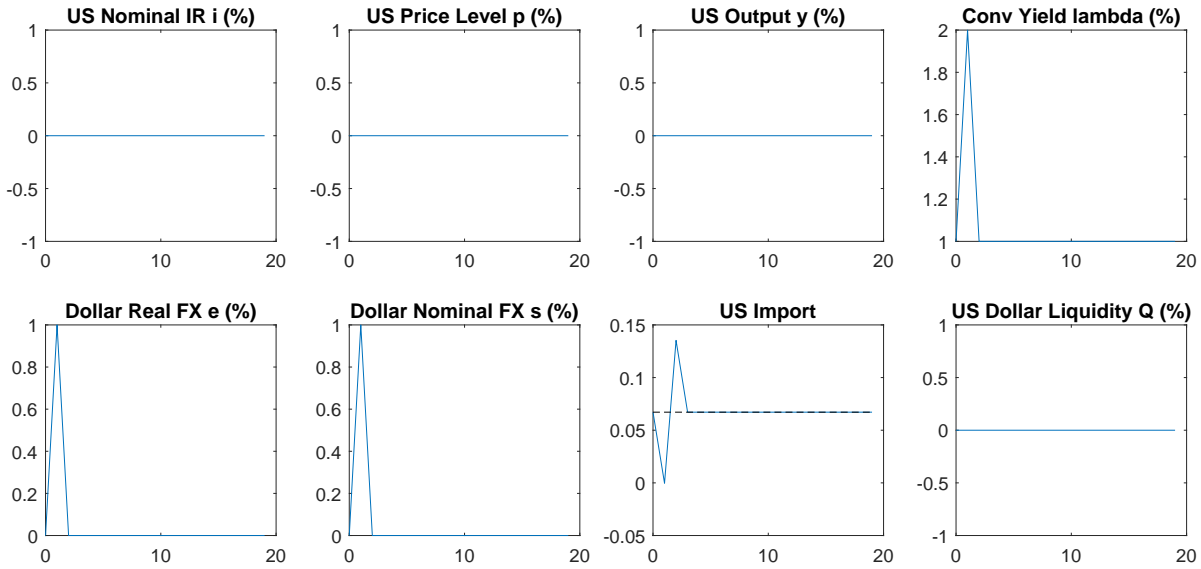


Figure 3: Impulse response to a safe asset demand shock of 1%

We consider a 1% one-time shock to λ_t in period $t + 1$ of the model, as in the top-right panel. The top-left panel plots i_t , with the x -axis in periods. The top-second panel plots the price level. The top-third 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 safe-asset supply (B_t), all as percentage deviations from their steady-state values.

more debt) which in turn increases Q_t and reduces the equilibrium value of λ_t . It is the increase in “liquidity” which offsets the safe asset demand shock. Of course such an increase in liquidity also leads to a build-up in U.S. leverage which can leave the U.S. firms vulnerable to firms, as argued by Caballero and Krishnamurthy (2009).

4 Dollar Spillovers

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

4.1 Foreign households and firms

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

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

$$\frac{1}{1 + i_t^*} c_{t+1}^* - l_t^* \quad (21)$$

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

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

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

We furthermore set these prices to be one for simplicity.

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

$$f(l_t^*, k_t^*) = A_{t+1}^* (l_t^* + k_t^*) \quad A_{t+1}^* > i_t^* \quad (22)$$

Firms are run by managers. These managers have wealth at date t of k_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,

$$\sum_{t=1}^{\infty} (\sigma^*)^{t-1} (1 - \sigma^*) k_t^* \quad (23)$$

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 upto $A_{t+1}^* (l_t^* + k_t^*)$. The firm raises foreign currency debt at the interest rate of i_t^* upto this maximum amount and

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

$$l_t^* = \frac{\theta A_{t+1}^*}{1 + i_t^*} (k_t^* + l_t^*) \Rightarrow l_t^* = k_t^* \frac{\theta A_{t+1}^*}{(1 + i_t^*) - \theta A_{t+1}^*} \quad (24)$$

and firm profits are:

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

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

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

$$i_t - (E_t s_{t+1} - s_t) < i_t^* \quad (26)$$

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 is lower than that of home. 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 (26).

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,

$$Q_t^*(1 + i_t)E_tS_{t+1} \leq \theta^*A_{t+1}^*(k_t^* + Q_t^*S_t) \quad (27)$$

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_tS_{t+1} in the constraint. We will assume shocks are small enough that there is no default in equilibrium (e.g., capital K_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 (27) binding, we find that:

$$Q_t^*S_t = k_t^* \frac{\theta^*A_{t+1}^*}{1 + i_t^* - \lambda_t - \theta^*A_{t+1}^*}. \quad (28)$$

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

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

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, $\frac{\theta^*}{1-\theta^*}$. That is, more dollar debt relative to local currency assets exacerbates this 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. 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.

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

$$Y_{t+1}^* = A_{t+1}^* k_t^* \left((1 - \gamma) \left(1 + \frac{\theta A_{t+1}^*}{1 + i_t^* - \theta A_{t+1}^*} \right) + \gamma \left(1 + \frac{\theta A_{t+1}^*}{1 + i_t^* - \lambda_t - \theta A_{t+1}^*} \right) \right) \quad (29)$$

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 shows up in profits next period as well as capital dynamics.

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

$$\lambda_t = \lambda(Q_t + Q_t^*). \quad (30)$$

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

$$K_{t+1}^* = K_t^* (1 - \gamma) (1 - \sigma^*) \frac{A_{t+1}^* (1 - \theta)}{1 - \frac{\theta A_{t+1}^*}{1 + i_t^*}} + \gamma (1 - \sigma^*) \Pi_t^* + K^{N*} \quad (31)$$

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, (K_t, K_t^*) . The non-stochastic steady state satisfies (12) and

$$K_{SS}^* = K_{SS}^* (1 - \gamma) (1 - \sigma^*) \frac{A_{SS}^* (1 - \theta^*)}{1 - \frac{\theta^* A_{SS}^*}{1 + i_{SS}^*}} + \gamma (1 - \sigma^*) \Pi_{SS}^* + K^{N*}. \quad (32)$$

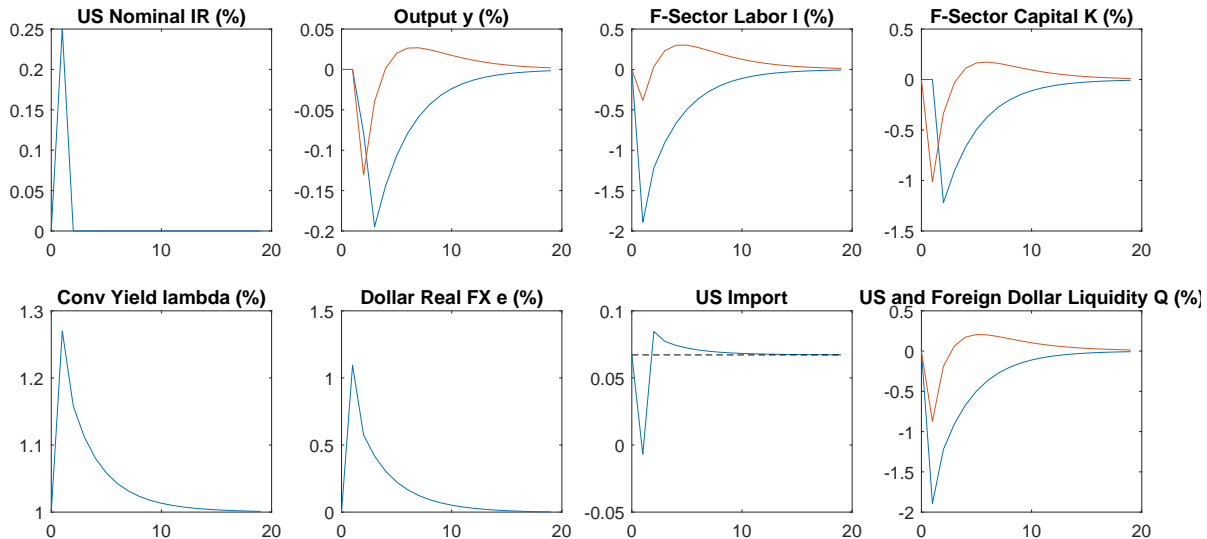


Figure 4: Impulse response to a U.S. monetary policy shock of 0.25%

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 the convenience yield, real dollar exchange rate, US imports, and dollar liquidity, all as percentage deviations from their steady-state values.

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 (K_t, K_t^*) , and the dynamics of K_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.

4.3 Monetary policy spillovers

Figure 4 presents the effects of monetary policy tightening in the U.S. on the foreign country and shows the spillover of U.S. monetary policy to the rest-of-the-world, which is a central result of our analysis. We also present the effects on the U.S. for comparison. Blue corresponds to the U.S., and red to the foreign country.

Tightening at $t + 1$ leads to an appreciation in the dollar, s_{t+1} rises, inducing losses to the multinationals. As a result, K^* , foreign output, and Q^* fall at date $t + 1$. Note that the fall in Q^* further amplifies the shock since it tightens safe asset supply, increases λ , and adds to the dollar appreciation.

Capital and output rise sharply in $t + 2$. This is because the losses are reversed in period $t + 2$ as the high convenience yield lowers the cost of borrowing dollars for foreign firms and hence leads to high profits and fast capital growth. In the figure, they overshoot the steady-state levels, but this result is parameter dependent. With other parameters, the model produces a fall and then recovery in output.

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

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

Holding λ_{t+1} constant, we can see that the firm's 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 5 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 5 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.

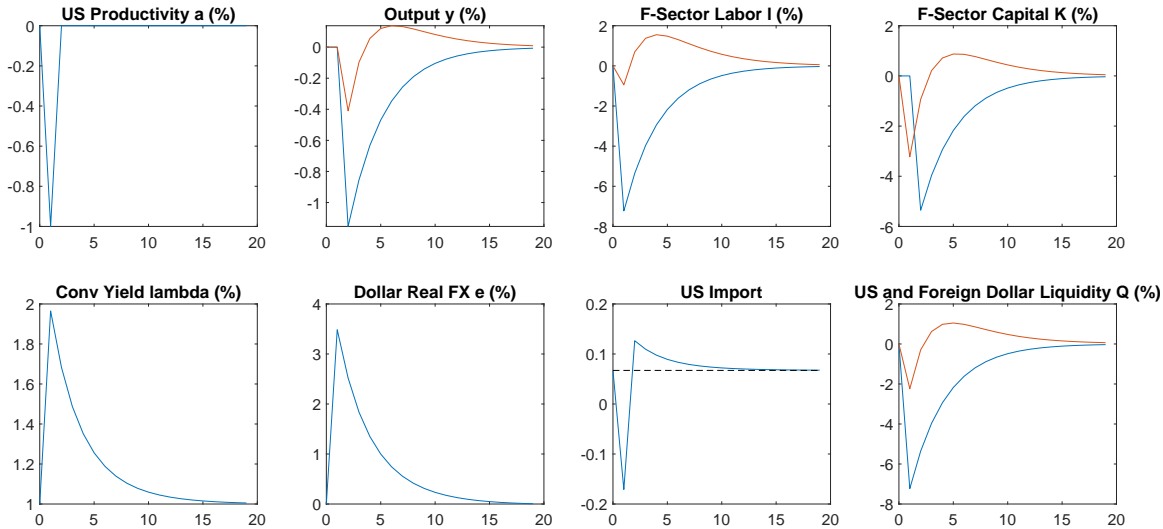


Figure 5: Impulse Responses to U.S. Productivity Shock.

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 the convenience yield, real dollar exchange rate, US imports, and dollar liquidity, all as percentage deviations from their steady-state values.

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 ways in 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 6 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

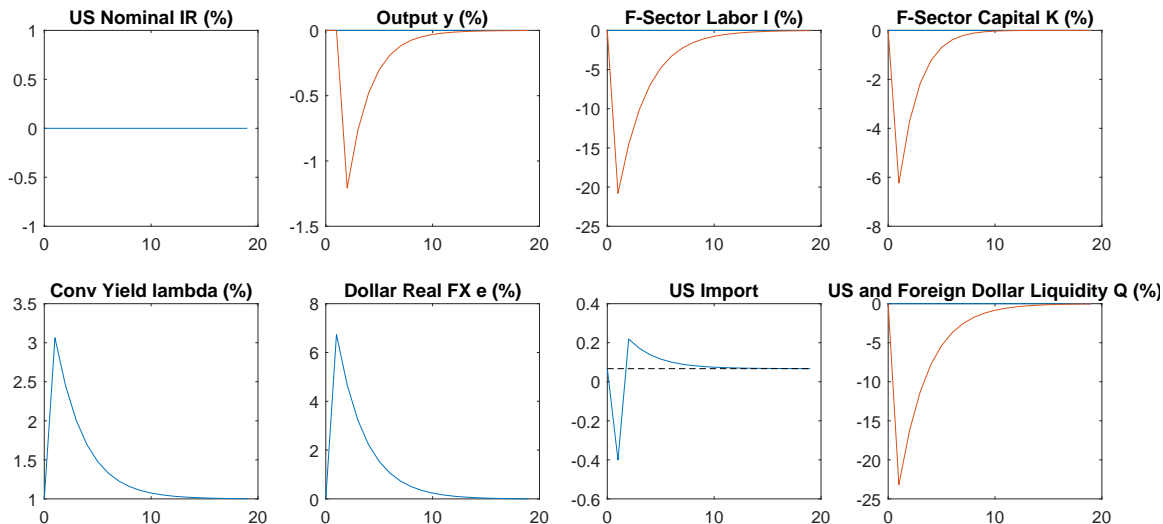


Figure 6: Impulse Responses to Foreign Pledgability Shock

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 the convenience yield, real dollar exchange rate, US imports, and dollar liquidity, all as percentage deviations from their steady-state values.

risers and the dollar appreciates, which then amplifies the shock through the impact on foreign firms' balance sheets.

Finally, while we only model one foreign country, it should be evident from our results thus far that this pledgability shock will create contagion across foreign countries. The dollar appreciation will deteriorate balance sheets for all foreign dollar borrowers, although likely more in the country with the original pledgability shock.

4.5 A new Triffin dilemma

The patterns described by our model rationalize many patterns in the world. The importance of the dollar and 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”).

In traditional open-economy macroeconomic models, these patterns should not arise. Foreign countries

with free capital mobility and floating exchange rates should be able to largely insulate themselves from foreign shocks. Moreover, there should no inherent asymmetry between U.S. and foreign.

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 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.²

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.³ 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

²There 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.

³Farhi, 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.

bound itself to a set of rules to stabilize the international monetary system. In the current *de-facto* standard, the international 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.

5 Empirical evidence

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

5.1 Global banks

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

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

Consider the global bank we introduced earlier. We described an equilibrium in which the global bank sells its dollar bonds to world safe asset investors to satisfy their safe asset demand. Here is another, economically equivalent, description of the equilibrium. The global bank offers dollar deposits to safe asset investors and

holds the firm-issued dollar bonds as loans on its portfolio. It uses some of the dollar deposits to run the carry trade of buying world bonds and earning the convenience yield. Moreover, the global bank also lends in dollars to foreign firms, accepting dollar deposits from safe asset investors. This latter set of transactions can be interpreted as the Eurodollar market. That is, consistent with the data, the global bank provides dollar deposits and intermediates flows into dollar bonds and world bonds.

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

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

5.2 Exchange rates and λ

In Jiang, Krishnamurthy and Lustig (2018), we present empirical evidence in support of equation (16) 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 (14). For government bonds, we posit that,

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

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

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

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

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

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

Figure 7 presents one of the graphs from Jiang, Krishnamurthy and Lustig (2018). We plot the US/UK real exchange rate and the Treasury basis using quarterly data from 1970 to 2017. The Treasury basis is proportional to the negative of λ_t . It is apparent that there is a strong negative correlation between the basis and the exchange rate, indicating that when the basis falls (λ rises), the dollar appreciates relative to the pound. We interpret this evidence as saying that safe asset demands are a significant driver of the value of the dollar.

5.3 Basis predicts change in Net Dollar Debt/GDP Ratio

Our model predicts that when λ_t rises, dollar debt is cheaper than local currency debt and hence foreign firms will have a greater incentive to issue dollar debt. We check whether this correlation holds in the data. We construct a single dollar debt measure by country. In particular, we construct each country’s net dollar debt/GDP ratio from Bénétrix, Lane and Shambaugh (2015). This measure sums across the dollar debt issued by firms, banks, and the sovereign, and nets this against any domestic holdings of dollar debt. The data is available annually from 1990 to 2012. We use the Treasury basis to measure λ_t . A more negative basis means that foreign firms will have a larger incentive to issue dollar debt.

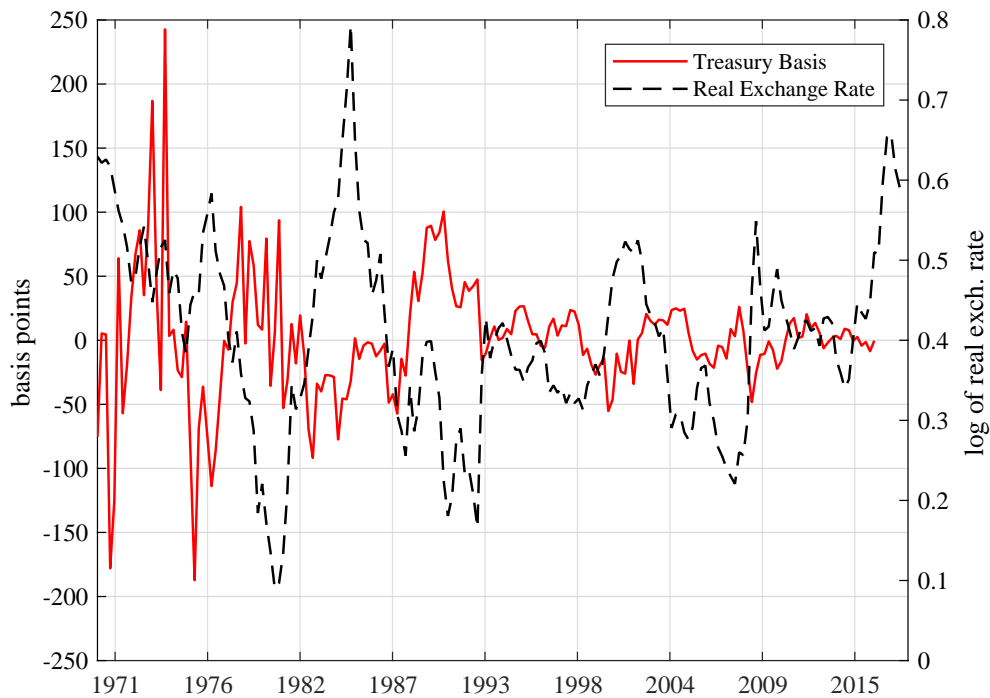


Figure 7: U.S./U.K. Treasury Basis and Real Exchange Rate

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).*

The results are in Table 1. We report two regressions, one in levels and one in changes. In column (1), we regress each country's change in the net dollar debt/GDP ratio during year t on the annual basis innovation during year $t - 1$. We include country fixed effects and cluster errors by year. In Column (2), we aggregate the panel data into a single time series by taking the cross-country average in the change in the net dollar debt/GDP ratio, and regress it on the annual basis innovation during the previous year. In Column (3) and (4), we repeat the exercise but replace the explanatory variable by the level of the Treasury basis at the end of year $t - 1$.

The results are in line with our model's prediction. A more negative basis correlates with more issuance of dollar debt. The caveat here is that we are treating the variation in the basis as exogenous, when as our model shows, it partly depends on variables including monetary policy and productivity.

	<i>Dependent variable:</i>			
	$Debt_t - Debt_{t-1}$			
	(1)	(2)	(3)	(4)
$InnovBasis_{t-1}$	-221.92** (92.72)	-213.77* (115.04)		
$Basis_{t-1}$			-298.82* (180.08)	-253.05 (225.25)
Constant		-0.76 (0.47)		-1.24* (0.69)
Observations	2,434	22	2,434	22
R ²	0.04	0.15	0.04	0.06
Adjusted R ²	-0.01	0.10	-0.01	0.01
<i>Note:</i>	*p<0.1; **p<0.05; ***p<0.01			

Table 1: Treasury Basis Predicts Change in Foreign Net Dollar Debt/GDP Ratio. Column (1) and (3) report results from pooled OLS. Column (2) and (4) report results from a single time series from the cross-sectional average.

5.4 Monetary policy and the Treasury basis

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

In Table 2, 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. Consistent with our model’s prediction, monetary tightening raises the convenience yield. We also see that increases in the VIX correlate with a widening of the Treasury basis, consistent with a global flight-to-quality episode and safe asset demand increases. Rey (2013) finds that movements in the VIX largely characterize the global financial cycle.

We can better identify the effects on Treasury basis innovations by inspecting the change in Treasury basis around FOMC announcements. From Gorodnichenko and Weber (2016) and Nakamura and Steinsson (2018), we obtain the changes in the 30-day fed funds future’s rate in 30-minute windows bracketing the FOMC press releases, from 1994 to 2014. Following Kuttner (2001), this shock can be interpreted as a US monetary policy surprise. This is also the data used by Wiriadinata (2018). For each FOMC meeting date t , we calculate the

	<i>Dependent variable:</i>						
	basis						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Fed Funds Rate	-2.45** (0.95)	-2.79*** (0.78)				-2.20*** (0.81)	-0.79 (0.95)
Inflation	8.03** (3.88)		3.03 (3.96)			5.88 (3.63)	6.35* (3.54)
GDP Gap	-2.28 (1.51)			-3.93*** (1.27)			-3.60*** (1.35)
VIX Index					-78.21*** (27.24)	-69.70** (27.50)	-82.20*** (27.15)
Constant	-34.32*** (8.25)	-15.67*** (3.37)	-30.44*** (7.40)	-30.62*** (2.80)	-7.64 (5.69)	-13.01 (9.56)	-21.00** (9.77)
Observations	118	118	118	118	110	110	110
R ²	0.15	0.10	0.01	0.08	0.07	0.14	0.19
Adjusted R ²	0.12	0.09	-0.004	0.07	0.06	0.12	0.16

Note:

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

Table 2: 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.

US Treasury basis movement from 4pm London (i.e. 11am New York) at t to the same time two days later ($t + 2$). The exchange rates and forward rates, from WM/Reuters Closing Spot Rates, are at 4pm London, which precedes the US monetary announcement at the same day. The timing of Treasury yields is less certain, and as a result we use a wider window.

In the first two columns of Table 3, we report the results from a pooled cross-sectional regression of the change in each foreign country's Treasury basis from date t to date $t + 2$ on the monetary surprise. We include the 10 developed countries. We add country level fixed effects and cluster the errors by date. We also include the foreign country's net dollar debt-to-GDP ratio and the interaction of this debt variable with the monetary surprise, borrowing a specification from Wiradinata (2018). The effect of the monetary surprise is consistent with the mechanism of the model. The debt interaction is difficult to interpret. In columns (3) and (4) we use the concurrent foreign country's exchange rate appreciation as dependent variable. The foreign currency depreciates with a surprise tightening of monetary policy.

We also have collected 30-min interval data of government debt futures, which helps improve the identifi-

cation of the effects, and indeed the preliminary results are stronger than those reported in Table 3. We will add this to the paper shortly.

	<i>Dependent variable:</i>			
	Δ Treasury Basis		Foreign Currency Appreciation	
	(1)	(2)	(3)	(4)
Monetary Surprise	-0.45*** (0.12)	-0.39*** (0.11)	-0.03*** (0.01)	-0.02*** (0.01)
Foreign Net USD Debt/GDP		0.07** (0.03)		0.004* (0.002)
Interaction		0.003*** (0.001)		0.0001 (0.0001)
Observations	1,474	1,454	1,710	1,690
R ²	0.06	0.07	0.04	0.04
Adjusted R ²	0.06	0.06	0.03	0.03

Note: *p<0.1; **p<0.05; ***p<0.01

Table 3: Two-day change in Treasury basis and exchange rate in response to monetary shocks around FOMC announcements. The dependent variables are the change in Treasury basis from t to $t + 2$ and the foreign currency appreciation from t to $t + 2$ where t is the date of FOMC announcement. Monetary surprise is the change in the 30-day fed funds future's rate in 30-minute window bracketing each FOMC press release.

6 Conclusion

To be written

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A Appendix

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

Table 4: **Parameter Values.**

year	RoW net dollar debt	% of RoW gdp	US net dollar debt	% of US gdp
1990	469.17	3.17	289.48	4.84
1991	500.64	3.14	338.06	5.48
1992	433.69	2.50	439.90	6.73
1993	272.31	1.56	503.54	7.32
1994	213.05	1.13	509.90	6.98
1995	81.82	0.37	646.99	8.44
1996	215.85	0.94	749.91	9.26
1997	129.62	0.58	1010.09	11.73
1998	-52.26	-0.24	1130.27	12.44
1999	1124.36	5.07	1281.98	13.27
2000	1296.81	5.76	1423.95	13.85
2001	1325.11	6.03	1919.61	18.07
2002	1198.53	5.28	2287.43	20.84
2003	998.03	3.79	2569.73	22.32
2004	1395.01	4.61	2806.09	22.86
2005	1480.75	4.51	2988.37	22.82
2006	1214.04	3.39	3128.91	22.58
2007	1930.77	4.66	2931.88	20.25
2008	2146.55	4.62	3333.76	22.65
2009	2533.99	5.81	3056.26	21.20
2010	2597.12	5.37	3432.87	22.94
2011	2512.94	4.61	4394.36	28.32
2012	2929.76	5.33	5067.52	31.37

Table 5: Quantities of Net US Dollar Debt Borrowed by Rest of World and by US, in Billion US Dollar and as a Percentage of Their Respective GDP. Data source: Benetrix, Shambaugh and Lane (2015)