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Dollar Safety and the Global Financial Cycle*

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Abstract

We build a model of the global financial cycle with one key ingredient: the demand for safe dollar assets. The model matches patterns of dollar borrowing and currency mismatch, the U.S. external balance sheet, low U.S. interest rates and exorbitant privilege, spillovers of the U.S. monetary policy to the rest of the world, and the dollar as a global risk factor. In doing so, we lay out a novel transmission mechanism through which the U.S. monetary policy affects the currency market and the global economy.

Keywords: Safe asset demand, U.S. monetary policy, convenience yields, exchange rates.

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1 Introduction

The U.S. and the dollar play a central role in the international financial system. This role manifests itself as follows:

Fact 1: Dollar convenience yield. Safe dollar bonds have low returns, especially for foreign investors (see Du, Im and Schreger, 2018; Krishnamurthy and Lustig, 2019).

Fact 2: Dollar debt dominance. There is a large quantity of dollar-denominated bonds in the world; outsized relative to the wealth share of the U.S. in the world (see Shin, 2012; Cetorelli and Goldberg, 2012; McCauley, McGuire and Sushko, 2015; Ivashina, Scharfstein and Stein, 2015; Bruno and Shin, 2017). Moreover, these dollar bonds are issued by both U.S. and non-U.S. entities, including banks, firms, and governments (see Bruno and Shin, 2014; Maggiori, Neiman and Schreger, 2017).

Fact 3: Dollar safety. During global downturns, the dollar currency appreciates and the dollar bonds' prices rise (see Jiang, Krishnamurthy and Lustig, 2018*a*,*b*).

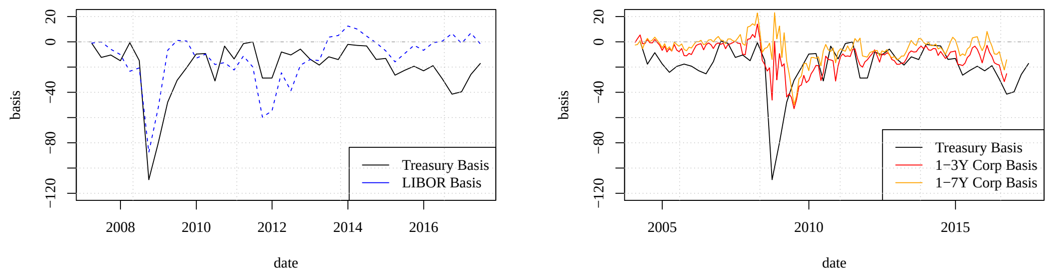
Fact 4: Global financial cycle. The U.S. monetary policy has an outsized role in macroeconomic outcomes for countries around the world (see Rey, 2013; Miranda-Agrippino and Rey, 2015). Conversely, the monetary policy of other large economies does not appear to be as important to the global cycle (see Gerko and Rey, 2017)

Fact 5: U.S. exorbitant privilege. The U.S. external portfolio resembles a levered carry position, which longs risky foreign assets and shorts safe dollar assets. This levered position earns an "exorbitant privilege" (see Gourinchas and Rey, 2007; Gourinchas, Rey and Govillot, 2010; Gourinchas, Rey and Truempler, 2012).

Fact 6: Dollar risk factor. The currency return on the dollar is a global risk factor (see Lustig, Roussanov and Verdelhan, 2014).

This paper offers a model to explain all of these facts of the global dollar-driven cycle in a unified framework. The model's central ingredient is the assumption that world investors are willing to pay a premium, a convenience yield, to own safe U.S. dollar denominate bonds. With this assumption, we show that all of the facts 1 to 6 arise naturally.

Evidence on the safe dollar premium: Figure 1(a) illustrates the safe dollar premium that



(a) Treasury and LIBOR basis

(b) Corporate and Treasury basis

Figure 1: Treasury, LIBOR, and Corporate Basis.

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

is the main input into our analysis.[1] The black line plots the "Treasury basis", which is the spread between 1-year U.S. Treasury bonds and foreign government bond yields, swapped into dollars. Dollar Treasury bonds have a lower yield than the foreign bonds. The observation that the U.S. Treasury basis is negative was made by Du, Im and Schreger (2018).

Why is the basis negative? We argue that the basis reflects the high value 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

[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 (2019) 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.

for the cash Treasury bond. See Jiang, Krishnamurthy and Lustig (2018*a*) for further details and empirical support.

The convenience yield is also reflected in private dollar bonds. Figure 1(a) also plots the LIBOR basis, defined analogously, reflecting the spread between dollar LIBOR and foreign LIBOR, swapped into the dollar. 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 1(b) 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.

The evidence in Figures 1(a) and 1(b) measures deviations from covered interest rate parity. We can observe the safe dollar phenomenon also from unhedged realized returns, where the convenience yields are even larger. Table 1, drawn from Krishnamurthy and Lustig (2019), offers data on this point. We use the Treasury International Capital System (TIC) Data from 1980:Q1 to 2019:Q2 on the net purchases of Treasurys by foreigners and compute the actual returns to these purchases. For the computations, we assume that purchases are of the entire Treasury market (Barclays U.S. Treasury Index). The dollar-weighted measure uses actual purchases to compute an internal rate of return on the trading strategy conducted by foreign investors. The time-weighted column is the return on a counterfactual where these investors simply executed a buy-and-hold strategy over the period.

There is a large gap of up to 9.34% between the time-weighted and dollar-weighted returns. Foreign investors, both official and private, have particularly bad market timing. They buy Treasury bonds and the dollar when they offer low returns and sell them when they offer high returns. The gap is both due to poor market timing on bonds and on the dollar exchange rate. The Nominal USD column measures the return to the strategy in USD; that is, excluding the gains and losses on the currency. The gaps here are around 5%. They buy Treasury bonds when they offer low returns and sell them when they offer high returns. We interpret these gaps

Table 1: Returns to foreign investors on purchases of Treasury bonds

We report the average returns to foreign investors from their purchases and sales of the U.S. Treasury bonds, from 1980:Q1 to 2019:Q2. The dollar-weighted measure uses actual purchases of foreign investors from the Treasury International Capital System to compute an internal rate of return on the trading strategy conducted by foreign investors. The time-weighted column is the return on a counterfactual where these investors simply executed a buy-and-hold strategy over the period.

Treasury Investor	Currency Denomination	Dollar-weighted	Time-weighted	Gap
Official + Private	Local Currency	5.43	13.74	8.32
	Nominal USD	5.46	10.33	4.87
Private	Local Currency	4.41	13.75	9.34
	Nominal USD	4.90	10.81	5.91

as evidence that foreign investors are willing to pay a substantial premium to own safe dollar bonds. This observation, *Fact 1: Dollar convenience yield*, is the key input into our model as we detail next.

Analysis: Our model includes productive units (interpreted as firms and banks) operating in the U.S. and in the foreign countries. These productive units make production and financing decisions, subject to a standard credit friction that limits debt capacity as a function of future revenues. We embed this production model in a new general equilibrium model of exchange rate determination with convenience yields. Lastly, we trace out the propagation of U.S. monetary policy via the interaction between the credit friction and the exchange rate mechanism.

We start with the firm side. Given our assumption that investors impute a convenience yield on safe dollar claims, it follows almost immediately that firms will have an 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 the dollar to exploit the convenience yield. U.S. borrowers will also issue dollar claims and benefit from the convenience yield.

The financing pattern is thus just the mirror of the convenience yield observation, and thus explains *Fact 2: Dollar debt dominance* detailed above. 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. Without a convenience yield on dollar claims, 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 (Schneider and Tornell, 2004). But, crucially this argument suggests that emerging market firms should all be borrowing in the lowest interest rate currency — say Yen or Swiss Francs rather than Dollars. The convenience yield hypothesis is specifically about the dollar.[2]

In our model, the convenience yield that world investors assign to safe dollar assets is determined by the supply of safe dollar bonds: Given a downward sloping world convenience-demand curve for safe dollar bonds, a decrease in the aggregate supply of safe dollar bonds leads to an increase in the equilibrium convenience yield, and in turn, a rise 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.

Then, we derive an expression for the dollar's exchange rate whereby the convenience yield 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, as in *Fact 3: Dollar safety.* As the quantity of safe dollar bonds determines the equilibrium convenience yield, it also enters exchange rate determination and helps explain dollar exchange rate patterns.

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, unlike Gabaix and Maggiori (2015), we associate the "dollar" 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

[2]We also note that the negative basis illustrated in Figure 1(a) cuts against the low-yield explanation. If firms are selling dollar debt because their absolute yields are low, then lenders will need some compensation to absorb all of this debt. All things equal, this will push up the relative swapped yield on dollar debt compared to foreign debt. We would then expect that the basis will be positive not negative. This argument also applies to the common search-for-yield explanation of investors. If low U.S. yields causes U.S. investors to search for foreign yield, then they effectively are less willing to absorb dollar debt, pushing up the swapped yields on dollar debt compared to foreign debt.

shortage. Jiang, Krishnamurthy and Lustig (2018*a*,*b*) provide evidence for the convenience yield/dollar relationship. Likewise, actions by the Federal Reserve to increase the supply of safe dollar bonds via crediting foreign central banks with dollar reserves, under the swap lines, should be expected to reduce convenience yields and depreciate the dollar.

U.S monetary policy shocks impact dollar bond supply and exchange rates leading to the asymmetric spillover effects of *Fact 4: Global financial cycle.* We model monetary policy transmission along the lines of Bernanke and Blinder (1992)'s credit channel. Tighter monetary policy reduces the present value of collateral cash flows and constrains borrowing, leading to a reduction in employment and output. Suppose the U.S. tightens its monetary policy, say for domestic reasons. Then the value of the dollar exchange rate rises for two reasons: (i) its interest rate rises (the standard uncovered interest rate parity channel); and (ii) the tightening reduces the supply of dollar bonds issued by the production units. The second channel renders dollar bonds scarcer and raises its convenience yield, further raising the dollar exchange rate.

As the firms around the world borrow in the dollar and face a currency mismatch on their balance sheets, they suffer additional losses since the dollar-denominated debt appreciates against their local currency-denominated revenues. Given the financial constraint, these losses will impact production and hiring decisions and lead to declines in foreign output.[3] U.S. output also falls due to the monetary tightening, but the effect on the U.S. firms will be through an increase in the flow cost of credit, while the impact for foreign firms will be through a revaluation effect on the stock of their dollar debt. This effect on the foreign firms can plausibly be as large if not larger than the impact on the U.S. firms, so that U.S. monetary policy can generate significant financial spillovers for other countries as *Fact 4* indicates.[4] An accelerator effect also kicks in: the higher value of dollar raises foreign firms' leverage, exacerbates the dollar shortage, increases the dollar convenience yield, appreciates the dollar, and so on.

In our model, the U.S. is a supplier of safe dollar bonds to the rest of the world, thus explain-

[3] See Aguiar (2005), Bleakley and Cowan (2008), and Kalemli-Ozcan, Kamil and Villegas-Sanchez (2016) for evidence on the real impact of currency mismatch.

[4] Akinci and Queralto (2018) offers a related model to explain monetary policy spillovers. In their model, the U.I.P. wedge is affected by monetary policy via credit market frictions. They show that the endogenous movement in the wedge gives rise to monetary policy spillovers.

ing the balance sheet characterization of Gourinchas and Rey (2007) (*Fact 5: U.S. exorbitant privilege*). On average, the U.S. earns a carry trade return by holding foreign bonds with higher yields and selling dollar bonds with lower yields. In states when the dollar appreciates, this carry trade leads to losses to the U.S. This pattern of gains and losses resembles the "exorbitant privilege/exorbitant duty" of Gourinchas, Rey and Govillot (2011). However, there is a nuance associated with the exorbitant duty in our model. Since the U.S. losses in the carry trade are associated with an increase in the convenience yield, future carry trade returns are expected to be high, and the present value of the U.S. profits (i.e. its exorbitant privilege) would rise. This capitalization effect arises because we associate the exorbitant privilege with a convenience yield rather than a risk premium. As a result, a global crisis can lead to a net gain in the U.S. wealth. We argue that this capitalization gain offers a further explanation for why the U.S. is a natural seller of safe dollar bonds. In a crisis, the value of the U.S. asset base rises relative to foreign countries, and we present evidence consistent with this point from the Global Financial Crisis.

Our analysis also highlights channels of contagion. Shocks to one foreign country will impact other foreign countries but will have limited spillover effects to the U.S. Suppose that a shock tightens financial constraints in one foreign country. As is standard in financial accelerator models, this shock will lead to a reduction in this foreign country's output. However, to the extent that this country reduces its supply of safe dollar claims, the dollar exchange rate will appreciate and create further losses to other foreign countries' dollar borrowers. In this way, a shock in one foreign country will lead to contagion, through the dollar balance sheet mismatch, to other foreign countries. Since the U.S. firms do not face the currency mismatch, 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 a fundamental asymmetry in shock transmission between the center—the U.S.—and the periphery—foreign countries. Negative foreign shocks lead to a flight to the dollar which further spreads around the non-U.S. world. The dollar is thus a global risk factor, as in *Fact 6: Dollar risk factor*.

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 dollar 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.

This paper is laid out as follows. Section 2 lays out the U.S. block of the model. Section 3 explains the international asset market equilibrium and exchange rate determination. Section 4 considers the foreign country and presents our main results on international spillovers. Section 5 concludes. We include an Appendix in a separate file. Part A presents the model's parameterization and proof. Part B presents empirical evidence consistent with the model's mechanisms. Part C discusses additional theoretical issues on hedging.

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, which we refer to as dollar liquidity.

We consider the U.S. economy with an infinite horizon. Time is discrete and indexed as $t = 0, 1, 2, \ldots$. U.S. households are modeled as living in overlapping generations (OLG). A unit mass of households 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 the households' 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 Eq. (1*) with Eq. (1+) 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. 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 hire labor l_t and produce goods, which take one period to produce. Given l_t labor and k_t capital, the production technology gives output at date $t+1$ of

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

where a_t is productivity which is known at time t.

The production technology in Eq. (2) is linear, and capital and labor are perfect substitutes. This modeling assumption 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 and the price of capital have to be equal to the price of the good. Thus the nominal wage and the nominal price of capital are both p_t as well.

The inflation rate is defined as

$$\pi_t = \frac{p_{t+1}}{p_t} - 1. \tag{3}$$

Let n_t denote the wealth of the manager at date t in real terms. The managers die with probability σ at the end of each period, and at death, consume their wealth. A manager maximizes the expected utility:

$$\sum_{t=1}^{\infty} (1-\sigma)^{t-1} \sigma n_t. \tag{4}$$

2.1 Borrowing constraint

Since it takes one period to produce goods, the firms need to borrow for production inputs labor and capital. To raise money to pay wages, firms issue nominal one-period bonds at the nominal interest rate i_t. Let b_t denote the nominal amount of borrowing. Then, the firm's budget constraint is

$$p_t n_t + b_t = p_t(l_t + k_t).$$

We assume that firms face financial constraints. A firm has debt capacity equal to a fraction $\theta < 1$ of the expected output in the next period, $f(l_t, k_t)$. So the maximal nominal amount of funding a firm can raise at time t is

$$b_t \leq \frac{\theta \cdot p_{t+1} \cdot f(l_t, k_t)}{1 + i_t}. \tag{5}$$

We focus on a parameterization under which $a_t \geq 1 + i_t - \pi_t > \theta a_t$ always. In this case, the marginal product of investment exceeds the real interest rate so that firms borrow and produce at the maximal scale, but not too much so that the maximal scale implies an infinite quantity of production.

We substitute from the debt constraint, (5), into the firm's budget constraint to find:

Proposition 1. *At time t, a firm's equilibrium labor and capital input satisfies*

$$l_t + k_t \approx n_t \frac{1}{1 - \theta a_t (1 + i_t - \pi_t)^{-1}}. \tag{6}$$

This proposition shows that employment and capital are decreasing in the real interest rate $(i_t - \pi_t)$, increasing in productivity a_t, and increasing in the manager's net worth n_t. Since we require that $(1 + i_t - \pi_t) - \theta a_t > 0$, this ratio is well-defined.

Given these expressions, the firm's real profits at $t + 1$ are

$$n_{t+1} \quad = \quad f(l_t, k_t) - \theta f(l_t, k_t) = n_t \cdot \frac{a_t(1-\theta)}{1 - \theta a_t(1 + i_t - \pi_t)^{-1}}. \tag{7}$$

Lastly, each period a fraction σ of managers die and consume their wealth. To facilitate the steady-state analysis, we assume that the same number of managers are born with $\bar{N}$ units of capital. Let N_t denote the aggregate net worth of the firm sector in real terms. Its law of motion is

$$N_{t+1} = (1-\sigma) \cdot N_t \cdot \frac{a_t(1-\theta)}{1 - \theta a_t(1 + i_t - \pi_t)^{-1}} + \sigma \cdot \bar{N}. \tag{8}$$

2.2 Monetary policy and price setting

We introduce 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 wage for hiring w_t as well as the price 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. Thus the inflation rate π_t is set before the nominal interest rate i_t is chosen and hence policy controls the real interest rate.

Monetary policy transmission works through price stickiness. In explaining the mechanisms of the model, little would be lost if we assumed that prices are fixed for all time. However, we opt instead to introduce a simple optimal price setting mechanism. We assume that workers can work in an alternative sector, called the informal (I) sector. The I-sector has productivity of one at all times, and its production function is linear in labor alone:

$$f'(l'_t) = l'_t.$$

The I-sector unit is owned by households, and faces no debt-capacity constraints. Loosely, think of this as an endeavor where people work for their neighbors. The I-sector also sets wage for hiring w'_t and the price for the output good p'_{t+1}, and holds these prices constant for one period. The expected profit of an I-sector unit as a function of its pricing and hiring decision is:

$$E_t[p'_{t+1} l'_t - w'_t(1 + i_t) l'_t] = p'_{t+1} l'_t - w'_t(1 + E_t[i_t]) l'_t.$$

Profit maximization implies that,

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

in other words, the I-sector sets prices so that the expected real interest rate is zero, thus equating the cost of capital and the marginal rate of transformation of labor into goods.

Next, note that since the labor and goods market are competitive. It then follows that the wages w'_t and w_t are equal, and they are equal to price for the capital good p_t. Also,

$$p_{t+1} = p'_{t+1}.$$

That is to say, prices and wages are set based on the optimality condition for the I-sector. Eq. (9) becomes

$$\frac{p_{t+1}}{p_t} = \frac{p'_{t+1}}{p'_t} = 1 + E_t[i_t];$$

it should be apparent that the I-sector is introduced primarily as a modeling device to describe optimal price-setting.

For comparison, an F-sector firm faces a similar profit maximization problem when setting prices, but with productivity $a_t > 1$. Since this sector faces financial constraints in hiring labor, profit maximization only gives the inequality:

$$\frac{p_{t+1}}{p_t} a_t \geq 1 + E_t[i_t].$$

2.3 Market clearing, output, and debt supply

There are two market clearing conditions. Labor market clearing is

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

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

$$K_t = N_t.$$

All of the manager's wealth is invested in capital. Note that this condition means that the F-sector's 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,

$$\begin{aligned} Y_{t+1} &= a_t(L_t + K_t) + (\bar{L} - L_t) \\ &= a_t K_t \left(1 + \frac{\theta(a_t - 1)}{(1 + i_t - \pi_t) - \theta a_t}\right) + \bar{L} \end{aligned} \tag{10}$$

Output is increasing in capital K_t and productivity a_t, and decreasing in the real interest rate $i_t - \pi_t$.[5]

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

[5]Note that workers are indifferent between the I-sector and the F-sector since wages are the same in both sectors. In writing Eq. (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 $p_t + \varepsilon$, so that workers strictly prefer working in the F-sector. As $\varepsilon \to 0$, we have our specified equilibrium.

real borrowing of the U.S. F-sector firms:

$$B_t = \frac{\theta \cdot p_{t+1} \cdot f(l_t, k_t)}{(1 + i_t) \cdot p_t}. \tag{11}$$

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

$$i_t = \bar{\pi} + \varepsilon_t. \tag{12}$$

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

$$N^{SS} = (1 - \sigma) \cdot N^{SS} \frac{a^{SS}(1 - \theta)}{1 - \theta a^{SS}} + \sigma \cdot \bar{N}. \tag{13}$$

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

To illustrate the impact of monetary policy, we consider the impulse responses to a one-time monetary policy shock ε_t. We calibrate the model at the quarterly frequency, and consider a 0.25% shock to the quarterly nominal interest rate at time $t + 1$ (which is equivalent to a 1% shock to the annualized interest rate). After time $t + 1$, the nominal interest rate returns to its steady-state level 0. We trace out the impact of this shock beginning from the steady-state of the model. Figure 2 illustrates the impulse responses.

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 the margins $(a_{t+1} - (i_{t+1} - \pi_{t+1}))$ decline and because the debt capacity falls. The

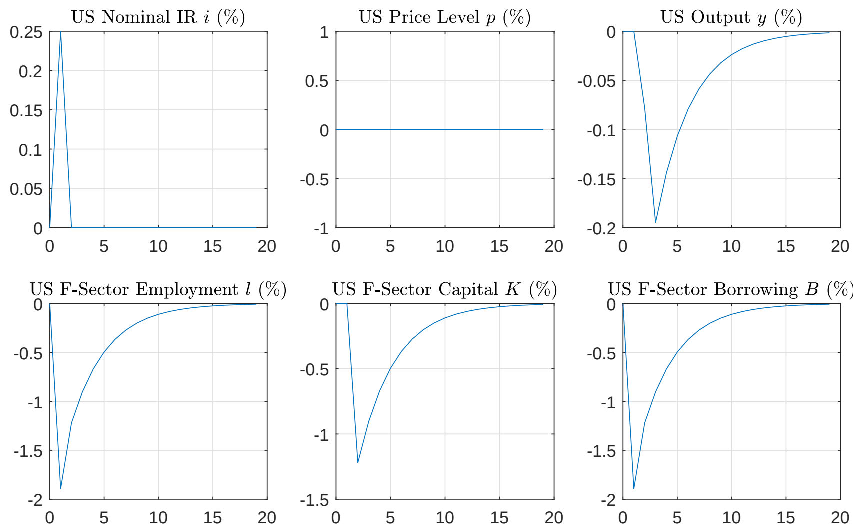


Figure 2: Impulse response to a U.S. monetary policy shock of 0.25%

We consider a 0.25% shock to the U.S. quarterly nominal interest rate i_{t+1} in period $t+1$. The top-left panel plots i_t, with the x-axis in periods. The top-middle panel plots the price level p_t. The top-right panel plots output y_t as a percent deviation from the steady-state value. The bottom panels plot hiring (l_t), capital (K_t) and borrowing (B_t) in the F-sector, all as percentage deviations from their steady-state values. See Table 2 for parameter values.

lower profits leads to a fall in capital K in the following period $t+2$ (bottom-middle panel). Output falls in period $t+2$ as labor is allocated to the less productive I-sector, and further at $t+3$, as the shock leads to a fall in capital K_{t+2}. The private dollar debt supply, B_t, which is equal to debt capacity, also falls on impact as illustrated in the bottom-right panel.

As in financial accelerator models (see Bernanke, Gertler and Gilchrist, 1996), the effect of the initial interest rate shock persists even after the shock disappears, through a propagation mechanism via the damage to capital K. 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). Our sign convention means that a stronger dollar is associated with a higher value of S_t. The real exchange rate is $\mathcal{E}_t = S_t p_t$ (the log rate is denoted e_t).

We suppose that world safe asset investors place an extra convenience yield of λ_t to own dollar liquidity, which in the model are the dollar bond issued by any firms. Let Q_t denote the amount of the dollar bond held by the world investors. We construct such an equilibrium in the next section. For now, we assume that the world safe asset investors are risk-neutral, and note that their optimality condition requires that

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

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

In real terms, this uncovered interest parity (U.I.P.) condition becomes:

$$E_t e_{t+1} - e_t = r_t^* - r_t - \lambda_t, \tag{15}$$

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

When world safe asset demand rises (high λ_t), then the dollar appreciates today and has an expected depreciation. This is the condition we derive in our other work (see Jiang, Krishnamurthy and Lustig, 2018*a*), which considers the case of risk-averse world investors so that the U.I.P. condition also reflects a currency risk premium. As the risk premium is not central to our present analysis, we set this aside and derive Eq. (15) for risk-neutral world investors.

We iterate on this equation forward and find

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

The term $\bar{e} = lim_{t \to \infty} e_t$ is a constant because we assume that the real exchange rate is stationary. From Eq. (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 ($r_j - r_j^*$). Jiang, Krishnamurthy and Lustig (2018*a*) presents evidence to support these points.

3.2 Dollar supply and the intermediation of 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 the U.S. engage in this carry trade while the world safe asset investors take the opposite position. 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 of safe asset holdings impacts equilibrium exchange rates, carry trade profits, and the dynamics of the trade balance.

To focus on a determination of exchange rates by the financial side, we adopt a similar approach to Gabaix and Maggiori (2015) in describing foreign asset trade. We suppose that U.S. households do not participate in the foreign exchange market. Instead, a set of banks intermediate the carry trade into the world bonds. More precisely, there is a measure $\chi < 1$ of banks. For each of these banks, it can contact exactly one (young) working U.S. 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 i_t^D. Once the bank receives the deposit, it can use this fund to trade with world safe asset investors in the foreign exchange market.

So, if a (young) working U.S. household is paired up with a bank, it can invest its nominal wage income of $p_t l_t$ either in the U.S. dollar bonds issued by firms at interest rate i_t, in central bank deposits at rate i_t, or in private bank deposits at rate i_t^D. Given depositors' outside option to invest in dollar bonds and central bank deposits, it follows that the deposit rate is also $i_t^D = i_t$.[6]

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. In raising d_t deposits from the household, the bank receives d_t units of the dollar bonds. The bank can hold these dollar bonds, or sell these dollar bonds to safe asset investors in return for their world bonds.[7] Let $h_t^{\$}$ and h_t^w denote the bank's holdings of the U.S. bonds and the world bonds. The bank's budget constraint is

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

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

$$h_t^w \left(i_t^* - (E_t s_{t+1} - s_t)\right) + h_t^{\$} i_t, \tag{17}$$

subject to a short-sale constraint on the dollar bonds:

$$h_t^{\$} \geq 0. \tag{18}$$

[6]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 some firms bonds are held in equilibrium by these households, it follows that the firm bonds must also pay i_t.

[7]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.

Note that the first term in Eq. (17) is the return on running the "carry" trade of investing in the world bond, $i_t^* - i_t - (E_t s_{t+1} - s_t) = \lambda_t > 0$, which is positive on average. Since the bank is risk-neutral, it maximizes expected profits by picking the corner solution where the short-sale constraint binds:

$$h_t^w = d_t \text{ and } h_t^\$ = 0.$$

The bank thus holds no U.S. dollar bonds and invests only in world bonds. In aggregate, the bank sells a fraction χ of the U.S. safe bonds to the world safe asset investors. Define the real dollar liquidity produced by the U.S. as:

$$Q_t = \chi B_t. \tag{19}$$

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

$$\Pi_{t+1}^b = Q_t \mathcal{E}_t \left(i_t^* - i_t - (s_{t+1} - s_t) \right), \tag{20}$$

where we note that the expected carry profits $\mathbb{E}_t[\Pi_{t+1}^b]$ are proportional to λ_t:

$$\mathbb{E}_t[\Pi_{t+1}^b] = Q_t \mathcal{E}_t \lambda_t.$$

The positive return on the carry trade stems from the "exorbitant" privilege of the U.S in producing safe dollar assets, consistent with the analysis of Gourinchas and Rey (2007).

Last, we suppose that the world investor's convenience yield for dollar bonds is downward sloping in quantity:

$$\lambda_t = \lambda(Q_t) \quad \text{with} \quad \lambda'(Q_t) < 0. \tag{21}$$

We note that since the U.S. firm borrowing B_t falls when the nominal interest rate i_t rises, the U.S. monetary policy impacts the exchange rate through two channels: a rise in i_t increases the real interest rate r_t and hence the real exchange rate e_t directly through the U.I.P. relation, and indirectly through a reduction in the dollar liquidity Q_t and a corresponding rise in the convenience yield λ_t.

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

$$\lambda_t = \bar{\lambda} - \beta^{\lambda}(Q_t - Q^{SS}) + \varepsilon_t^{\lambda}. \tag{22}$$

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. In particular, the dollar liquidity Q_t should also include these safe assets. Consistent with this mechanism, Krishnamurthy and Lustig (2019) presents evidence that relates convenience yield movements to QE announcements.

- *If more U.S. entities could issue safe debt, would not the convenience yield effects disappear?* The short-sale constraint, Eq. (18), 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 even more dollar 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 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).[8] Finally, one can think of the bonds of our models as an amalgam of financial sector debt and non-financial sector debt; our

[8] 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 h_t^w and $h_t^{\$}$ are positive and affect equilibrium exchange rates, as Gabaix and Maggiori (2015) show. We can see this most clearly by noting that in Eq. (19), 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.

firms are the 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 and household segmentation primarily to clearly delineate the carry trade profits.

- *Can you talk about safe assets in a model in which all bonds are risk-free?* 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 certain adverse shocks reduce the supply of bonds (Q_t). In a model with risky and safe bonds, adverse shocks would turn some safe bonds risky and thereby reduce the supply of safe bonds.

3.4 Trade balance and external assets

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 U.S. trade balance and external assets.

First, we adjust our earlier definition of household preferences from Eq. (1*) to allow for trade in goods and thus describe the trade dynamics. The generation-t U.S. household maximizes utility

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

and we normalize by setting $\alpha_H + \alpha_T + \alpha_X = 1$. Here, $c_{t+1,H}$ is consumption of the U.S. home good and $c_{t+1,T}$ is consumption of the world good. The term x_{t+1} is a bequest of bank equity shares left to generation $t+1$, which we introduce to connect the exorbitant privilege (i.e. carry profits) of the U.S. banks with the U.S. households' consumption decision and trade balance. The generation-t households receive x_t worth of shares of bank equity and at $t+1$ these shares are worth $x_t\left(V_{t+1} + \Pi^b_{t+1}\right)/V_t$. Here V_{t+1} is the market value of the bank, in units of the world good, and Π^b_{t+1} are bank earnings defined in Eq. (20). In particular, we define the net bank payments to the U.S. households in foreign currency units as

$$BP_{t+1} = x_t \frac{\Pi^b_{t+1}}{V_t}. \tag{23}$$

The generation-t households then allocate their wealth between consumption and a bequest to the next generation. Their budget constraint is

$$\mathcal{E}_{t+1} c_{t+1,H} + c_{t+1,T} + x_{t+1} = w_{t+1} \equiv \mathcal{E}_{t+1}(1 + i_t - \pi_t)\bar{L} + x_t \left(\frac{V_{t+1} + \Pi^b_{t+1}}{V_t} \right). \tag{24}$$

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.

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 U.S. 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.

The following proposition characterizes the international trade and investment equilibrium:

Proposition 2. *(a) In equilibrium, the U.S. trade balance (import minus export) in foreign currency units is*

$$TB_{t+1} = \mathcal{E}_{t+1}(1 + i_t - \pi_t)\bar{L} - (\alpha_T + \alpha_H)\, w_{t+1}. \tag{25}$$

(b) The U.S. households bequeath a fixed fraction of their wealth to the next generation,

$$x_{t+1} = \alpha_X w_{t+1}, \tag{26}$$

and this law of motion gives rise to the following steady-state household bequest,

$$x^{SS} = \frac{\alpha_X}{1-\alpha_X(1+r^*)}\mathcal{E}^{SS}(1+i^{SS}-\pi^{SS})\bar{L}. \tag{27}$$

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

To better understand the trade dynamics of the model, it is useful to express trade balance and wealth in real dollar units,

$$\begin{aligned}
\frac{TB_{t+1}}{\mathcal{E}_{t+1}} &= (1+i_t-\pi_t)\bar{L} - (\alpha_T+\alpha_H)\frac{w_{t+1}}{\mathcal{E}_{t+1}} \\
\frac{w_{t+1}}{\mathcal{E}_{t+1}} &= (1+i_t-\pi_t)\bar{L} + x_t\left(\frac{V_{t+1}+\Pi^b_{t+1}}{V_t}\right)\frac{1}{\mathcal{E}_{t+1}}.
\end{aligned}$$

Trade balance dynamics are described by the wealth dynamics $w_{t+1}/\mathcal{E}_{t+1}$. Wealth dynamics are in turn affected by both the current carry trade profit Π^b_{t+1} and the present value of future carry trade profits V_{t+1}. All else equal, a decline in U.S. wealth leads to an improvement of the trade balance as the U.S. household reduces consumption of home and foreign goods.

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

$$-TB^{SS} = BP^{SS} = x^{SS}r^*.$$

In other words, in the steady state the U.S. finances its trade balance (imports minus exports) entirely using the dividend payments from the banks, which in turn are profits from the banks'

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

$$x_{t+1} = \alpha_X\mathcal{E}^{SS}(1+i^{SS}-\pi^{SS})\bar{L} + \alpha_X(1+r^*)\cdot x_t.$$

Since $0 < \alpha_X(1+r^*) < 1$, starting from any initial value of x_t, $\lim_{s\to\infty} x_{t+s} = x^{SS}$.

carry trade.

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 (13).

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}. Krishnamurthy and Lustig (2019) presents evidence for this convenience yield channel of monetary policy from examining event-day responses around both conventional

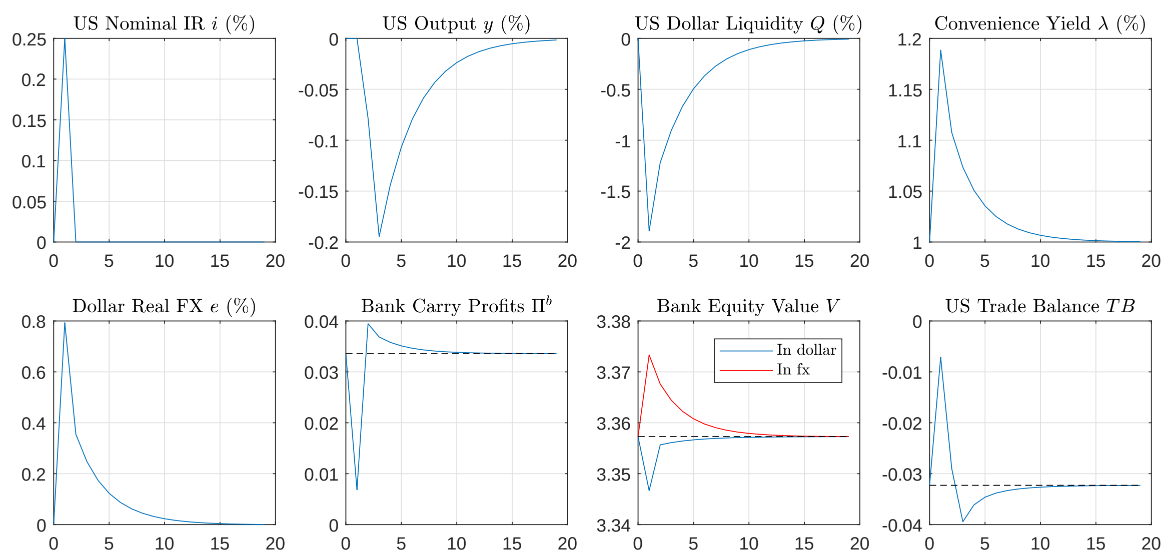


Figure 3: Impulse response to a U.S. monetary policy shock of 0.25%

We consider a 0.25% shock to the U.S. nominal interest rate i_{t+1} in period $t+1$. The top-left panel plots i_t, with the x-axis in periods. The rest of the panel traces out the endogenous variables in the U.S. economy. All except for the trade balance, the bank payments, the carry profits, and the banks' equity value are expressed as percentage deviations from their steady-state values. The bank carry profits are in the units of the world good, and the U.S. trade balance are in dollar units. See Appendix Table 2 for parameter values.

and unconventional monetary policy announcements.

The U.S. banks run a carry trade that is long the foreign currency and short the dollar. As the dollar appreciates on impact, the U.S. banks suffer a loss at time $t+1$. Subsequently, they earn higher profits as the convenience yield λ_{t+k} rises. This pattern of losses and gains is reflected in the panel of the banks' carry profits Π_t^b. 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, leading to a reduction of the U.S. trade deficit.

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 Eq. (16). To maintain a constant real exchange rate e_t, the real interest rate 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 Jiang, Krishnamurthy and Lustig (2018*a*).

- 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, earning a spread on this position. 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 trade 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. In both models, the mechanism of exorbitant privilege is driven by 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 and transfers wealth to the rest of the world.

A key implication of this risk-sharing mechanism is that the U.S. on average runs a current account deficit, but in a crisis runs a surplus as it pays out on the insurance it provides to the rest of the world. Gourinchas, Rey and Truempler (2012), studying the global financial crisis, compute that the U.S. loses \$2.2 trillion to the rest-of-the-world on its net-foreign-asset position from 2007Q4 to 2009Q1, and interpret this loss as corresponding to the insurance payment.

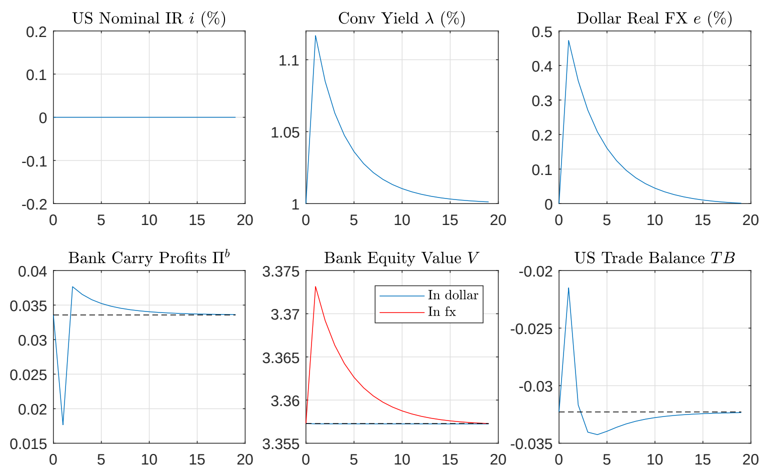
In our model, the world pays a convenience yield to own dollar assets. Because it is a convenience yield, as opposed to a risk premium, the U.S. earns a seigniorage from providing safe dollar claims without incurring the crisis liability. In fact, the convenience yield may rise in a crisis, leading to even higher present and future profits from this seigniorage. This last implication highlights a new mechanism at work in our model. As we discuss next, it provides a novel perspective on the U.S. as a safe asset provider to the world.

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 $\varepsilon^{\lambda}_{t+1} = 0.1\%$ (10 basis points), 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 bottom-left 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 dollar's appreciation almost perfectly offsets the rise in the banks' profits. This should be expected in our model. To a first order, the value of bank profits is the discounted present value of the dollar liquidity Q_{t+j-1} multiplied by the convenience yield,

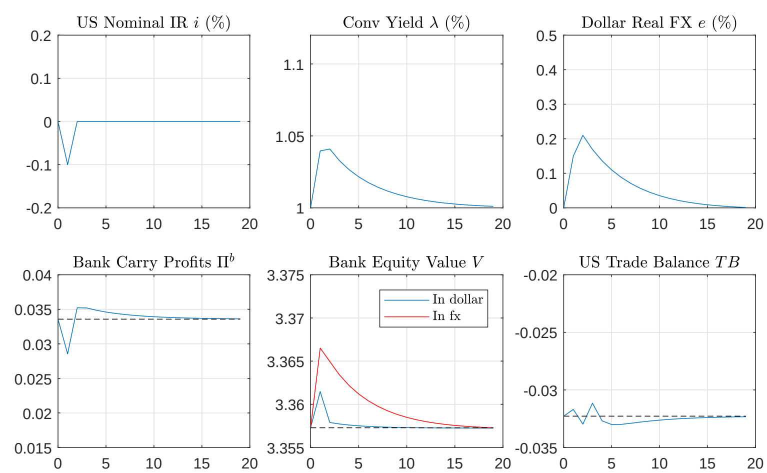
$$V_t \approx \mathbb{E}_t \sum_{j=1}^{\infty} \frac{Q_{t+j-1}\lambda_{t+j-1}}{(1+i^*)^j},$$

while the exchange rate is the sum of expected future convenience yield:

$$s_t = \mathbb{E}_t \sum_{j=0}^{\infty} \lambda_{t+j} + \mathbb{E}_t \sum_{j=0}^{\infty} (i_{t+j} - i^*_{t+j}).$$



(a) Panel A: Impulse responses to a safe asset demand shock of 10 basis points



(b) Panel B: Impulse response to a safe asset demand shock of 10 basis points and a U.S. nominal interest rate shock of -10 basis points

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

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 U.S. nominal interest rate shock of -10 basis points. The bank carry profits are in the units of the world good, and the U.S. trade balance are in dollar units. See Table 2 for parameter values.

Both V_t and s_t reflect a common convenience yield term $\mathbb{E}_t \sum_{j=0}^{\infty} \lambda_{t+j}$ which to a first-order offset each other.

In Panel B, instead of fixing the U.S. monetary response to the flight-to-dollar, we suppose that the Fed lowers interest rates by 10 basis points, 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, although the current flow from profit from the carry trade turns negative. Bank equity value rises in both dollar and foreign currency terms, reflecting the present value of future carry trade profits. Bank payments to the U.S. households are negative in the first period and then turn positive. To a first-order, the U.S. trade balance remains stable as these effects offset. [10]

The rise in future seigniorage profits in this example illustrates a broader point regarding the specialness of the U.S. If one only considers the current flow profits from the carry trade, the U.S. loses money in a crisis as in Gourinchas, Rey and Govillot (2010); however, accounting for the future, there is a net transfer of wealth to the U.S. due to the future carry trade profits. We argue that the future-value effect is another rationale behind why the U.S. is a safe-asset provider to the rest of the world: it is naturally hedged against crises. Gourinchas, Rey and Truempler (2012) compute that the U.S. loses \$2.2 trillion to the rest-of-the-world on its net-foreign-asset position from 2007Q4 to 2009Q1. We perform a related but broader computation. We compute that the total market value of traded wealth in the U.S. (equities, bonds, and deposits held by both U.S. and non-U.S. entities) falls by \$5.5 trillion over this period. See the Section B.2 of the Appendix for the details of this computation. The same measure for the five largest wealth non-U.S. countries (Canada, Germany, France, Great Britain, Japan) is \$9.8 trillion, when measured in dollars. See Figure 5. That is, on a relative basis, the U.S.

[10] 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.

gains $4.3 trillion in present value terms relative to the rest-of-the world, while the rest-of-the-world receives a flow transfer equivalent to $2.2 trillion via the net-foreign-asset position. These patterns indicate that the U.S. and rest-of-the-world share financial risks almost perfectly and offer another rationale behind the U.S. role as safe asset provider. The stochastic patterns of convenience yields hedge the U.S. when issuing safe dollar bonds. Jiang et al. (2019) make a similar point in the context of the U.S. government's fiscal capacity.

Our convenience yield mechanism also helps resolve another puzzle raised by Maggiori (2017). In his risk-sharing model, the U.S. transfers wealth to the rest of the world in a crisis. As a result, the foreign consumption of U.S. goods would rise, absent other forces, causing the foreign currency to appreciate relative to the dollar in real terms. But as Maggiori (2017) notes, these crisis predictions regarding trade surplus and the dollar depreciation appear at odds with the

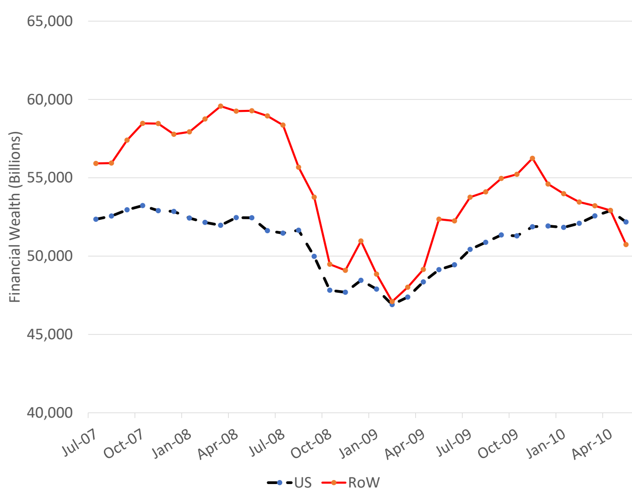


Figure 5: U.S. and RoW Financial Wealth

We graph the total market value of traded wealth in the U.S. (equities, bonds, and deposits issued in the U.S. and held by both U.S. and non-U.S. entities) in black-dashed line. The same measure for the five largest wealth non-U.S. countries (Canada, Germany, France, Great Britain, Japan) is graphed in red. Wealth is measured in dollars and not local currency. Note that in order to measure the gains and losses of the U.S. and non-U.S. investors, one must also measure the gain/loss on the net foreign asset position and net this against the measures graphed. See the Section B.2 of the Appendix for underlying computations.

patterns in the 2007—2009 global financial crisis. Maggiori (2017) suggests a resolution by introducing higher trade costs in crisis states. Our mechanism offers a different resolution of this puzzle. The U.S. on net gains wealth, on a relative basis, in crisis states via the future carry trade profits. This wealth gain offsets the carry trade losses and can thus be consistent with the dollar appreciation in the crisis without having to appeal to increased trade costs.

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 the 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 foreign country are OLG. Their utility function is,

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

where 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 $\frac{1}{1+i_t^*}$ 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 1 for simplicity.

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

$$f(l_t^*, k_t^*) = a_t^*(l_t^* + k_t^*), \qquad a_t^* > i_t^*. \tag{29}$$

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

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

Foreign firms may choose to borrow in foreign currency or in dollars. First, suppose that the firm only borrows in the foreign currency. This case follows readily from our U.S. analysis. The firm can promise repayments up to $\theta^* a_t^*(l_t^* + k_t^*)$. 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,

$$l_t^* + k_t^* = n_t^* \frac{1}{1-\theta^* a_t^*(1+i_t^*)^{-1}} \tag{31}$$

and firm profits are:

$$\Pi_t^{*,local} = (1-\theta^*)a_t^*(l_t^* + k_t^*) = n_t^* \cdot \frac{a_t^*(1-\theta^*)}{1-\theta^* a_t^*(1+i_t^*)^{-1}}. \tag{32}$$

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 the demand for dollar safe assets generates a wedge in the U.I.P condition, as in Eq. (33). We could imagine a richer model in which the risk-shifting and the convenience yield explanation are both present. In this case, for a borrower with discount factor β^*, the perceived cost of dollar borrowing is,

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

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

The foreign firm's dollar borrowing in the model captures the oversea dollar borrowing market, such as 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 (2012) reports numbers of about \$10 trillion in 2010, indicating the relevance of these entities in the world dollar market. Shin (2012) 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-U.S. 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.

The following proposition characterizes a foreign firm's borrowing and profits if it has access to dollar funding.

Proposition 3. *The equilibrium quantity of dollar debt a foreign firm issues is*

$$Q_t^* S_t = n_t^* \frac{\theta^* a_t^*}{1 + i_t^* - \lambda_t - \theta^* a_t^*}. \tag{34}$$

The foreign firm's profits based on the realization of s_{t+1} *are,*

$$\Pi_t^{*,dollar}(s_{t+1}) = n_t^* a_t^* \frac{(1-\theta^*) - \theta^*(s_{t+1} - E_t[s_{t+1}])(1 + i_t^* - \lambda_t)^{-1}}{1 - \theta^* a_t^* (1 + i_t^* - \lambda_t)^{-1}}. \tag{35}$$

We can compare this last expression for profits to that in Eq. (32). Note that the profits depend on the realized exchange rate movement, $s_{t+1} - E_t[s_{t+1}]$. 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 Eq. (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.[11] 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.

The total foreign profit at date $t+1$ is the sum of profits from the two divisions of the conglomerate:

$$\begin{aligned}(1-\gamma)\Pi_t^{*,local} + \gamma\Pi_t^{*,dollar} &= a_t^* N_t^* \left((1-\gamma)\frac{(1-\theta^*)}{1-\theta^* a_t^*(1+i_t^*)^{-1}} \right. \\ &+ \left. \gamma \frac{(1-\theta^*) - \theta^*(s_{t+1} - E_t[s_{t+1}])(1+i_t^* - \lambda_t)^{-1}}{1-\theta^* a_t^*(1+i_t^* - \lambda_t)^{-1}} \right);\end{aligned}$$

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.

In this model, foreign firms also produce dollar safe assets. We define the global dollar liquidity as $Q_t + Q_t^*$. We thus alter the international market equilibrium to take global liquidity as the argument:

$$\lambda_t = \lambda(Q_t + Q_t^*) = \bar{\lambda} - \beta^\lambda (Q_t + Q_t^* - Q^{SS}) + \varepsilon_t^\lambda. \tag{36}$$

[11] 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 Eq. (32) and (35). 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 Appendix C.

4.2 Equilibrium and steady state

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

$$N_{t+1}^{*} = (1-\sigma^{*})((1-\gamma)\Pi_{t}^{*,local} + \gamma\Pi_{t}^{*,dollar}) + \sigma^{*} \cdot \bar{N}^{*} \tag{37}$$

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

The equilibrium has two state variables, (N_t, N_t^*). The non-stochastic steady state satisfies Eq. (13) and

$$N_{SS}^{*} = (1-\sigma^{*})((1-\gamma)\Pi_{SS}^{*,local} + \gamma\Pi_{SS}^{*,dollar}) + \sigma^{*} \cdot \bar{N}^{*}. \tag{38}$$

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.

4.3 Monetary policy spillovers

Figure 6 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

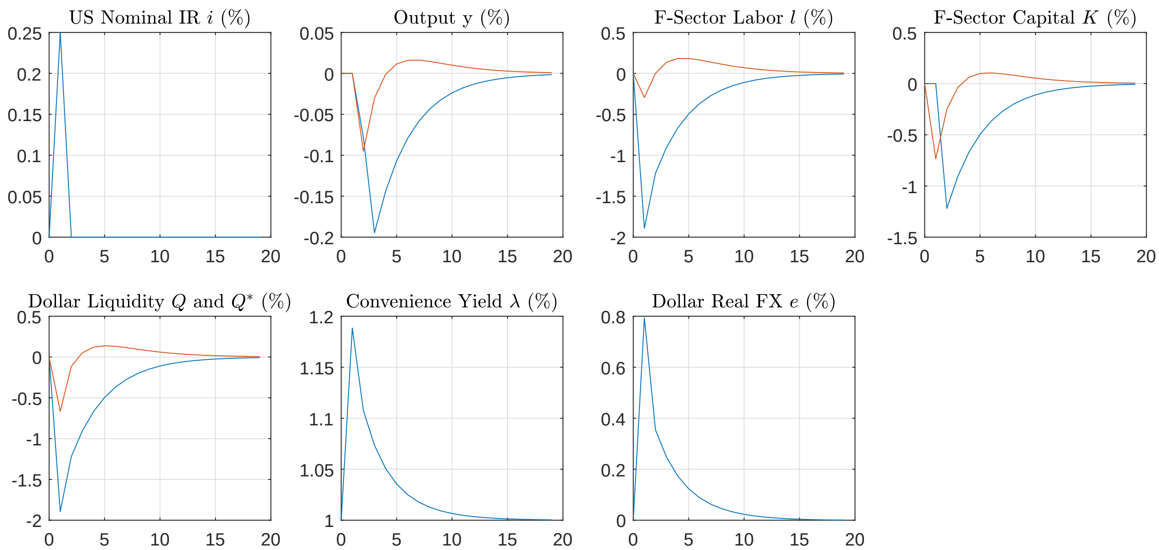


Figure 6: Impulse response to a U.S. monetary policy shock of 0.25%

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, U.S. bank carry profits, all except the last as percentage deviations from their steady-state values. See Appendix Table 2 for parameter values.

$t+2$ 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 7 presents a different experiment. We lower a_t 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

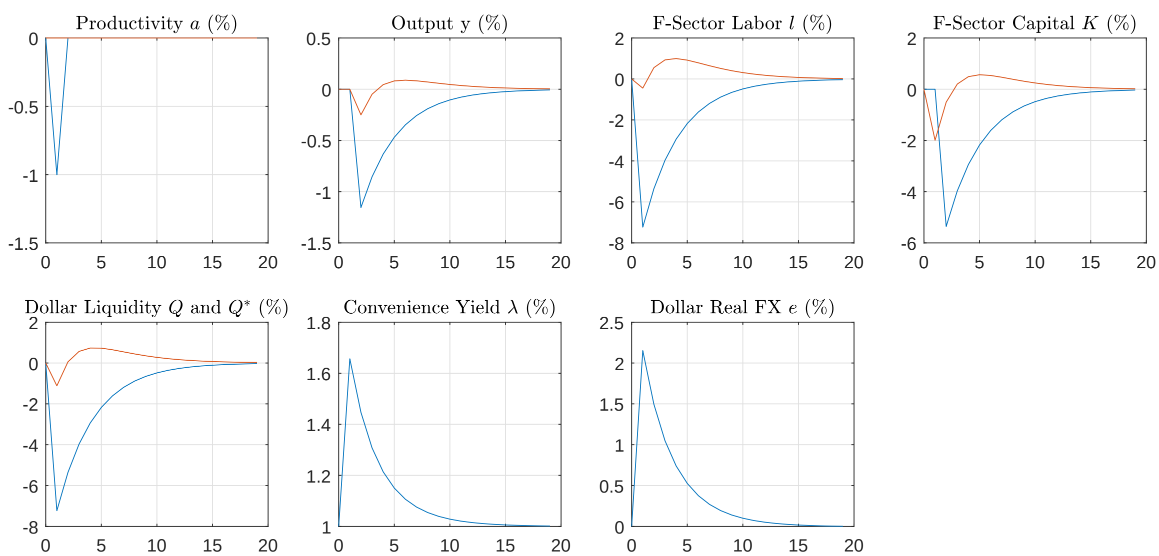


Figure 7: Impulse Responses to U.S Productivity Shock.

We consider a -1% shock to the U.S. productivity a_t in period $t+1$. 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, U.S. bank carry profits, all except the last as percentage deviations from their steady-state values. See Appendix Table 2 for parameter values.

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 7 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 8 plots the impulse response to a shock that reduces θ^*_{t+1} unexpectedly by 5%. We assume that the shock dissipates with autocorrelation of 0.7. The reduction in θ^*_{t+1} 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 9 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 then feeds back to both foreign countries by deteriorating the balance sheets of all foreign dollar borrowers. After period $t + 1$,

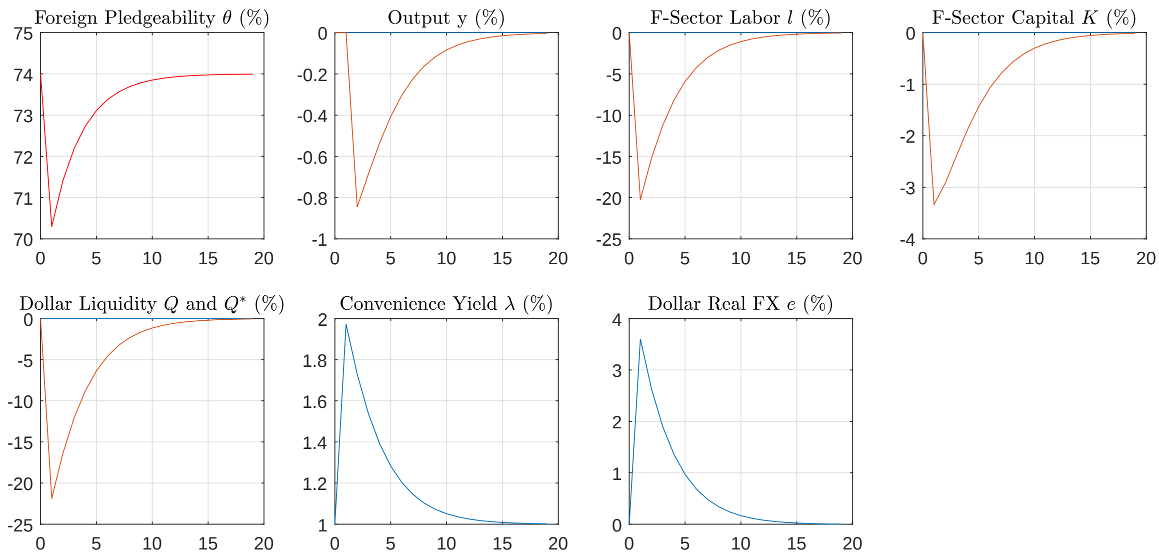


Figure 8: Impulse Responses to Foreign Pledgability Shock

We reduce the foreign F-sector's cash flow pledgeability θ^* unexpectedly by 5% at time $t+1$. 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, U.S. bank carry profits, all except the last as percentage deviations from their steady-state values. See Appendix Table 2 for parameter values.

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

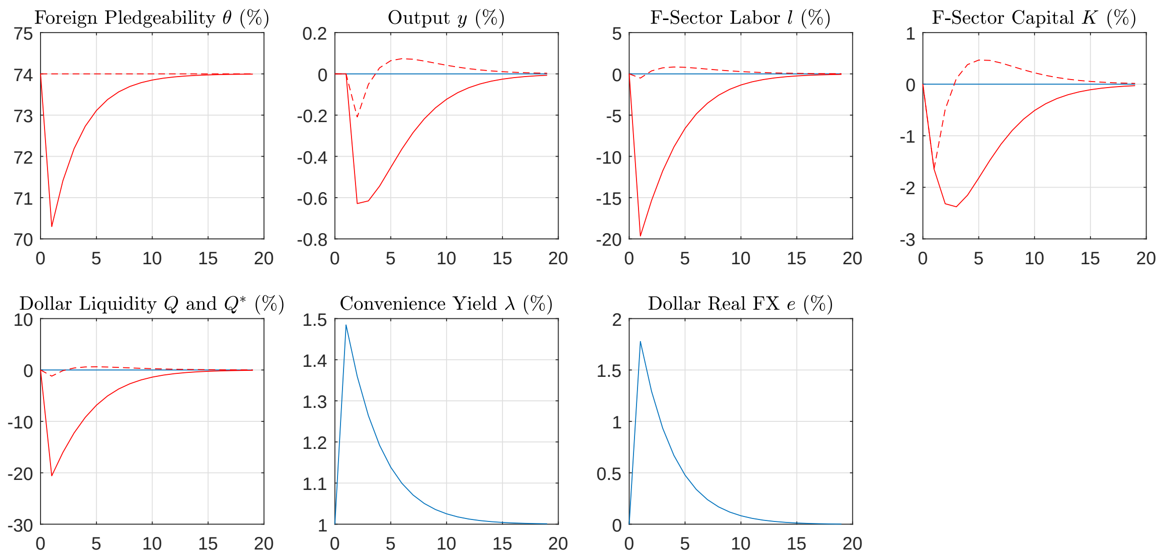


Figure 9: Impulse Responses to Foreign Pledgeability Shock and Foreign Contagion

We consider two foreign countries. We reduce the first foreign country's F-sector cash flow pledgeability θ^* unexpectedly by 5% at time $t+1$. 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 Appendix Table 2 for parameter values.

Rajan, 2016). Finally, the importance of the dollar as a risk factor for foreign countries is also apparent from the model. Papers such Lustig, Roussanov and Verdelhan (2014), Verdelhan (2018) 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.[12]

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.[13] 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 econ-

[12]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.

[13]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.

omy, 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.[14]

5 Conclusion

Our model of the global financial cycle starts from the global demand for dollar-denominated safe assets. The model delivers a dollar-driven global financial cycle that matches the U.S. balance sheet relative to the ROW, exorbitant privilege, monetary policy spillovers, contagion across non-U.S. countries, and the dollar as a global risk factor. In tying together these disparate phenomena, our analysis calls attention to the importance of understanding the dollar safe-asset demand phenomena. There has been a growing body of theoretical work on the topic. See in particular Farhi and Maggiori (2017), Maggiori (2017), He, Krishnamurthy and Milbradt (2018), and Gopinath and Stein (2019). Discriminating among the explanations offered in these theories is an important challenge for future research.

[14] We have side-stepped hedging considerations and pecuniary externalities in the choice of debt denomination that arise in dynamic models with financial constraints. See the Appendix section C. With financial constraints, a pecuniary externality emerges whereby foreign borrowers will not internalize the impact of their currency mismatch on other firms in the economy.

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Appendix for *Dollar Safety and the Global Financial Cycle*

Zhengyang Jiang, Arvind Krishnamurthy, and Hanno Lustig

A Model Appendix

A.1 Parameter Values

Parameter	Notation	Estimate
U.S.		
Pledgibility	θ	0.825
Firms' Exit Rate	σ	0.48
Productivity	$\bar{a}$	1.055
Share of Global Banks	χ	0.5
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	λ	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 U.S. F-Sector Labor	ℓ^{SS}	6.71
Steady-State Foreign F-Sector Labor	$\ell^{SS,*}$	3.48
New U.S. F-Sector Capital	k^N	0.54
New Foreign F-Sector Capital	$k^{N,*}$	0.75
Steady-State U.S. Dollar Liquidity	Q^{SS}	3.36
Steady-State Foreign Dollar Liquidity	$Q^{SS,*}$	1.78
Steady-State U.S. Bank Profits	$\Pi^{b,SS}$	0.03
Steady-State U.S. Trade Balance	TB^{SS}	-0.03

Table 2: **Parameter Values.**

We calibrate the model to make qualitative points. The steady-state U.S. interest rate is 0% and the steady-state foreign interest rate is 1%. The steady-state convenience yield on U.S. bonds is also 1%, so that the real exchange rate is stationary with a steady-state value of 1.

We normalize the U.S. and foreign steady-state capital to 1. The F-sector productivity is 1.055

whereas the I-sector productivity is normalized to 1. We also pick other production parameters so that a 0.25% increase in quarterly interest rate leads to 0.2% decline in output and 2% decline in the F-sector's employment.

The share of global banks χ is chosen to be 0.5 so that half of the dollar safe assets issued by the U.S. is held by the foreign safe asset investors. The steady-state foreign dollar liquidity $Q^{SS,*}$ is chosen to be 1.78 so that half of the dollar safe assets is issued by the foreigners.

A.2 Proofs

Proof of Proposition 1 Combining the budget constraint with the borrowing constraint,

$$p_t n_t + \frac{\theta \cdot p_{t+1} \cdot a_t (l_t + k_t)}{1 + i_t} = p_t (l_t + k_t)$$

which implies

$$l_t + k_t = n_t \frac{1}{1 - \theta a_t \frac{(p_{t+1}/p_t)}{1+i_t}} \approx n_t \frac{1}{1 - \theta a_t (1 + i_t - \pi_t)^{-1}}.$$

Proof of Proposition 2 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,

$$V_t = \sum_{j=1}^{\infty} \frac{\Pi_{t+j}^b}{(1 + r^*)^j}. \tag{39}$$

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,

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

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,

$$c_{t+1,T} = \alpha_T w_{t+1}$$

total exports are,

$$\mathcal{E}_{t+1}(1 + i_t - \pi_t)\bar{L} - \alpha_H w_{t+1}.$$

By definition, the trade balance (expressed in foreign currency units) is,

$$TB_{t+1} = \mathcal{E}_{t+1}(1 + i_t - \pi_t)\bar{L} - (\alpha_T + \alpha_H)\, w_{t+1}. \tag{40}$$

In the steady state, the trade deficit must be matched by a payment from abroad. Steady-state bank profits $\Pi^{b,SS}$ are positive

$$\Pi^{b,SS} = Q^{SS}\mathcal{E}^{SS}\lambda^{SS} \tag{41}$$

and proportional to λ^{SS}. The U.S. household owns shares in the banking sector and thus receives a dividend proportional to $\Pi^{b,SS}$. To compute how much dividends the U.S. household receives, we need to compute x^{SS}. The F.O.C. for the bequest gives that $\alpha_X w_{t+1} = x_{t+1}$. Using the expression for w_{t+1} from the budget constraint, we find that,

$$x^{SS} = \alpha_X \left(\mathcal{E}^{SS}(1 + i^{SS} - \pi^{SS})\bar{L} + x^{SS}(1 + r^*)\right) = \frac{\alpha_X}{1 - \alpha_X(1 + r^*)}\mathcal{E}^{SS}(1 + i^{SS} - \pi^{SS})\bar{L}. \tag{42}$$

Proof of Proposition 3 Suppose that the firm sells Q_t^* dollars of bonds 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,

$$Q_t^*(1 + i_t)E_t S_{t+1} \leq \theta^* a_t^*(k_t^* + Q_t^* S_t) \tag{43}$$

On the left is the expected repayment on the bonds in units of foreign currency. On the right is the amount of output in time $t + 1$ that can be pledged as collateral. 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 n_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 Eq. (43) binding, we find that:

$$Q_t^* S_t = n_t^* \frac{\theta^* a_t^*}{(1+i_t)E_t S_{t+1}/S_t - \theta^* a_t^*} \approx n_t^* \frac{\theta^* a_t^*}{1 + i_t^* - \lambda_t - \theta^* a_t^*}. \tag{44}$$

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

$$\begin{aligned}
\Pi_t^{*,dollar}(s_{t+1}) &= a_t^*(n_t^* + Q_t^* S_t) - Q_t^*(1+i_t)S_{t+1} \\
&= a_t^* n_t^* + Q_t^* S_t(a_t^* - (1 + i_t + s_{t+1} - s_t)) \\
&= a_t^* n_t^* + n_t^* \frac{\theta^* a_t^*}{1 + i_t^* - \lambda_t - \theta^* a_t^*}(a_t^* - (1 + i_t + s_{t+1} - s_t)) \\
&= a_t^* n_t^* \frac{(1-\theta^*) + i_t^* - \lambda_t - \theta^*(i_t + s_{t+1} - s_t)}{1 + i_t^* - \lambda_t - \theta^* a_t^*}.
\end{aligned}$$

Since

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

we rewrite the profits expression to find:

$$\Pi_t^{*,dollar}(s_{t+1}) = n_t^* a_t^* \frac{(1-\theta^*)(1 + i_t^* - \lambda_t) - \theta^*(s_{t+1} - E_t[s_{t+1}])}{1 + i_t^* - \lambda_t - \theta^* a_t^*}.$$

B Empirical Evidence

B.1 The Treasury Basis and λ

In Jiang, Krishnamurthy and Lustig (2018*a*), we present empirical evidence in support of Eq. (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*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 precisely, the negative of this difference) using Treasury bond rates and forward exchange rates, and denote the resulting measure as the "Treasury basis." We have plotted the basis in Figure 1(a) and 1(b) for the crisis and post-crisis sample.

B.2 Construction of Wealth Data

We measure wealth in three asset classes: bonds, equities, and deposits. We measure the total outstanding quantities, measured in local currency, in these asset classes as of December 2006 for each of Germany, France, Great Britain, Japan, United States, and Canada. The quantities is assembled using data from country central banks, the BIS, the World Bank, and the London Stock Exchange. To construct the time series of these wealth measures, we use the Bloomberg Barclays Aggregate Bond total return (unhedged) indices for each country and apply these returns to bonds. For equities, we use total return series for the S&P500 (U.S.), Nikkei 225 (Japan), FTSE All-Share Index (Great Britain), CAC 40 Index (France), Deutsche Boerse AG German Stock Index (Germnay), and S&P/TSX Composite Index (Canada). We use interest rates from the OECD for the deposits. Finally, we convert wealth from local currency to dollars using foreign exchange spot rates from the Federal Reserve.

C 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,

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

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

$$\frac{n^*_{t+1}}{n^*_t} = \frac{a^*(1-\theta^*)}{1-\theta^* a^*(1+i^*-\lambda_t)^{-1}}$$

and we find that,

$$V(n^*_{t+1}, \lambda^*_{t+1}) = n^*_{t+1}\sigma^* \sum_{k=t+1}^{\infty} \left(((1-\sigma^*)a^*(1-\theta^*))^{k-(t+1)} \prod_{j=t+1}^{k-1} \frac{1}{1-\theta^* a^*(1+i^*-\lambda_j)^{-1}} \right)$$

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,

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

The key property of this marginal value is that it is increasing in λ_j (for each j). In states of the world with higher λ's, a firm can lever up and make more profits, for any level of wealth. As a result, the marginal value of wealth is higher in high λ states.

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

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

where,

$$n^*_{t+1} = a^*_t n^*_t \left\{ (1-\gamma)\frac{1-\theta^*}{1-\theta^* a^*_t (1+i^*_t)^{-1}} + \gamma \left(\frac{(1-\theta^*) - \theta^*(s_{t+1} - E_t[s_{t+1}])}{1-\theta^* a^*_t (1+i^*_t - \lambda_t)^{-1}} \right) \right\}$$

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

The term $E_t[n^*_{t+1}]$ 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 $\frac{dn^*_{t+1}}{ds_{t+1}}$ 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 trade-off. 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.