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ABSTRACT

We develop a model of the global financial cycle with one key ingredient: the international demand for safe dollar assets. The model matches patterns of dollar borrowing and currency mismatch, the U.S. external balance sheet, 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. The global financial cycle is a dollar cycle.

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1 Introduction

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

Fact 1: Dollar funding advantage. Safe dollar bonds have low returns (see Du, Im and Schreger, 2018; Krishnamurthy and Lustig, 2019). In particular, investors receive lower returns when investing in dollar bonds than in foreign currency bonds. Moreover, foreign investors have poor market timing and tend to buy dollar U.S. Treasury bonds when the return gap is particularly adverse (see Jiang, Krishnamurthy and Lustig, 2022).

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, 2020).

Fact 3: Flight to dollar safety. During global downturns, the dollar appreciates and the dollar bond prices rise (see Jiang, Krishnamurthy and Lustig, 2018, 2021).

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, 2022; Gourinchas, Rey and Truempler, 2012; Jiang, Richmond and Zhang, 2022).

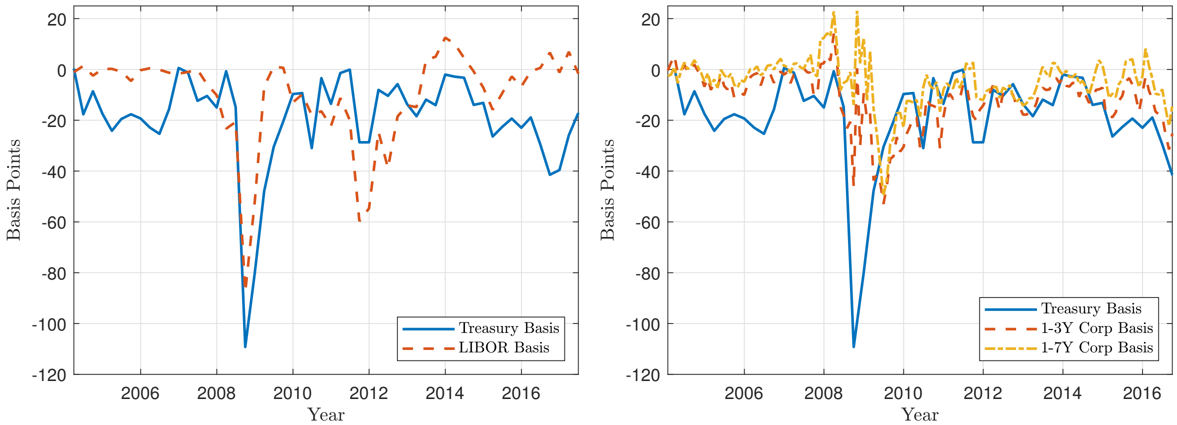
Fact 6: Dollar risk factor. The currency return on the dollar is a global risk factor (see Lustig, Roussanov and Verdelhan, 2014).

We present a model that jointly explains these facts based on one key asymmetry between U.S. and foreign: we assume that safe dollar bonds are especially valued by foreign investors and carry a premium, i.e., a convenience yield. In our model, a second asymmetry arises endogenously: while both U.S. and foreign entities can provide these safe dollar assets, the U.S. entities are in a better position to do so. Our model shows that the global financial cycle of Rey (2013) can be understood as a dollar cycle.

The existing literature provides an insurance-based explanation of the U.S. and the dollar's centrality (Gourinchas and Rey (2022); Maggiori (2017)), particularly tying together facts 1, 2, and 5. The U.S. is less risk averse than the foreign and provides insurance to the rest of the world by taking a long position on risky assets and a short position on safe debt. On average, the U.S. earns a positive return spread between its external assets and liabilities, which helps finance its persistent trade deficit. However, in times of global stress, the U.S. transfers wealth to foreign countries as the insurance pays off. As pointed out by Maggiori (2017), there is a challenge (namely, the "reserve currency paradox") with this theory. The insurance explanation predicts that the U.S. runs a trade surplus in the crisis, paying out on the insurance as wealth is transferred to foreign. Further, the dollar needs to depreciate in order to generate this trade surplus. Neither pattern is consistent with the data.

In this paper, we propose a different explanation of these facts. Our central ingredient is the assumption that foreign investors are willing to pay convenience yield to own safe U.S. dollar denominated bonds. Crucially, the convenience yield is fundamentally different from a risk premium: it generates seigniorage to issuers of convenience assets rather than generating compensation for their exposure to a risk factor. Figure 1 presents evidence for the existence of the dollar convenience yield. On the left panel, the black line plots the Treasury basis, which is the yield spread between the 1-year U.S. Treasury and 1-year foreign government bonds swapped into the dollar. The Treasury basis has been negative, suggesting that the U.S. Treasury has a lower yield than the foreign bonds even after the exchange rate risk has been accounted for by the currency swap.

This negative Treasury basis, we argue, reflects a non-pecuniary value that investors place on cash dollar safe assets for their safety and liquidity. The short-term U.S. Treasury bond being the par-excellence of world safe assets especially reflects this valuation. In comparison, even



(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 and foreign government bonds swapped into the dollar. LIBOR basis is the same construction but using LIBOR rates. Data is from 2004 to 2017. Foreign in both cases refers to the average across a sample of developed economies. Panel (b): The corporate basis is constructed from a sample of corporate bonds issuing in dollars and foreign currencies, as described by Liao (2020). 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.

though the foreign bond plus a currency swap has the same pecuniary payoff, it is an imperfect substitute for the cash Treasury bond and has a lower valuation.[1]

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 yields on both dollar Treasury bonds and dollar bank deposits, relative to their swapped foreign counterparts. Figure 1(b) plots the basis for safe corporate issuers from Liao (2020). The negative corporate basis, despite being smaller than the Treasury basis, indicates that firms with high credit ratings also earn a fraction of the dollar's convenience yield.[2]

[1]The observation of the negative dollar Treasury basis is made by Du, Im and Schreger (2018). Also see Jiang, Krishnamurthy and Lustig (2021) for further details and empirical support.

[2]In addition to the empirical support for the safe dollar phenomenon provided by the figures, there are theo-

Using this assumption of the dollar convenience yield, we develop a unified framework in which all of the facts arise naturally. 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 couple this production side with a model of exchange rate determination where foreign demand for dollar bonds drives a convenience yield on dollar bonds and the dollar exchange rate.

We start with the firm side. Given our assumption that investors impute a convenience yield on safe dollar claims, *Fact 1: Dollar funding advantage* is immediate. It also follows that firms will have an incentive to tilt their liabilities towards issuing dollar claims to take advantage of the dollar convenience yield. For example, 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, but unlike foreign borrowers, their claims will not incur currency mismatch since they are backed naturally by dollar revenues.

The asymmetric financing patterns in the world are thus just the mirror of the convenience yield observation, and 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. But this argument is incomplete as over the last few decades the globally lowest interest currency has been the Japanese Yen or the Swiss Franc. In this light, the large literature on balance sheet mismatch in emerging markets (Schneider and Tornell, 2004; Caballero and Krishnamurthy, 2003; Bocola and Lorenzoni, 2020) is about why emerging market firms denominate borrowings in a foreign currency rather than

retical models that aim to explain the safe-dollar phenomenon. See He, Krishnamurthy and Milbradt (2018) and Coppola, Krishnamurthy and Xu (2023) 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 Gopinath and Stein (2021) 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 of the convenience yield 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.

their home currency. In comparison, our convenience yield hypothesis is specifically about the U.S. dollar.

In our model, the dollar exchange rate and the dollar convenience yield is determined by foreign demand for dollar bonds and the equilibrium supply of dollar bonds. We posit a key asymmetry between U.S. and foreign investors: we assume that foreign investors derive a convenience yield on dollar bonds, with a convenience-demand function that is decreasing in the quantity of dollar bonds. Then, a reduction in the aggregate supply of safe dollar bonds leads to an increase in the equilibrium convenience yield. The foreign investor's indifference condition for investing in foreign versus dollar bonds leads to an uncovered interest rate parity condition where the convenience yield enters as an intertemporal wedge. A high convenience yields leads to an appreciation of the dollar, and an expected depreciation to satisfy the uncovered interest rate parity condition. We thus explain *Fact 3: Flight to dollar safety.* During crises, the convenience yield on dollar bonds rises and the dollar appreciates. Jiang, Krishnamurthy and Lustig (2021, 2018) provide evidence for the convenience yield-dollar relationship. 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. Thus, for example, we interpret the increase in the value of the dollar in a financial crisis as in part due to a reduction in the outstanding quantity of safe dollar bonds as many previously safe bonds turn risky. 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, consistent with the evidence in Baba and Packer (2009) and Kekre and Lenel (2023*b*).[3]

U.S. monetary policy shocks impact the dollar bond supply and exchange rates, leading to

[3] In a domestic context, Krishnamurthy and Vissing-Jorgensen (2012, 2015) and Greenwood, Hanson and Stein (2015) present evidence that the convenience yield on U.S. dollar safe and liquid assets is decreasing in the quantity of Treasury debt as well as the quantity of U.S. bank deposits. The analysis is based on a long sample spanning a century of data. Such evidence does not exist in the international context at present. The nearest such evidence for a quantity-price relationship is from Du, Tepper and Verdelhan (2018) who show that the reduction of dollar foreign-exchange lending by European banks at quarter-ends widens the CIP basis, which can measure the convenience yield on dollar bonds. This quarter-end behavior leads to a net reduction in the supply of dollar bonds, driven by regulatory constraints on European banks, and is thus consistent with the quantity-price relation of our analysis.

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 dollar appreciates 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. 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. There is considerable empirical support for the dollar currency mismatch channel of the model (see Aguiar (2005), Bleakley and Cowan (2008), and Kalemli-Ozcan, Kamil and Villegas-Sanchez (2016)). The channel has also been modeled in prior work (see Bruno and Shin, 2014; Akinci and Queralto, 2018).[4] Our contribution is to show that this channel naturally arises when starting from the assumption of safe-asset demand for dollar bonds, and rationalizes the dollar-driven global financial cycle.

In our model, the U.S. is a net supplier of safe dollar bonds to the rest of the world, thus explaining the balance sheet characterization of Gourinchas and Rey (2007) (*Fact 5: U.S. ex-*

[4]In Akinci and Queralto (2018) 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. Bruno and Shin (2014) present a model of spillovers through bank balance sheets. An appreciation of the dollar hurts bank balance sheets leading them to contract credit supply. In our model, this effect also arises, with the additional effect that the credit contraction further appreciates the dollar via the convenience yield channel, creating a Kiyotaki and Moore (1997)-type dynamic multiplier.

orbitant 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 and Rey (2022).

However, there is a nuance associated with the exorbitant duty in our model. Since the U.S. losses in the carry trade during a financial crisis are associated with an increase in the dollar 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 in the asymmetric position as 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. The capitalization effect also points to a mechanism for resolving the *reserve currency paradox* identified by Maggiori (2017). The capitalization effect gives rise to a relative wealth gain for the U.S. with respect to the foreign countries. In comparison, insurance-based models as in Maggiori (2017) generate a wealth transfer from the U.S. to the foreign countries. In the presence of home bias in consumption goods, the insurance mechanism means that U.S. households with relatively less wealth demand less home goods and the U.S. runs a trade surplus in a crisis, accompanied by a dollar depreciation. But this prediction is inconsistent with the data. Our seigniorage mechanism leads to a wealth transfer to the U.S. and does not necessitate a U.S. trade surplus. We note that our analysis only offers a mechanism that can resolve the reserve currency paradox. As the analysis is not a full multi-country general equilibrium one, we stop short of solving the paradox.

Our analysis also highlights asymmetry in the channels of contagion. Shocks to one set of foreign countries 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 region. As is standard in financial accelerator models, this shock will lead to a reduction in these foreign countries' output. However, to the extent that these countries reduce their 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 region 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, the impact on the U.S. will be limited to trade and expenditure switching channels. 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 the world demand for dollar grows, the incentive for both U.S. and foreign firms to supply dollar assets will grow. In particular, if the growth in the world demand for dollar safe assets exceeds the growth in U.S. 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.

We present a stylized model, aiming to clarify how the international demand for dollar safe assets can tie together a number of observations about the U.S. and the dollar in the international financial system. Thus, for tractability, we make simple assumptions about preferences, the production technology, and financial constraints, and we generate a convenience yield on dollar bonds via bonds-in-the-utility function. Bianchi, Bigio and Engel (2021) present a micro-founded model of the convenience yields on dollar bonds, and the role of monetary policy in driving this convenience yield. Their model is less suited to addressing the collection of facts we address. Our goals are also qualitative not quantitative. Kekre and Lenel (2023*a*) develop a quantitative New Keynesian model with a time-varying demand for dollar safe bonds that aims to match many of the facts we are after. Like us, they offer a mechanism around convenience yields on dollar bonds, and some aspects of our analysis are echoed in theirs. Two differences are: (1) they introduce heterogeneity in risk-bearing capacity and derive implications for risk premia, while our model features risk-neutral agents and generates a convenience yield rather than risk premia. (2) They resolve the reserve currency paradox by having a dollar demand shock generate a recession in the U.S., rather than the seigniorage wealth effect of our model. Their mechanism is similar to the safety-trap of Caballero and Farhi (2018), where a safe-asset demand shock arising when the zero lower bound binds leads to an endogenous rise in the discount rate on risky assets and a recession. Devereux, Engel and Wu (2023) also focus on the U.S. being a special producer of dollar assets, developing a two-country New Keynesian model where U.S. government bonds carry a convenience yield. Dahlquist et al. (2023) and Sauzet (2023) consider Lucas-tree environments, aiming to explain the appreciation of the dollar in crisis states. Sauzet (2023) extends the insurance model of Gourinchas and Rey (2022) and explains the dollar appreciation with a decline in U.S. output, while Dahlquist et al. (2023) develop a model of deep habits where wealth is transferred to the U.S. in crisis states, thus explaining the dollar appreciation. They build on our empirical work, offering further evidence that the relative wealth share of the U.S. rises during global downturns.

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 countries and presents our results on international spillovers. Section 5 concludes. We also include an Appendix. Part A contains the model's parameterization and proofs. Part B contains empirical evidence consistent with the model's mechanisms. Part C discusses additional theoretical issues on hedging.

2 Closed-Economy Model of the U.S.

Our model has three blocks: U.S., foreign, and international markets. We begin with the U.S. block and assume the economy is closed to simplify the exposition. The results in this section highlight the monetary transmission mechanism and the supply of U.S. dollar assets, which we refer to as dollar liquidity. This supply plays an important rule in the international equilibrium of the next section.

Time is discrete and indexed by $t = 0, 1, 2, \ldots$ U.S. households are modeled as living in overlapping generations (OLG). A unit mass of households are born and supply labor of ℓ_t at date t, save their wages until date $t+1$ at which time they consume c_{t+1}.

We define the households' utility over consumption and labor as

$$\frac{1}{1+\rho}\mathbb{E}_t[c_{t+1}] - \ell_t. \tag{1}$$

For now, consumption is in terms of the single U.S. goods. In Section 3, we embed the U.S. block in an international model, and replace Eq. (1) with Eq. (34) that describes utility over both home and foreign goods.

The households' budget constraint is,

$$p_{t+1}c_{t+1} = w_t\ell_t(1+i_t). \tag{2}$$

The household works at date t to receive nominal wages of w_t. The household can save their wages in a local-currency bond at nominal interest rate i_t in order to afford consumption of c_{t+1} at date $t+1$ at nominal goods price p_{t+1}. We define the inflation rate as,

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

We will show in the next section that in equilibrium the nominal wage and the nominal price of the goods are equal: $w_t = p_t$. Thus, the household solves,

$$\max_{\ell_t, c_{t+1}} \frac{1}{1+\rho}\mathbb{E}_t[c_{t+1}] - \ell_t \tag{4}$$

subject to,

$$c_{t+1} = \ell_t \frac{1+i_t}{1+\pi_t}, \tag{5}$$

and $\ell_t, c_{t+1} \geq 0$. Given the linear household preferences with discount rate ρ, the household chooses $\ell_t > 0$ as long as $i_t - \pi_t \geq \rho$. We restrict attention to model parameterizations where this condition is met. Note that if $i_t - \pi_t$ is strictly greater than ρ, the household will choose to work infinite hours. We assume that hours are pinned down by labor demand from firms, as we outline next.[5]

2.1 Financial friction in borrowing

Households work for a unit mass of identical firms (F). The production process takes one period. Given ℓ_t labor and k_t capital at date t, the production technology gives output at date $t+1$ of

$$y_{t+1} = f(\ell_t, k_t) = a_t(\ell_t + k_t), \tag{6}$$

where a_t is productivity which is known at time t.

We assume capital and goods can be freely converted into each other at 1-to-1 ratio, so that the price of capital and the price of goods are equal in an interior equilibrium. In addition, since capital and labor are perfect substitutes in the production function, they also have the same price in an interior equilibrium. Thus, as noted earlier $p_t = w_t$.

Each firm is run by a manager subject to a standard agency problem that limits borrowing. The manager has a net worth of n_t in real terms at date t. The managers die with probability σ at the end of each period, and at death, consume their net worth. A manager maximizes the

[5] In this case, there is involuntary unemployment, and our assumption is that workers are equally rationed.

expected utility:

$$\sum_{t=1}^{\infty}(1-\sigma)^{t-1}\sigma \cdot n_t. \tag{7}$$

Conditional on survival at time t, the manager can borrow to hire labor and purchase capital to produce goods. They issue nominal one-period bonds at the interest rate i_t. Let b_t denote the nominal amount of borrowing. Then, the firm's budget constraint is

$$p_t n_t + b_t \geq w_t \ell_t + p_t k_t. \tag{8}$$

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

$$b_t \leq \frac{\theta \cdot p_{t+1} \cdot f(\ell_t, k_t)}{1+i_t}. \tag{9}$$

We focus on a parameterization under which $a_t \geq 1+i_t-\pi_t > \theta a_t$. In this case, the marginal return from production 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. Likewise, managers use all of their net worth to invest in the capital of their firm rather than purchasing bonds (lending to other firms). Since the managers/firms are identical, this will mean that in general equilibrium we will have that $k_t = n_t$. For now, we will allow k_t to differ from n_t. We impose market clearing in the next section.

We substitute from the debt constraint (9) into the firm's budget constraint to find:

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

$$\ell_t + k_t \approx n_t \frac{1}{1-\theta a_t(1+i_t-\pi_t)^{-1}}. \tag{10}$$

The proof is given in Appendix A.2. 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 $t+1$, which is equal to the manager's date $t+1$ net worth is:

$$n_{t+1} = f(\ell_t, k_t) - \theta f(\ell_t, k_t) = n_t \cdot \frac{a_t(1-\theta)}{1 - \theta a_t(1 + i_t - \pi_t)^{-1}}. \tag{11}$$

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

$$N_{t+1} = (1-\sigma) \cdot N_t \cdot \frac{a_t(1-\theta)}{1 - \theta a_t(1 + i_t - \pi_t)^{-1}} + \sigma \cdot \widehat{N}. \tag{12}$$

2.2 Monetary policy sets the real rate r_t

We introduce sticky prices and wages so that monetary policy affects the real interest rate $r_t = i_t - \pi_t$. First, we suppose that the central bank sets the nominal interest rate i_t. Second, we assume that prices and wages are sticky, and are set prior to the central bank's choice of i_t. To keep the analysis simple, we further assume in our simulations that prices are fixed for all t, and take the expected inflation rate, π_t, to be zero. Thus, the real interest rate is equal to the nominal interest rate:

$$r_t = i_t \tag{13}$$

We will consider the impulse response of the economy to a shock that raises the interest rate i_t. A tightening of monetary policy reduces firm's debt capacity and labor demand as in Proposition 1. At fixed wages, the equilibrium quantity of labor must fall and there is involuntary unemployment. In case of unemployment, we assume all workers are equally rationed. Finally, it is straightforward to extend the model so that prices are sticky but can be reset periodically.

2.3 Equilibrium and market clearing

Definition 1. *An equilibrium of the closed-economy U.S. model is a collection of household labor and savings decisions solving (4), as well as firm borrowing, hiring and capital investment decisions satisfying Proposition 1, given a path of interest rates i_t and productivity a_t. At these decisions, the market for capital, labor, goods, and bonds clear.*

We now describe the market clearing conditions for capital, labor, goods, and bonds. We use the uppercase variables to denote the aggregate quantities of the corresponding individual choices expressed in lower cases. In doing so, we show that the economy can be described by one state variable, N_t, the aggregate net worth of the firm sector.

First, note that capital market clearing requires that

$$K_t = N_t. \tag{14}$$

All of a manager's wealth is invested in capital of his own firm. With some abuse of terminology, when describing the equilibrium, we use net worth and capital interchangeably.

Aggregate output at date $t+1$ is $Y_{t+1} = a_t(L_t + K_t)$. In equilibrium, firms saturate their borrowing constraint, borrowing up to the fraction θ of output Y_{t+1}, and use the borrowed resources to hire workers. Thus, the total labor is:

$$L_t = \frac{\theta Y_{t+1}}{1 + r_t}. \tag{15}$$

Then, given K_t, we have that,

$$Y_{t+1} = a_t K_t \frac{1}{1 - \theta a_t (1 + r_t)^{-1}}. \tag{16}$$

This equation also defines L_t as a linear function of K_t.

The bond market clearing condition is

$$p_t L_t = B_t = p_t \frac{\theta Y_{t+1}}{1 + r_t}. \tag{17}$$

Households save all of their labor income, and their savings is equal to how much firms borrow in each period. Given that firms saturate their borrowing constraint we have that $B_t = p_t \theta Y_{t+1}/(1+r_t)$. We can substitute in for L_t from above and verify that the bond market clears.

In the goods market, total output goes toward the consumption of the old generation t, the consumption of exiting managers (fraction σ), and net worth of continuing managers (fraction $1-\sigma$):

$$Y_{t+1} = C_{t+1} + \sigma N_{t+1}^{-} + (1-\sigma) N_{t+1}^{-}, \tag{18}$$

where N_{t+1}^{-} refers to net worth that does not include the new entrants. It is straightforward to substitute in $C_{t+1} = (1+r_t)L_t$ to solve for N_{t+1}^{-} and verify that the goods market clearing condition is satisfied.

We define the private safe debt supply of the U.S. as the aggregate nominal borrowing of the U.S. firms:

$$B_t = \frac{\theta \cdot p_{t+1} Y_{t+1}}{(1+r_t)}. \tag{19}$$

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 equilibrium.

2.4 Impulse response to a monetary policy shock

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

$$N_{SS} = (1-\sigma) \cdot N_{SS} \cdot \frac{a_{SS}(1-\theta)}{1-\theta a_{SS}(1+r_{SS})^{-1}} + \sigma \cdot \widehat{N}. \tag{20}$$

We require that $(1-\sigma)a_{SS}(1-\theta)/(1-\theta a_{SS}) < 1$ and $\sigma\widehat{N} < N_{SS}$ to ensure stable dynamics around the steady state.

We evaluate the impact of a one-time monetary policy shock at date $t = 1$, ε_t, which raises nominal and real interest rate,

$$r_t = r_{SS} + \varepsilon_t. \tag{21}$$

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 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.

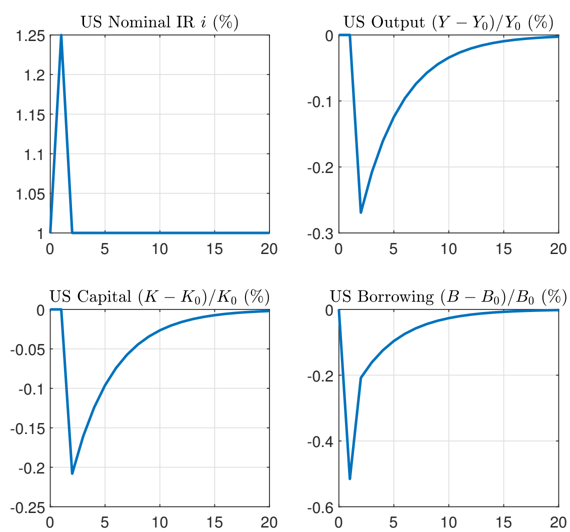


Figure 2: Impulse response to a U.S. monetary policy shock of 0.25%

We consider a 0.25% shock to the U.S. quarterly nominal interest rate i_t in period $t = 1$. Output, labor, capital, and dollar borrowing are expressed as percentage deviations from their steady-state values. See Table A.1 for parameter values.

A surprise tightening of monetary policy at $t = 1$ reduces the debt capacity of firms on impact. The private dollar debt supply, B_t, which is equal to debt capacity, falls on impact as illustrated in the last panel. As a result, firms hire less labor (top right panel) in $t = 1$, and make less profit both because the margins decline and because the debt capacity falls leading them to downsize, with lower labor. The lower profit leads to a fall in capital K in the following period $t = 2$ (bottom left panel). Since output is determined by labor and capital in the previous period, it falls in period $t = 2$ (top middle panel).

As in financial accelerator models (see Bernanke, Gertler and Gilchrist, 1996), the initial interest rate shock creates persistent effects even after the shock disappears, through a propagation mechanism via the damage to capital K_t. Capital returns gradually to its steady-state level as managers' net worth accumulates and new managers enter. Output, labor, and debt supply are below the steady-state level through this entire path.

3 International Equilibrium and Dollar Liquidity

In this section, we embed the U.S. block which describes the supply of dollar liquidity into the international equilibrium, where there is a demand for dollar liquidity. First, we introduce a set of international investors who have a special demand for dollar bonds (dollar liquidity). Second, the dollar demand leads to a positive carry-trade profit opportunity for U.S. entities. We model a U.S. banking sector that engages in this carry trade, selling dollar bonds to the international investors. In equilibrium, the trade in dollar bonds determines the exchange rate. Third, banks turn over the carry profits to its equity-owners, who include U.S. households. The equity shares of this bank are traded, and we solve for the price of bank equity. Last, we modify U.S. household preferences to derive utility from consumption of both home (U.S.) goods and foreign goods and explain how shocks to the dollar equilibrium impact the trade balance.

A shortcoming of our analysis is that we do not close the goods market in a general equilibrium. That is, at the asset-market determined exchange rate, we assume that the rest of the world is willing to trade home and foreign goods to accommodate U.S. household demands.

3.1 International safe asset investors and dollar convenience yield

We start by describing the international investors. There is a unit mass of risk-neutral international investors. They can invest in foreign and dollar bonds, but receive extra convenience benefits when investing in the dollar bonds.

Let i_t^* denote the nominal interest rate on the foreign bond. Without loss of generality, we set the price of the foreign goods to be one at all dates, so that the real interest rate $r_t^* = i_t^*$, and the foreign bonds effectively pay in foreign goods. Recall that r_t denotes the real interest rate of the dollar bonds, which will be issued by the U.S. firms in our model.

Denote the real exchange rate in foreign-per-dollar as $\mathcal{E}_t$ (the log rate is denoted e_t). Our sign convention means that a stronger dollar is associated with a higher value of e_t. Then, the international investors' objective is to choose consumption c_s^{intl} of the foreign good and dollar bond holdings q_s^{demand} to maximize:

$$\mathbb{E}_t \left[\sum_{s=t}^{\infty} \left(\frac{1}{1+\rho^*} \right)^{s-t} \left(c_s^{intl} + \frac{\mathcal{E}_s v_s(q_s^{demand})}{1+\rho^*} \right) \right] \tag{22}$$

subject to the dynamic budget constraint,

$$w_{t+1}^{intl} + c_{t+1}^{intl} = (w_t^{intl} - \mathcal{E}_t q_t^{demand})(1+r_t^*) + \mathcal{E}_t q_t^{demand}(1+r_t)\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}, \tag{23}$$

and given some initial wealth w_0^{intl} which we take to be large. The quantity of dollar bonds held at time t is q_s^{demand}, with the remaining wealth invested in the foreign bond. The function $v_t(q)$ is the convenience value that the investor receives from the dollar bond investment, satisfying $v_t(q) \geq 0$ and $v_t'(q) < 0$.[6]

Proposition 2. *The international investors' problem implies the following Euler equations:*

$$1 = \mathbb{E}_t \left[\frac{1}{1+\rho^*}(1+r_t^*) \right], \tag{24}$$

$$1 - \frac{v_t'(q_t^{demand})}{1+\rho^*} = \mathbb{E}_t \left[\frac{1}{1+\rho^*}(1+r_t)\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right], \tag{25}$$

The first equation implies that $r_t^* = \rho^*$. Taken together, and omitting the higher-order terms,

[6] Note that q_s^{demand} is measured in units of dollars. In the objective function, we multiply $v_t(q_s^{demand})$ by $\mathcal{E}_s$ to keep things in the same units with the investors' consumption.

these equations give the uncovered interest parity equation (U.I.P.) with a convenience yield:

$$\mathbb{E}_t[\Delta e_{t+1}] + r_t - r_t^* = -v_t'(q_t^{demand}) = -\lambda_t, \tag{26}$$

where the convenience yield is defined as $\lambda_t = v_t'(q_t^{demand})$.

The proof is given in Appendix A.2. The U.I.P. with a convenience yield equation, (26), states that the return to owning dollar bonds plus the convenience yield must equal the return to owning foreign bonds, accounting for the expected appreciation of the exchange rate. A similar condition is derived in Valchev (2020) and Jiang, Krishnamurthy and Lustig (2021) who additionally present evidence linking the convenience yield and the U.I.P. condition.

3.2 U.S. banks, dollar carry trade, and dollar bond supply

Given a positive foreign convenience yield λ_t, a U.S. agent who does not have a special demand for dollar bonds can earn a "carry trade" profit by selling U.S. dollar bonds and investing in foreign bonds. We next describe the equilibrium in which the U.S. engages in this carry trade while the foreign investors take the opposite position.

We introduce U.S. banks that engage in this carry trade, who earn profits and pay out these profits as dividends to their equity-holders. We assume that the U.S. households cannot directly do the carry trade, but hold the equity of the banks and thus indirectly reap these profits. We introduce this layer of intermediation for the following reason. Since in our modeling the banks are long-lived, the value of the equity of a bank will reflect both current and future expected carry profits. An alternative modeling would have the U.S. households directly enter the carry trade and earn profits, but in this alternative model, as households are OLG, they would not benefit from higher future carry profits. The capitalized future carry profits play a key role in our model and banks are a modeling device to keep track of the stream of carry profits.

There is a measure $\chi \leq 1$ of banks, owned by its equity-holders, that take deposits, make loans to firms, and trades bonds with foreign investors. Domestically, each bank can contact exactly one (young) working U.S. household and offer to take a deposit of d_t from this household.

It takes these funds and makes b_t^L dollar loans to firms. Internationally, the bank can also sell $b_t^\$$ dollar bonds to international investors for foreign currency and use the proceeds to invest in b_t^F foreign bonds. The budget constraint for the bank is

$$b_t^L + \frac{b_t^F}{\mathcal{E}_t} = b_t^\$ + d_t. \tag{27}$$

We assume that the bank can sell dollar bonds to international investors to fund the foreign bond investment, but only to the extent that it owns dollar loans. Alternatively, and realistically, we can think of the bank as using the dollar firm loans as collateral against a repo loan from the international investors. The key assumption in our model is that the supply of dollar bonds is limited and tied to the productive capacity of the U.S. firms who issue bonds against their future revenues. The bank's funding constraint is then,

$$\frac{b_t^F}{\mathcal{E}_t} = b_t^\$ \leq b_t^L. \tag{28}$$

The bank is assumed to have monopoly power over the depositor and can dictate the deposit rate i_t^D. More precisely, when a (young) working U.S. household is paired with a bank, it can invest its nominal wage income 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 banks will offer a deposit rate at $i_t^D = i_t$. The real profit of a bank at $t+1$ given its portfolio is,

$$b_t^L(1+r_t) + \frac{b_t^F}{\mathcal{E}_t}(1 + r_t^* - \Delta e_{t+1}) - b_t^\$(1+r_t) - d_t(1+r_t). \tag{29}$$

The bank maximizes this expected profit. Clearly, given the positive carry profit, $\frac{b_t^F}{\mathcal{E}_t} = b_t^\$ = b_t^L$. The bank sells all of its dollar bonds to the international investors who place a convenience value on these bonds. The budget constraint further implies that $b_t^L = d_t$ giving $t+1$ bank profit of:

$$b_t^L(r_t^* - \Delta e_{t+1} - r_t). \tag{30}$$

We note that expected profit is $b_t^L \lambda_t$.

Proposition 3. *Each bank chooses to sell all of its dollar loans to international investors and invest 100% of its portfolio in foreign bonds. In aggregate, banks make loans to a measure χ of the firms and sell dollar bonds to the international investors. The supply of real dollar liquidity produced by the U.S. is,*

$$Q_t = \chi B_t / p_t. \tag{31}$$

Let Π_{t+1} denote the aggregate bank profits from this carry trade, which we will measure in units of the foreign currency. Also let V_t denote the ex-dividend valuation of the equity of the banking sector, which is a claim to the stream of profits. We solve for V_t in equilibrium. Ex-ante, the expectation of Π_{t+1} is determined by the convenience yield λ_t:

$$\mathbb{E}_t[\Pi_{t+1}] = Q_t \lambda_t \times \mathcal{E}_t, \tag{32}$$

where $Q_t \lambda_t$ is the expected profit in dollars, and we measure profit in foreign currency terms, thus multiplying by $\mathcal{E}_t$. Ex-post, bank profits are subject to the fluctuation in the exchange rate:

$$\Pi_{t+1} = Q_t \mathcal{E}_t \left(r_t^* - r_t - \Delta e_{t+1} \right) = Q_t \mathcal{E}_t (\lambda_t - (e_{t+1} - \mathbb{E}_t[e_{t+1}])); \tag{33}$$

that is, as the banks take a carry trade position that longs the foreign currency and shorts the dollar, a stronger dollar lowers the banks' profits.

Finally, we note again that banks are the only U.S. entity that earns the carry profits in our modeling. The banks' monopoly power on the deposit side means that banks pay its depositors their outside option rate of i_t rather than bidding up deposit rates and passing on some of the carry profits to its depositors. The bank pays out these profits instead as dividends to the equity-holders of the bank, who include U.S. households.[7]

[7] Another alternative modeling would allow the firms to also run a carry profit, for example by issuing more dollar bonds than is needed for their real investments and investing the proceeds in foreign bonds. In practice, the carry profits our model describes likely accrue to households, firms, and banks (as well as the U.S. government). One way of understanding our modeling choices is that we fold all of these profits back to the U.S. households.

3.3 U.S. households revisited

We modify the U.S. households' preferences to derive utility from consumption of the home (U.S.) goods, $c_{H,t+1}$, the foreign goods, $c_{F,t+1}$, as well as a bequest of bank equity shares worth x_{t+1}. The generation-t U.S. household maximizes utility

$$\max_{c_{H,t+1},c_{F,t+1},x_{t+1},\ell_t} \frac{1}{1+\rho}\mathbb{E}_t\left[c_{H,t+1}^{\alpha_H}\ c_{F,t+1}^{\alpha_F}\ x_{t+1}^{\alpha_X}\right] - \psi\ell_t, \tag{34}$$

subject to the budget constraint,

$$\mathcal{E}_{t+1}c_{H,t+1} + c_{F,t+1} + x_{t+1} = h_{t+1} = \mathcal{E}_{t+1}(1+r_t)\ell_t + x_t\left(\frac{V_{t+1}+\Pi_{t+1}}{V_t}\right). \tag{35}$$

The budget is measured in units of the foreign good, which keeps our expressions simpler. At time t, a generation-t U.S. household works and earns labor income in dollars of $p_t\ell_t$. We multiply by $\mathcal{E}_{t+1}/p_t$ to measure this income in foreign goods. At time $t+1$, the labor income earns real interest rate of $1+r_t$, and the household receives a bequest of equity shares from the previous generation, which is worth x_t times the cum-dividend return of $(V_{t+1}+\Pi_{t+1})/V_t$. The household allocates its wealth to consumption of both goods and the bequest for the next generation. In choosing consumption and the bequest, the household can trade equity shares with the international investors.

We can optimize at $t+1$, where the Cobb-Douglas form over within-period expenditures implies that the expenditure shares on goods and the bequest are a constant fraction of wealth. We normalize by setting $\alpha_H+\alpha_F+\alpha_X=1$ and $\psi=\alpha_H^{\alpha_H}\alpha_F^{\alpha_F}\alpha_X^{\alpha_X}$. The first-order condition for labor, which reflects an inter-temporal choice, is altered slightly from the U.S. model of (4). The household supplies labor as long as $(1+r_t)\mathbb{E}_t\mathcal{E}_{t+1}^{1-\alpha_H}\geq 1+\rho$, and we assume this condition always holds. See the Appendix for details.

Proposition 4. *The U.S. generation-*$(t+1)$ *household's consumption and bequest choices in* *the units of the foreign goods are*

$$\mathcal{E}_{t+1} c_{H,t+1} = \alpha_H h_{t+1}, \tag{36}$$

$$c_{F,t+1} = \alpha_F h_{t+1}, \tag{37}$$

$$x_{t+1} = \alpha_X h_{t+1}. \tag{38}$$

The proof is given in Appendix A.2. Consumption and bequest are linear and increasing in wealth. For given wealth, as the dollar exchange rate appreciates, spending on the foreign good rises relative to spending on the home good. This is the standard expenditure switching effect.

3.4 Equilibrium

Definition 2. *An international equilibrium is a collection of household consumption, labor and savings decisions as in Proposition 4, international investors' decision as in Proposition 2, bank supply as in Proposition 3, as well as firm borrowing, hiring and capital investment decisions satisfying Proposition 1, given a path of interest rates* i_t*, exchange rates* e_t*, bank equity value,* V_t*, productivity* a_t*, and dollar-demand shocks,* ϵ_t^λ*. At these decisions, the market for U.S. capital, U.S. labor, dollar liquidity, and bank equity clear.*

The equilibrium is still described by the single-state variable N_t. The steady-state level of N_{SS} is given as before from Eq. (20). In the international economy model, relative to the U.S. economy model, we have two more active agents: the international investors and the U.S. banks, and two asset prices, the exchange rate and value of bank equity.

Consider first the exchange rate equilibrium. In aggregate, the international investors purchase Q_t^{demand} units of dollar bonds. In our simulations below, we model the convenience yield $\lambda_t = v_t'(Q_t^{demand})$ and parameterize it as a linear function of the quantity of dollar liquidity plus a shock capturing demand shifts:

$$\lambda_t = \bar{\lambda} - \beta^\lambda (Q_t^{demand} - Q_{SS}) + \varepsilon_t^\lambda. \tag{39}$$

We iterate on the U.I.P. equation, (26), forward and find

$$e_t = \mathbb{E}_t \sum_{k=0}^{\infty} \lambda_{t+k} + \mathbb{E}_t \sum_{k=0}^{\infty} (r_{t+k} - r^*_{t+k}) + \bar{e}, \tag{40}$$

where the term $\bar{e} = \lim_{k\to\infty} \mathbb{E}_t[e_{t+k}]$ is a constant because the real exchange rate is stationary. See Appendix A.2 for the proof of stationarity.

From Proposition 3, we have that the supply of dollar liquidity is $Q_t = \chi B_t/p_t$, and market clearing gives that,

$$Q_t^{demand} = \chi \frac{B_t}{p_t}. \tag{41}$$

Together, these equations pin down the exchange rate as a function of B_t, which we have seen is linear in the state-variable N_t.

Bank equity is traded by the (old) domestic households and international investors, and does not carry a convenience yield. Old households buy or sell equity to international investors to finance their consumption plans. Thus, we use the discount factor of the international investors to value bank equity. Given risk-neutral international investors who discount using rate r^*_t, the banks' (ex-dividend) equity value is simply the present value of future profits from the carry trade,

$$V_t = \mathbb{E}_t \sum_{j=1}^{\infty} \frac{\Pi_{t+j}}{(1+r^*_t)^j}. \tag{42}$$

By equation (33), these profits are functions of B_t and e_t, and thus V_t can also be written in terms of the state variable N_t.

To summarize, relative to the U.S. economy model, we additionally clear the dollar liquidity market and the equity market. We also clear the market for U.S. firm capital and labor, as in the basic model. Moreover, we included a market clearing condition for home goods in the U.S. economy model, whereas we do not clear the home and foreign goods market in the international economy model. We assume that there are unmodeled world households who are willing to trade home and foreign goods with the U.S. households at the equilibrium exchange rate determined in the asset market.

3.5 NFA and steady state exorbitant privilege

To determine the U.S. net foreign assets (NFA), we need a residence assumption on the banking sector. We assume that the banks of the model correspond to large U.S. domiciled banks, in which case the U.S. NFA in the units of foreign goods is

$$NFA_{t+1} = X_{t+1} - V_{t+1}. \tag{43}$$

Conversely, the foreign NFA is $V_{t+1} - X_{t+1}$, which represents the total value of banks minus the value of U.S. holdings.[8] In our model, the NFA is negative to the extent that foreign owns some of the U.S. banking sector, thereby receiving a portion of the profits from the U.S. banks' carry trade. In our numerical example, foreign's NFA with respect to the U.S. is about 4% of the total value of banks.

The law of motion for the U.S. NFA is

$$NFA_{t+1} - NFA_t = TB_{t+1} + IB_{t+1} + CG_{t+1}, \tag{44}$$

where TB is the trade balance, IB is the income balance and CG is the capital gains (see Gourinchas and Rey, 2007; Jiang, Richmond and Zhang, 2022).

The trade balance (exports minus imports) can be expressed as

$$TB_{t+1} = \mathcal{E}_{t+1}(1 + r_t)L_t - (\alpha_F + \alpha_H)\, H_{t+1}. \tag{45}$$

The income balance is the dividend payments from foreign assets to U.S. investors minus the dividend payments from U.S. assets to foreign investors. In our model, the dividend payments from foreign assets to U.S. investors are the carry trade profit Π_{t+1}, and the dividend payments from U.S. assets to foreign investors are the bank dividends paid to the foreigners $\Pi_{t+1} \cdot (V_t -$

[8]If we assume that the banks reside outside the U.S., the U.S. NFA is equal to the U.S. holding of the bank equity shares: $NFA_{t+1} = X_{t+1}$. Note that there is no ambiguity with respect to the trade balance nor is their any ambiguity over U.S. wealth which is X_{t+1} under either residence assumption.

$X_t)/V_t$. The capital gains are the changes in the value of U.S. holdings of foreign assets minus the changes in the value of foreign holdings of U.S. assets. In our model, they are driven by the change in the value of bank equity held by the foreigners $(V_{t+1} - V_t) \cdot (V_t - X_t)/V_t$. Thus, the sum of income balance and capital gains can be expressed as

$$IB_{t+1} + CG_{t+1} = \frac{X_t}{V_t}\Pi_{t+1} - \frac{V_t - X_t}{V_t}(V_{t+1} - V_t). \tag{46}$$

Further details on these computations are in Appendix A.2. We have noted that $NFA_t = X_t - V_t < 0$, which further implies that an increase in the value of banks will reduce the NFA of the U.S. We return to this point when discussing the 2008 financial crisis through the lens of the model.

In comparison, the wealth of the U.S. households is X_{t+1},

$$X_{t+1} = \alpha_X H_{t+1} = \alpha_X \mathcal{E}_{t+1}(1 + r_t)L_t + \alpha_X X_t \left(\frac{V_{t+1} + \Pi_{t+1}}{V_t} \right), \tag{47}$$

is increasing in the valuation of the bank equity V_{t+1}. Therefore, in a recession, the U.S. households could suffer a loss on their income balance IB_{t+1} due to a negative carry trade profit Π_{t+1}, which lowers the U.S. NFA, while experiencing an appreciation of their wealth X_{t+1} due to the valuation effect. This difference in the response of wealth and NFA is also evident in equation (43), i.e., $X_{t+1} = NFA_{t+1} + V_{t+1}$, as the market value of domestic assets V_{t+1} explains the difference between the responses of NFA and wealth.

Finally, we describe the steady-state values of the carry profits, bank equity and trade balance. 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). The bequest X_{t+1} is strictly positive, indicating that the households hold a positive share of bank equity in steady state. The steady-state value of bank equity is $V_{SS} = \Pi_{SS}/r^*$ and the household owns X_{SS}/V_{SS} fraction of the banking sector.[9] In the steady state, the NFA is constant, implying that

$$-TB_{SS} = IB_{SS} + CG_{SS}. \tag{49}$$

Since the net profits come from the banks' carry trade profits:

$$IB_{SS} + CG_{SS} = \frac{X_{SS}}{V_{SS}} \Pi_{SS}, \tag{50}$$

we have that:

Proposition 5. *In the non-stochastic steady state, the U.S. finances its trade deficit entirely using the dividend payments from the banks, which in turn are profits from the banks' carry trade. This steady-state deficit is the "exorbitant privilege" of the U.S. in our model.*

$$-TB_{SS} = \frac{X_{SS}}{V_{SS}} \Pi_{SS}. \tag{51}$$

3.6 Impulse response function

Figure 3 plots the impulse response to a 0.25% shock to the nominal interest rate in period $t = 1$. U.S. output, labor and capital behaves exactly the same as in the U.S.-only model, and we omit these plots in this figure. The new results are reported. The rise in the U.S. interest rate reduces safe asset supply, i.e., the U.S. dollar liquidity Q_t, and hence increases the convenience yield, λ_t. The dollar appreciates in period $t = 1$ both because of the rise in the nominal interest rate i_t and the increase in the convenience yield λ_t. Krishnamurthy and Lustig (2019) presents evidence for this convenience yield channel of monetary policy from examining event-day responses around both conventional and unconventional monetary policy announcements.

The U.S. banks run a carry trade that is long the foreign currency and short the dollar. As

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

$$X_{t+1} = \alpha_X \mathcal{E}_{SS}(1 + i_{SS} - \pi_{SS})L_{SS} + \alpha_X(1 + r^*)X_t. \tag{48}$$

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

the dollar appreciates on impact, the U.S. banks suffer a loss at time $t = 1$. Subsequently, they earn higher profits as future convenience yields rise. This pattern of losses and gains is reflected in the panel of the banks' carry profits Π_t. The value of bank equity, measured in either foreign currency or dollar, rises on impact because the present value of bank profits is increasing in the expected convenience yields. In this parameterization, the rise in bank (ex-dividend) equity value is still dominated by the reduction in the carry profits in the current period $t = 1$ (i.e. in bottom-left panel, profits falls by about 1.5% while in the next panel, equity rises by 0.3%). As a result, the U.S. households reduce consumption and the trade deficit shrinks.

3.7 Discussion: international financial equilibrium

We note that our model of the international financial equilibrium captures important features of the world economy post-Bretton Woods.

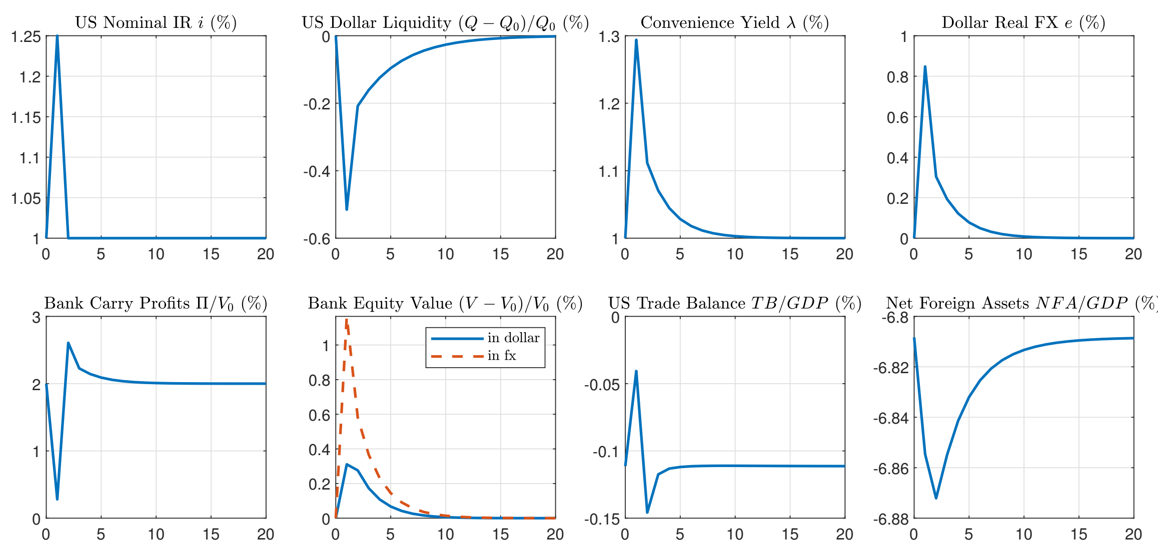


Figure 3: Impulse response to a U.S. monetary policy shock of 0.25%

We consider a 0.25% shock to the U.S. nominal interest rate i_t 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. The dollar liquidity is expressed as percentage deviations from its steady-state values, and the exchange rate is in log. Bank carry profits and bank equity value are normalized by the steady-state bank equity value, and the U.S. trade balance and NFA are normalized by the U.S. GDP. See Appendix Table A.1 for parameter values.

- 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 (2021).

- 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.

  The steady-state NFA position of the U.S. is negative, which is in line with the data. However, our model does not speak to the low-frequency trends in the NFA which are also evident in the data (Jiang, Richmond and Zhang, 2022; Atkeson, Heathcote and Perri, 2022).

- 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-à-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.

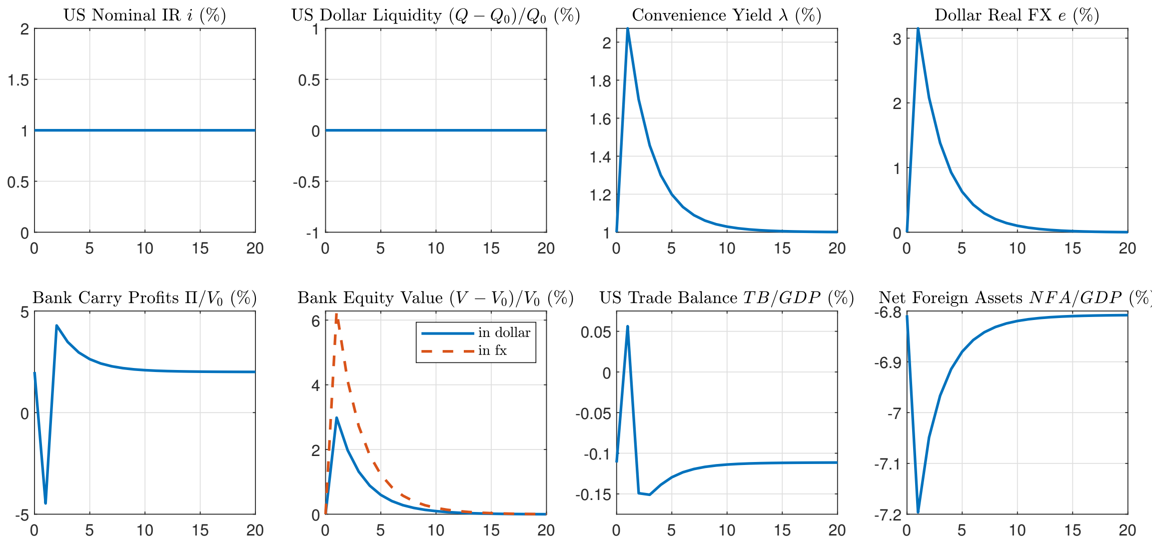
Lastly, it is useful to contrast our convenience yield mechanism for the exorbitant privilege with the risk-sharing mechanism of Gourinchas and Rey (2022) and Maggiori (2017). In their models, the U.S. provides safe assets to the rest of the world as part of a risk-sharing arrangement. Gourinchas and Rey (2022) rationalizes the U.S. balance sheet as due to the U.S. being less risk-averse than the 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 trade 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.

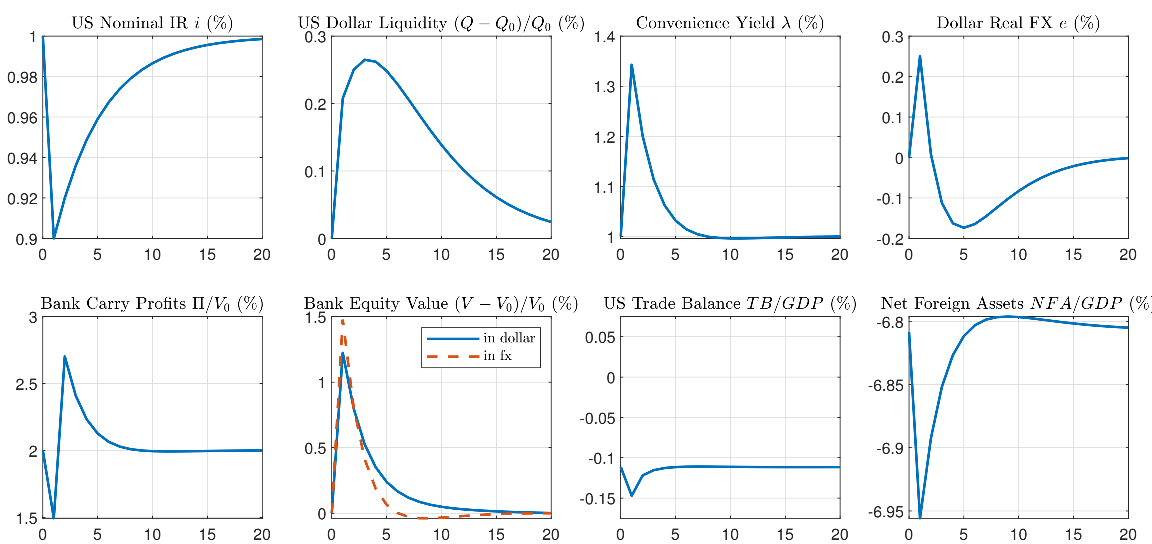
In our model, the world pays a convenience yield to own dollar assets. Because it is a convenience yield, as opposed to a risk premium, the U.S. earns a seigniorage from providing safe dollar claims without incurring the crisis liability. In fact, the convenience yield may rise in a crisis, leading to an even higher present value of 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(a) 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 consider a demand shock by increasing the convenience yield in period $t = 1$ unexpectedly to $\varepsilon_t^\lambda = 0.5\%$ (50 basis points), which gradually dissipates with an autocorrelation of 0.8. The shock increases the convenience yield and the value of the dollar, while the supply of the dollar liquidity is kept constant. The NFA of the U.S. falls, consistent the Global Financial Crisis evidence of Gourinchas, Rey and Truempler (2012).

We note that, in response to this shock, bank equity value rises in foreign currency, reflecting higher future carry trade profits. Bank equity value also rises in dollar units, though the dollar's



(a) Impulse responses to a safe asset demand shock



(b) Impulse responses to a safe asset demand shock accompanied by U.S. monetary easing

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

In Panel (a) we plot the impulse response to a safe asset demand shock of 50 basis points. In Panel (b) we plot the impulse response to a safe asset demand shock of 50 basis points accompanied by a U.S. nominal interest rate shock of -10 basis points. The shocks in both panels dissipate with an autocorrelation of 0.8. The dollar liquidity is expressed as percentage deviations from its steady-state values, and the exchange rate is in log. Bank carry profits and bank equity value are normalized by the steady-state bank equity value, and the U.S. trade balance and NFA are normalized by the U.S. GDP. See Table A.1 for parameter values.

appreciation partially offsets the rise in the banks' profits. In this case, the flow carry losses exceed the bank equity gain, and hence the U.S. reduces consumption and the trade balance swings from a deficit to a surplus. Thus, in this panel we arrive at trade dynamics that resemble the insurance mechanisms of Maggiori (2017) and Gourinchas and Rey (2022).

In Panel (b), we illustrate a new mechanism due to the convenience yield channel. Instead of fixing U.S. monetary response to the flight-to-dollar shock, we suppose that the Fed lowers interest rates by 10 basis points. This monetary easing induces an increase in the supply of dollar liquidity which enables banks to run a larger quantity of the carry trade and harvest larger seigniorage profits. Now the increase in equity value due to future convenience yields roughly offsets the losses in current bank carry profits. As a result, the U.S. trade balance remains stable.[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 and Rey (2022). Indeed, consistent with their finding, the figures show that the U.S. NFA is negative and turns more negative when V_t rises. However, we see from Proposition 4 that U.S. households' consumption and trade decisions are a function of U.S. households' total wealth, not just the NFA. A significant portion of the former is domestically held U.S. securities such as equities and bonds. Our model shows that there is a net transfer of wealth to the U.S. due to the future carry trade profits, which manifests itself as an increase in the domestically held component of V_t.

This broader lesson is consistent with data from the Global Financial Crisis. 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 Appendix B.2 for the details of this computation. The same measure for the five non-U.S. countries with the largest wealth (Canada, Germany, France, Great Britain, Japan) is \$9.8 trillion, when measured in dollars. Figure 5 plots these two series. On a relative basis, the U.S. gains \$4.3 trillion in

[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 also plausible that some of the convenience yield profits flow to firms and are capitalized into the value of corporate equity.

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.

Our new mechanism offers an avenue to resolve the "reserve currency paradox" of Maggiori (2017). In the risk-sharing models of Gourinchas and Rey (2022) and Maggiori (2017), the U.S. loses wealth to the rest of the world in a crisis. As a result, the U.S. cuts consumption of foreign goods and runs a trade surplus in the crisis. This prediction regarding trade surplus is at odds with the patterns in the 2007—2009 global financial crisis. Indeed, the challenge identified by Maggiori (2017) arises even without going to the two-country general equilibrium model of Maggiori (2017), as it is evident from the U.S. household first-order condition in Eq. (45). There we see that the trade balance is increasing in U.S. wealth. Our mechanism shows that the U.S. can run a trade deficit in the crisis because the U.S. 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 lack of a trade surplus in a crisis.

Maggiori (2017) also notes that, absent other forces, the dollar needs to depreciate to achieve

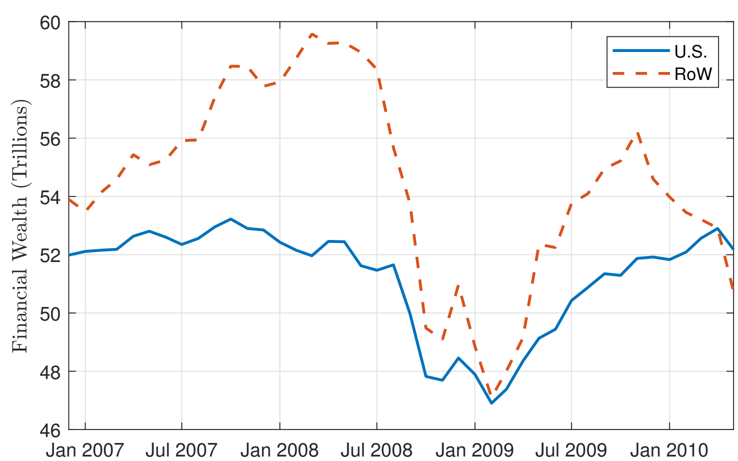


Figure 5: U.S. and RoW Financial Wealth

We plot 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 solid blue. The same measure for the five largest wealth non-U.S. countries (Canada, Germany, France, Great Britain, Japan) is plotted in dashed 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 Section B.2 of the Appendix for underlying computations.

the trade surplus, which is also inconsistent with the pattern of dollar appreciation in crises. Although we do not close the goods market in a general equilibrium model as in Maggiori (2017), so that we do not claim to fully resolve the paradox, our model provides a new insight. It is a small step to see that the model's convenience yield force can also be consistent with the dollar appreciation in the crisis. That is, in a fuller model, in the crisis state our model would generate a dollar appreciation and increase in wealth of the U.S. relative to foreign – as in our current analysis – and if we added a market clearing condition for the world goods market, this market would clear with the U.S. running a trade deficit at the appreciated dollar exchange rate.

Finally, 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. The \$2.2 trillion loss in the GFC on the NFA is consistent with the U.S. as safe-asset provider sharing this relative gain with the rest-of-the-world. Indeed, the loss indicates that the U.S. and rest-of-the-world share financial risks almost perfectly with the U.S. losing on net \$7.7 trillion ($= -5.5 - 2.2$) and foreign losing \$7.6 trillion ($= -9.8 + 2.2$). This offers 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.

4 Dollar Spillovers in Foreign Countries

We next extend our model to introduce a continuum of identical foreign countries to trace the impact of U.S. monetary policy and dollar demand on the rest of the world. The modeling is largely the same as the U.S. model, except that we give foreign firms a debt-denomination choice: they can borrow in foreign currency or dollar.

4.1 Foreign households and firms

Each country has households and firms who provide labor, produce, and consume. The foreign country produces and consumes the foreign (tradable) goods. The law of one price holds: the price of the foreign goods is identical in the U.S. and in the foreign countries. The world real interest rate is r_t^* which the country takes as given; i.e., each foreign country is a "small open economy."

The foreign households are OLG. Their utility function is of the same form as the U.S. households in the domestic setting, i.e.,

$$\frac{1}{1+\rho^*}\mathbb{E}_t[c_{t+1}^*] - \ell_t^* \tag{52}$$

where c_{t+1}^* is consumption of the foreign goods. Other than these aspects, the rest of the model mirrors the U.S. model. As with the U.S. block, households supply labor as long as the real interest rate $r_t^* \geq \rho^*$.

Firms in the foreign country produce the foreign goods using the following production technology:

$$f(\ell_t^*, k_t^*) = a_t^*(\ell_t^* + k_t^*), \qquad a_t^* > r_t^*. \tag{53}$$

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

$$\sum_{t=1}^{\infty} (1-\sigma^*)^{t-1} \sigma^* n_t^*. \tag{54}$$

4.2 Borrowing choice

Foreign firms may choose to borrow in the foreign currency or in dollars. First, suppose that the firm only borrows in the foreign currency. This case follows readily from our analysis of the U.S. The firm can promise repayments up to $\theta^* p_{t+1}^* f(\ell_t^*, k_t^*)$. The firm raises foreign currency debt at the interest rate of r_t^* up to this maximum amount and uses the proceeds to expand production. Following Proposition 1, the firm's equilibrium labor and capital input satisfies

$$l_t^* + k_t^* \approx n_t^* \frac{1}{1-\theta^* a_t^* (1+r_t^*)^{-1}}, \tag{55}$$

and firm profits after debt payments are:

$$n_t^{*,local} = (1-\theta^*)a_t^*(\ell_t^* + k_t^*) = n_t^* \cdot \frac{a_t^*(1-\theta^*)}{1-\theta^* a_t^*(1+r_t^*)^{-1}}. \tag{56}$$

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":

$$r_t + (\mathbb{E}_t[e_{t+1}] - e_t) < r_t^* \tag{57}$$

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.

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

Proposition 6. *The equilibrium quantity of dollar debt a foreign firm issues is*

$$q_t^* \mathcal{E}_t = n_t^* \frac{\theta^* a_t^*}{1 + r_t^* - \lambda_t - \theta^* a_t^*}. \tag{58}$$

The foreign firm's profits are,

$$n_t^{*,dollar} = n_t^* a_t^* \frac{(1-\theta^*) - \theta^*(e_{t+1} - \mathbb{E}_t[e_{t+1}])(1+r_t^* - \lambda_t)^{-1}}{1 - \theta^* a_t^*(1+r_t^* - \lambda_t)^{-1}}. \tag{59}$$

We can compare this last expression for profits to that in Eq. (56). Note that the profits are exposed to the exchange rate movement, $e_{t+1} - \mathbb{E}_t[e_{t+1}]$. 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 $r_t^* - \lambda_t$, resulting in higher profits compared to Eq. (56). The benefit of dollar borrowing is cheaper financing, driven by the positive convenience yield.

To close the foreign block of the model, we suppose that firms in the foreign country are 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 the manager's net worth is the only foreign state variable and 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:

$$(1-\gamma)N_t^{*,local} + \gamma N_t^{*,dollar} = a_t^* N_t^* \Bigg((1-\gamma)\frac{(1-\theta^*)}{1-\theta^* a_t^*(1+r_t^*)^{-1}} \tag{60}$$

$$+ \gamma \frac{(1-\theta^*) - \theta^*(e_{t+1} - \mathbb{E}_t[e_{t+1}])(1+r_t^* - \lambda_t)^{-1}}{1-\theta^* a_t^*(1+r_t^*-\lambda_t)^{-1}} \Bigg). \tag{61}$$

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

$$\lambda_t = \lambda(Q_t + Q_t^*) = \bar{\lambda} - \beta^\lambda (Q_t + Q_t^* - Q_{SS} - Q_{SS}^*) + \varepsilon_t^\lambda. \tag{62}$$

To facilitate the steady-state analysis, we assume that new firms are born each period with capital of $\widehat{N}^*$. Then the dynamics of net worth are:

$$N_{t+1}^* = (1-\sigma^*)((1-\gamma)N_t^{*,local} + \gamma N_t^{*,dollar}) + \sigma^* \widehat{N}^* \tag{63}$$

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

[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. (56) and (59). 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.

4.3 Equilibrium and steady state

Definition 3. *A global equilibrium is a collection of household consumption, labor and savings decisions as in Proposition 4, foreign household consumption, labor and savings decisions that solve (4), international investors' decision as in Proposition 2, bank supply as in Proposition 3, U.S. firm borrowing, hiring and capital investment decisions satisfying Proposition 1, foreign firm borrowing, hiring and capital investment decisions satisfying Proposition 6, given a path of interest rates i_t, i_t^*, exchange rates e_t, bank equity value, V_t and productivity a_t, a_t^*. At these decisions, the market for U.S. capital, U.S. labor, foreign capital, foreign labor, dollar liquidity, and bank equity clear.*

Relative to the analysis of the previous sections, the equilibrium has two state variables, (N_t, N_t^*). The market clearing condition for the dollar exchange rate has both dollar bonds supplied by the U.S. and foreign countries, as in equation (62). Additionally, we solve the foreign firm financing problem of issuance in dollars or foreign currency. The rest of the analysis mirrors that of the previous sections.

The non-stochastic steady state satisfies equation (20) and

$$N_{SS}^* = (1-\sigma^*)((1-\gamma)N_{SS}^{*,local} + \gamma N_{SS}^{*,dollar}) + \sigma^* \widehat{N}^*. \tag{64}$$

In order to compute impulse response paths, we need to tackle a more complex problem. 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 take an initial guess of the convenience yield on dollar bonds for $t \geq 1$ and solve the state variables and exchange rate. We then use the implied state variables to compute the convenience yield, and iterate until convergence. Given that each simulation has only a single shock at $t = 1$, this problem remains tractable.

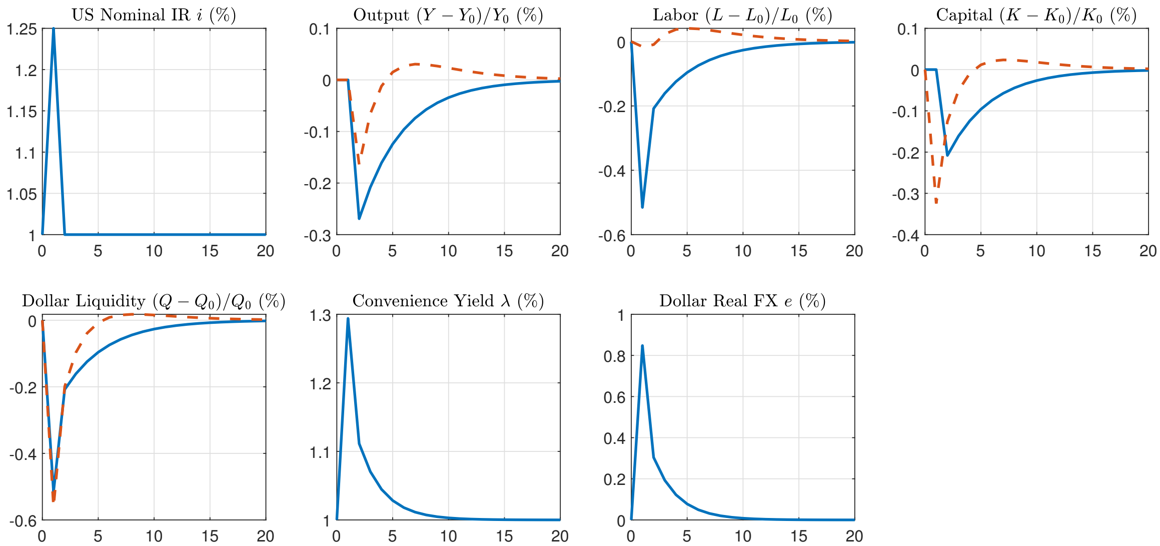


Figure 6: Impulse response to a U.S. monetary policy shock of 0.25%

We consider a 0.25% shock to i_t in period $t = 1$. In blue, we plot the response of U.S. variables, while in dashed red, we plot foreign variables. The output, labor, capital, and dollar liquidity are expressed as percentage deviations from their steady-state values. See Appendix Table A.1 for parameter values.

4.4 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. We also present the effects on the U.S. for comparison. Blue corresponds to the U.S. and dashed red to a representative foreign country. Tightening at $t = 1$ leads to an appreciation in the dollar, e_t rises, inducing losses to the multinationals. As a result, the foreign capital K_t^*, foreign output Y_t^*, and overseas dollar liquidity Q_t^* fall at $t = 1$. Note that the fall in Q_t^* further amplifies the shock since it tightens safe asset supply, increases λ_t, and adds to the dollar appreciation.

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

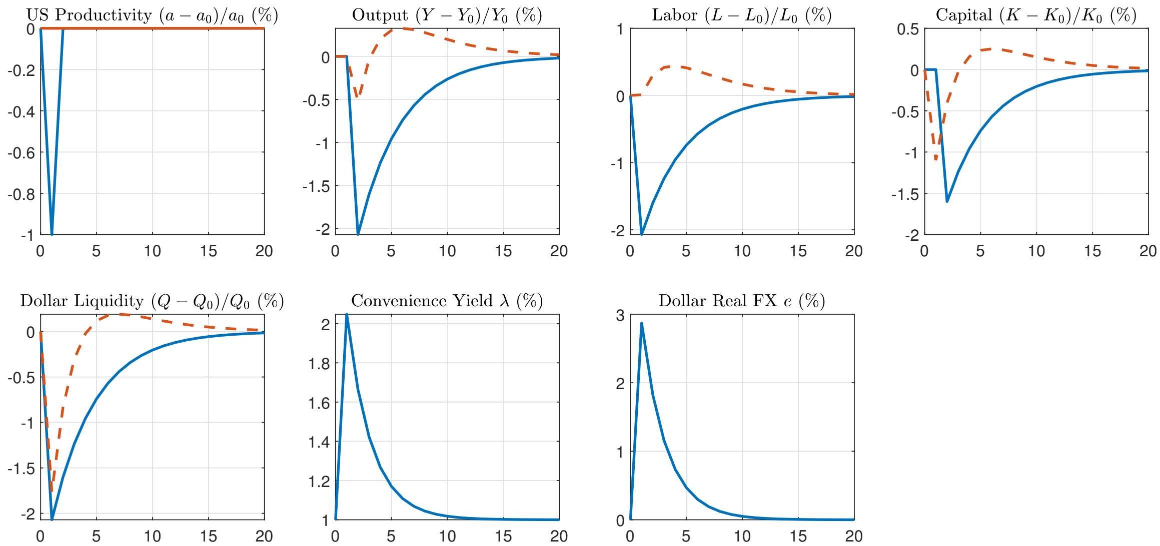


Figure 7: Impulse Responses to U.S. Productivity Shock.

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 dashed red, we plot foreign variables. The output, labor, capital, and dollar liquidity are expressed as percentage deviations from their steady-state values. See Appendix Table A.1 for parameter values.

Figure 7 presents a different experiment. We lower the U.S. productivity a_t unexpectedly at date $t = 1$. The impact on the U.S. (blue) is as expected: borrowing, capital, labor, and output all fall. The effect is persistent through the financial accelerator effects of the model. The effects on foreign are novel. The U.S. recession leads to a decline in dollar liquidity, an increase in the convenience yield, and an appreciation in the U.S. dollar. As a result of the currency mismatch, foreign firms suffer temporarily. The economics here are exactly the same 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 a financial channel through which U.S. shocks spillover to foreign economies.

4.5 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 the pledgeability parameter θ_t^* unexpectedly by 5% at $t = 1$. We assume that the shock dissipates with autocorrelation of 0.7. The reduction in θ_t^* 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'

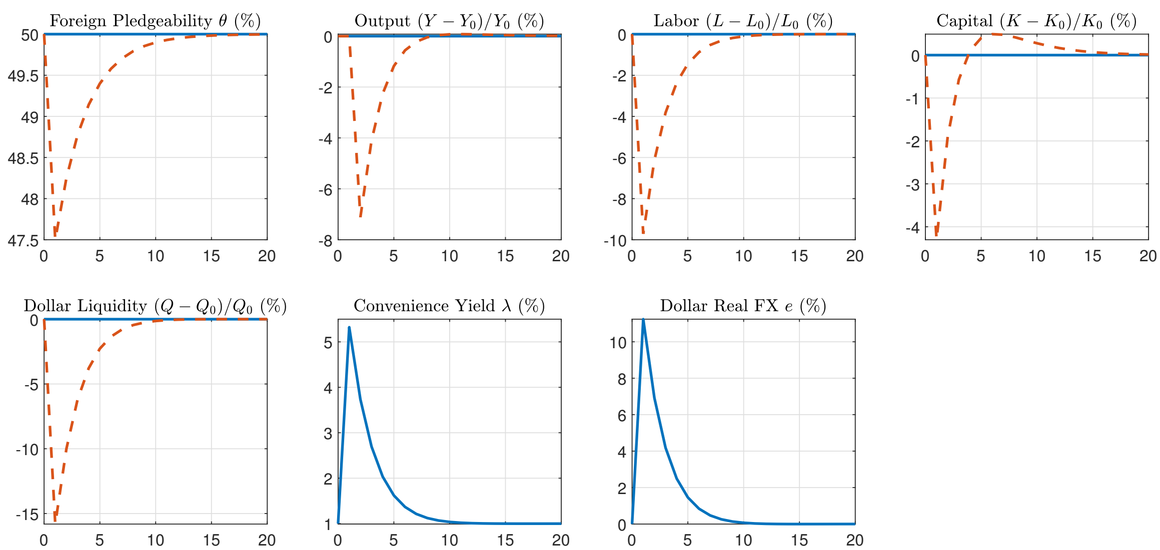


Figure 8: Impulse Responses to Foreign Pledgeability Shock

We reduce the foreign firms' cash flow pledgeability θ^* unexpectedly by 5% in period $t = 1$. The shock dissipates with autocorrelation of 0.7. In blue, we plot the response of U.S. variables, while in dashed red, we plot foreign variables. The output, labor, capital, and dollar liquidity are expressed as percentage deviations from their steady-state values. See Appendix Table A.1 for parameter values.

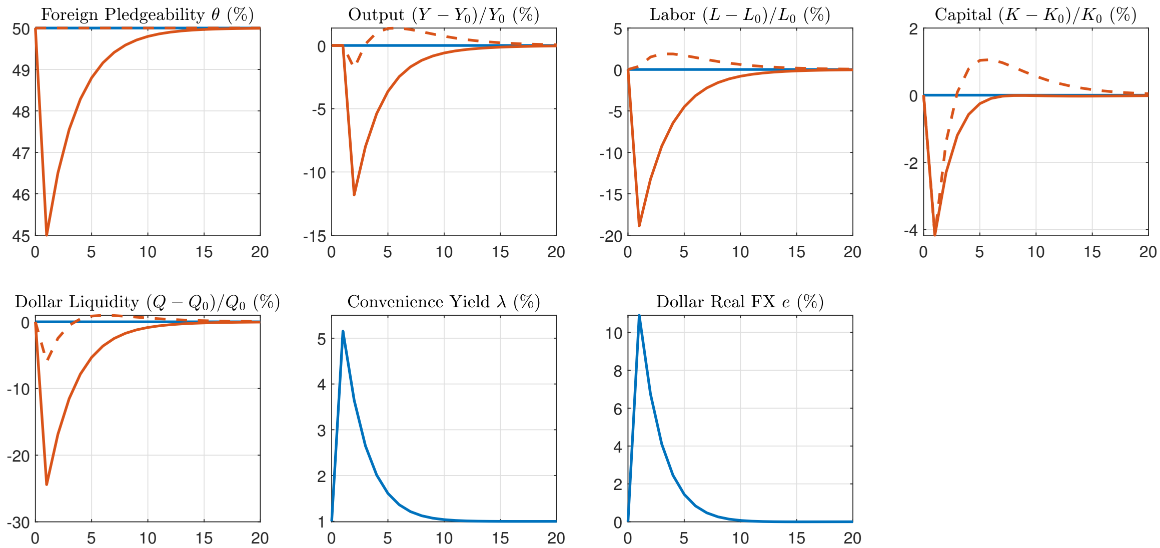


Figure 9: Impulse Responses to Foreign Pledgeability Shock and Foreign Contagion

We consider two types of foreign countries. We reduce the first type of foreign country's firm 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 shocked foreign country's variables, and in dashed red we plot that of the non-shocked foreign country's variables. The output, labor, capital, and dollar liquidity are expressed as percentage deviations from their steady-state values. See Appendix Table A.1 for parameter values.

balance sheets. In comparison, this foreign shock does not affect the U.S. output, capital, or employment, because the U.S. firms do not have currency mismatch on their balance sheets and are therefore not exposed to the exchange rate movement.

Furthermore, this pledgeability shock creates contagion across foreign countries. In Figure 9, we consider an extension of our model in which there are two types of foreign countries, each of measure one-half (i.e. 50% of the foreign countries in the prior setup). The pledgeability shock hits the first type of foreign countries in period $t = 1$ causing global dollar liquidity to fall. The convenience yield rises and the dollar appreciates, which then feeds back to both types of foreign countries by deteriorating the balance sheets of all foreign dollar borrowers. After period $t = 1$, both types of foreign countries' capital recovers, but the shocked foreign countries' recovery is slower as the pledgeability shock is persistent. In our parameterization, the non-shocked foreign country bounces back and overshoots the steady-state output. This is because the convenience yield remains high due to the shock to the first type of countries and hence financing terms are actually better for the non-shocked countries. The experiment shows how a financial crisis in one area of the world (e.g., Brazil and Russia) can propagate to other areas (e.g., Thailand and Korea) via the dollarized financial system.

4.6 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 helps explain the global financial cycle of Rey (2013) and show that this is really a dollar cycle. The asymmetry that foreign shocks have limited impact on the U.S., but not other foreign countries, also squares with experience ("spillovers but limited spillbacks") of many emerging markets (see Mishra and Rajan, 2016). Finally, the importance of the dollar as a risk factor for foreign countries is also apparent from the model. Lustig, Roussanov and Verdelhan (2014); Verdelhan (2018); Wiriadinata (2018); Jiang and Richmond (2023) present compelling evidence that the dollar is a common 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 economy, but also depreciates the exchange rate and hence contracts the dollarized sectors of the economy. Thus, effectively foreign countries have blunt ex-post instruments to deal with shocks. Their only option is to use ex-ante instruments such as capital controls and hoarding of foreign reserves. The basic fact of the international equilibrium is that when the dollar is the safe-asset

[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.

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 patterns of the U.S. balance sheet relative to the rest-of-the-world, 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.

The analysis also points to next steps for both macroeconomics and finance in this research area. For international macroeconomics, a shortcoming of the paper is that we do not offer a multi-country general equilibrium analysis, and in particular do not clear the world goods market. We have investigated the issue and think it should be feasible to extend our analysis to this case. Our model is also stylized, aiming to explain many features of the global financial cycle at the cost of making simplifying assumptions that renders the analysis ill-suited to a quantification exercise. There has been recent work aiming to quantify the macroeconomic effects of the global demand for dollar safe assets (Kekre and Lenel, 2023*a*; Devereux, Engel and Wu, 2023). For finance, our analysis has stopped short of explaining what makes dollar safe assets special in the international financial system, which is a necessary step in order to address the normative questions raised by our analysis. There has been a growing body of theoretical work on the topic. See in particular He, Krishnamurthy and Milbradt (2018), Gopinath and Stein (2021), Chahrour and Valchev (2017) and Coppola, Krishnamurthy and Xu (2023). Our analysis also has no risk, so that while in the world the convenience yield attaches to dollar safe

[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.

assets, our model does not meaningfully discriminate between dollar safe assets and dollar risky assets. Enriching the corporate finance of the model to allow for both dollar equity claims and safe dollar bond claims, and examining the separate forces arising from the convenience yield on the safe claims would be an important step forward. Likewise, measuring the convenience yields on different dollar debt claims – corporate, financial, government – is an important step in understanding where in the economy the convenience seigniorage of our analysis is located. Finally, although our model points to a mechanism whereby the dollar is a global risk factor, it does not take the step of deriving a risk premium on the dollar. Including aggregate risk in the analysis will be important to explain the dollar risk premium component of currency returns which is a prominent feature of the data (Lustig, Roussanov and Verdelhan (2011)).

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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

We calibrate the model to make qualitative points. The steady-state U.S. interest rate is 1% and the steady-state foreign interest rate is 2%. The steady-state convenience yield on U.S. bonds is 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 productivity is 1.055. We also pick

Parameter	Notation	Estimate
U.S.		
Pledgeability	θ	0.5
Firms' Exit Rate	σ	0.3
Productivity	$\bar{a}$	1.055
Share of Global Banks	χ	0.5
Steady-State Interest Rate	$\bar{i}$	1.00%
Steady-State Firm Capital	k_{SS}	1
Expenditure Share of Home Consumption	α_H	0.8
Expenditure Share of Foreign Consumption	α_F	0.1
Expenditure Share of Bequest	α_X	0.1
Global Safe Asset Investors		
Steady-State Convenience Yield	$\bar{\lambda}$	1%
Convenience Yield Per Dollar Liquidity	β_λ	0.5
Foreign		
Pledgeability	θ^*	0.5
Firms' Exit Rate	σ^*	0.3
Productivity	$\bar{a}^*$	1.055
Share of Firms that Can Borrow Dollar	γ	0.5
Steady-State Interest Rate	$\bar{i}^*$	2.00%
Steady-State Firm Capital	k^*_{SS}	1
Implied Parameters		
Steady-State U.S. Labor	ℓ_{SS}	1.09
Steady-State Foreign Labor	ℓ^*_{SS}	1.08
New U.S. Capital	$\widehat{N}$	0.76
New Foreign Capital	$\widehat{N}^*$	0.77
Steady-State U.S. Dollar Liquidity	Q_{SS}	0.55
Steady-State Foreign Dollar Liquidity	Q^*_{SS}	0.55
Steady-State U.S. Bank Profits	Π_{SS}	0.0055
Steady-State U.S. Trade Balance	TB_{SS}	-0.0025

Table A.1: **Parameter Values.**

other production parameters so that a 0.25% increase in quarterly interest rate leads to 0.25% decline in output and 0.5% decline in employment.

The steady-state foreign dollar liquidity Q^*_{SS} is chosen to be 0.55 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,

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

which implies

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

Proof of Proposition 2 Write foreign investors' Lagrangian as follows:

$$\begin{aligned}\mathcal{L}_t = \mathbb{E}_t \Bigg[& \sum_{s=t}^{\infty} \left(\frac{1}{1+\rho^*}\right)^{s-t} \left(c_s^{intl} + \frac{\mathcal{E}_s v_s(q_s^{demand})}{1+\rho^*} \right) \\ & - \sum_{s=t-1}^{\infty} \mu_{s+1} \left(w_{s+1}^{intl} + c_{s+1}^{intl} - (w_s^{intl} - \mathcal{E}_s q_s^{demand})(1+r_s^*) - \mathcal{E}_s q_s^{demand}(1+r_s)\frac{\mathcal{E}_{s+1}}{\mathcal{E}_s} \right) \Bigg],\end{aligned}$$

which yields the first-order conditions w.r.t. c_s^{intl}, w_s^{intl} and $\mathcal{E}_s q_s^{demand}$

$$\begin{aligned} \left(\frac{1}{1+\rho^*}\right)^{s-t} - \mu_s &= 0, \\ -\mu_s + \mathbb{E}_s[\mu_{s+1}(1+r_s^*)] &= 0, \\ \left(\frac{1}{1+\rho^*}\right)^{s-t} \frac{v_s'(q_s^{demand})}{1+\rho^*} + \mathbb{E}_s\left[\mu_{s+1}\left((1+r_s)\frac{\mathcal{E}_{s+1}}{\mathcal{E}_s} - (1+r_s^*)\right)\right] &= 0, \end{aligned}$$

i.e.,

$$\begin{aligned} 1 &= \mathbb{E}_t\left[\frac{1}{1+\rho^*}(1+r_t^*)\right], \\ -v_t'(q_t^{demand}) &= \mathbb{E}_t\left[(1+r_t)\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} - (1+r_t^*)\right]. \end{aligned}$$

The first equation implies that $r_t^* = \rho^*$, and the RHS of the second equation can be approximated by

$$\begin{aligned}\mathbb{E}_t\left[(1+r_t)\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} - (1+r_t^*)\right] &= \mathbb{E}_t\left[(1+r_t)\exp(\Delta e_{t+1}) - (1+r_t^*)\right] \\ &\approx \mathbb{E}_t\left[(1+r_t)(1+\Delta e_{t+1}) - (1+r_t^*)\right] \\ &\approx \mathbb{E}_t\left[\Delta e_{t+1} + r_t - r_t^*\right]\end{aligned}$$

which gives an uncovered interest parity condition (U.I.P.) with a convenience yield λ_t,

$$\mathbb{E}_t[\Delta e_{t+1}] + r_t - r_t^* = -v_t'(q_t^{demand}) = -\lambda_t$$

Proof of Proposition 4 Below, we first characterize households' problem, given $\mathcal{E}_{t+1}$, V_{t+1} and Π_{t+1}. The Lagrangian is

$$\mathcal{L}_{t+1} = \frac{1}{1+\rho}\mathbb{E}_t\left[c_{H,t+1}^{\alpha_H}\ c_{F,t+1}^{\alpha_F}\ x_{t+1}^{\alpha_X}\right] - \psi\ell_t + \mathbb{E}_t\left[\mu_{t+1}\left(h_{t+1} - \mathcal{E}_{t+1}c_{H,t+1} - c_{F,t+1} - x_{t+1}\right)\right].$$

We first consider the problem conditional on knowing the information in period $t+1$. The first-order conditions are:

$$\begin{aligned}\frac{1}{1+\rho}\left(c_{H,t+1}^{\alpha_H}\ c_{F,t+1}^{\alpha_F}\ x_{t+1}^{\alpha_X}\right)\frac{\alpha_H}{c_{H,t+1}} &= \mu_{t+1}\mathcal{E}_{t+1}, \\ \frac{1}{1+\rho}\left(c_{H,t+1}^{\alpha_H}\ c_{F,t+1}^{\alpha_F}\ x_{t+1}^{\alpha_X}\right)\frac{\alpha_F}{c_{F,t+1}} &= \mu_{t+1}, \\ \frac{1}{1+\rho}\left(c_{H,t+1}^{\alpha_H}\ c_{F,t+1}^{\alpha_F}\ x_{t+1}^{\alpha_X}\right)\frac{\alpha_X}{x_{t+1}} &= \mu_{t+1}\end{aligned}$$

Substitute these first-order conditions into the budget constraint to get:

$$\begin{aligned}\mathcal{E}_{t+1}c_{H,t+1} &= \alpha_H h_{t+1}, \\ c_{F,t+1} &= \alpha_F h_{t+1}, \\ x_{t+1} &= \alpha_X h_{t+1},\end{aligned}$$

which further implies:

$$c_{H,t+1}^{\alpha_H}\ c_{F,t+1}^{\alpha_F}\ x_{t+1}^{\alpha_X} = (\alpha_H h_{t+1}/\mathcal{E}_{t+1})^{\alpha_H}(\alpha_F h_{t+1})^{\alpha_F}(\alpha_X h_{t+1})^{\alpha_X} = \psi h_{t+1}\mathcal{E}_{t+1}^{-\alpha_H}$$

where we use the fact that $\alpha_H + \alpha_F + \alpha_X = 1$ and $\psi = \alpha_H^{\alpha_H} \alpha_F^{\alpha_F} \alpha_X^{\alpha_X}$.

Given this, we can rewrite the households' optimization problem in period t as

$$\frac{1}{1+\rho}\mathbb{E}_t\left[\psi h_{t+1}\mathcal{E}_{t+1}^{-\alpha_H}\right] - \psi\ell_t = \psi\left(\frac{1}{1+\rho}\mathbb{E}_t\left[\mathcal{E}_{t+1}^{-\alpha_H}h_{t+1}\right] - \ell_t\right) \tag{A.1}$$

Now we can substitute in the expression h_{t+1} to characterize households' labor supply decision

$$\psi\left(\frac{1}{1+\rho}\mathbb{E}_t\left[\mathcal{E}_{t+1}^{-\alpha_H}h_{t+1}\right] - \ell_t\right) = \psi\left(\frac{1+r_t}{1+\rho}\mathbb{E}_t\left[\mathcal{E}_{t+1}^{1-\alpha_H}\right] - 1\right)\ell_t + \frac{\psi}{1+\rho}\mathbb{E}_t\left[\mathcal{E}_{t+1}^{-\alpha_H}x_t\frac{\Pi_{t+1}+V_{t+1}}{V_t}\right]$$

We note that x_t is the bequest from the previous generate to the generate-t households, which is not controlled by the generation-t households. Hence, households supply labor as long as $(1+r_t)\mathbb{E}_t\mathcal{E}_{t+1}^{1-\alpha_H} \geq 1+\rho$.

Exchange Rate Stationarity Given our focus on the impulse responses around a steady state, we show that the real exchange rate is stationary if, after a certain time period, the expected convenience yield $\mathbb{E}_t[\lambda_{t+j}]$ and the expected interest rate differential converges $\mathbb{E}_t[r_{t+k} - r_{t+k}^*]$ converge to their steady states. This is obtained, for example, if the productivity and monetary shocks are stationary. Then, for a large enough j,

$$\begin{aligned} e_{t+j} &= \mathbb{E}_{t+j}\sum_{k=0}^{\infty}\lambda_{t+j+k} + \mathbb{E}_{t+j}\sum_{k=0}^{\infty}(r_{t+j+k} - r_{t+j+k}^*) + \lim_{k\to\infty}\mathbb{E}_{t+j}e_{t+j+k} \\ &\to_{j\to\infty} \lim_{k\to\infty}\mathbb{E}_{t+j}e_{t+j+k}. \end{aligned}$$

Then, $\bar{e} = \lim_{k\to\infty}\mathbb{E}_t e_{t+k}$ is well defined, and the real exchange rate converges to a given level in the long-run future.

Details on NFA Below, we use capital letter to denote variables in aggregate level. As shown above, total imports (in foreign currency value) are given by,

$$C_{F,t+1} = \alpha_F H_{t+1}$$

and total exports are,

$$\mathcal{E}_{t+1}(1 + i_t - \pi_t)L_t - \alpha_H H_{t+1}.$$

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

$$
\begin{aligned}
TB_{t+1} &= \mathcal{E}_{t+1}(1+i_t-\pi_t)L_t - (\alpha_F+\alpha_H)\,H_{t+1} \\
&= \alpha_X \mathcal{E}_{t+1}(1+i_t-\pi_t)L_t - (\alpha_F+\alpha_H)\,X_t\left(\frac{V_{t+1}+\Pi_{t+1}}{V_t}\right)
\end{aligned}
$$

To confirm the law of motion for NFA,

$$
NFA_{t+1} - NFA_t = TB_{t+1} + IB_{t+1} + CG_{t+1},
$$

plug in the expression for each component in the RHS,

$$
\begin{aligned}
TB_{t+1} + IB_{t+1} + CG_{t+1} &= \mathcal{E}_{t+1}(1+i_t-\pi_t)L_t - (\alpha_F+\alpha_H)\,H_{t+1} \\
&\quad + \frac{X_t}{V_t}(\Pi_{t+1}+V_{t+1}-V_t) - (V_{t+1}-V_t)
\end{aligned}
$$

Since,

$$
\begin{aligned}
&H_{t+1} = \mathcal{E}_{t+1}(1+i_t-\pi_t)L_t + X_t\left(\frac{V_{t+1}+\Pi_{t+1}}{V_t}\right), \\
&\frac{X_{t+1}}{\mathcal{E}_{t+1}} = \alpha_X \frac{H_{t+1}}{\mathcal{E}_{t+1}},
\end{aligned}
$$

we have that

$$
\begin{aligned}
TB_{t+1} + IB_{t+1} + CG_{t+1} &= \alpha_X \mathcal{E}_{t+1}(1+i_t-\pi_t)L_t - (\alpha_F+\alpha_H)\,\frac{X_t}{V_t}\,(V_{t+1}+\Pi_{t+1}) \\
&\quad + \frac{X_t}{V_t}(\Pi_{t+1}+V_{t+1}-V_t) - (V_{t+1}-V_t) \\
&= \alpha_X \mathcal{E}_{t+1}(1+i_t-\pi_t)L_t + \alpha_X \frac{X_t}{V_t}(\Pi_{t+1}+V_{t+1}) + (V_t - X_t) - V_{t+1} \\
&= X_{t+1} - V_{t+1} - (X_t - V_t) = NFA_{t+1} - NFA_t
\end{aligned}
$$

which confirms the NFA law of motion. Note that

$$
NFA_{t+1} = X_{t+1} - V_{t+1} = \alpha_X \mathcal{E}_{t+1}(1+i_t-\pi_t)L_t + \alpha_X \frac{X_t}{V_t}\,(V_{t+1}+\Pi_{t+1}) - V_{t+1} \tag{A.2}
$$

and $\alpha_X \frac{X_t}{V_t} < 1$, then, the U.S. NFA deteriorates when the value of the bank equity V_{t+1} rises.

Lastly, we consider the steady state, where the trade deficit must be matched by a payment from abroad. Steady-state bank profits Π_{SS} are positive

$$\Pi_{SS} = Q_{SS}\mathcal{E}_{SS}\lambda_{SS} \tag{A.3}$$

and proportional to λ_{SS}. The U.S. household owns shares in the banking sector and thus receives a dividend proportional to Π_{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 $\alpha_X H_{t+1} = X_{t+1}$. Using the expression for H_{t+1} from the budget constraint, we find that,

$$X_{SS} = \alpha_X \left(\mathcal{E}_{SS}(1 + i_{SS} - \pi_{SS})L_{SS} + X_{SS}(1 + r^*)\right) = \frac{\alpha_X}{1 - \alpha_X(1 + r^*)}\mathcal{E}_{SS}(1 + i_{SS} - \pi_{SS})L_{SS}. \tag{A.4}$$

Proof of Proposition 6 Suppose that the firm sells q_t^* dollars of bonds and raises $q_t^*\mathcal{E}_t$ units of goods in this way. We impose the financial constraint that the maximum number of dollar bonds issued by this firm is,

$$q_t^*(1 + r_t)\mathbb{E}_t\mathcal{E}_{t+1} \leq \theta^* a_t^*(k_t^* + q_t^*\mathcal{E}_t) \tag{A.5}$$

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 $\mathbb{E}_t\mathcal{E}_{t+1}$ 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:

$$(1 + r_t)\mathbb{E}_t\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \approx 1 + r_t^* - \lambda_t.$$

Then, solving for q_t^*, with Eq. (A.5) binding, we find that:

$$q_t^*\mathcal{E}_t = n_t^*\frac{\theta^* a_t^*}{(1 + r_t)\mathbb{E}_t\mathcal{E}_{t+1}/\mathcal{E}_t - \theta^* a_t^*} \approx n_t^*\frac{\theta^* a_t^*}{1 + r_t^* - \lambda_t - \theta^* a_t^*}.$$

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

$$\begin{aligned}
n_t^{*,dollar}(e_{t+1}) &= a_t^*(n_t^* + q_t^*\mathcal{E}_t) - q_t^*(1+r_t)\mathcal{E}_{t+1} \\
&= a_t^* n_t^* + q_t^*\mathcal{E}_t(a_t^* - (1 + r_t + e_{t+1} - e_t)) \\
&= a_t^* n_t^* + n_t^* \frac{\theta^* a_t^*}{1 + r_t^* - \lambda_t - \theta^* a_t^*}\left(a_t^* - (1 + r_t + e_{t+1} - e_t)\right) \\
&= a_t^* n_t^* \frac{(1-\theta^*) + r_t^* - \lambda_t - \theta^*\left(r_t + e_{t+1} - e_t\right)}{1 + r_t^* - \lambda_t - \theta^* a_t^*}.
\end{aligned}$$

Since

$$e_t = \mathbb{E}_t[e_{t+1}] + r_t + \lambda_t - r_t^*,$$

we rewrite the profits' expression to find:

$$n_t^{*,dollar}(e_{t+1}) = n_t^* a_t^* \frac{(1-\theta^*)(1 + r_t^* - \lambda_t) - \theta^*(e_{t+1} - \mathbb{E}_t[e_{t+1}])}{1 + r_t^* - \lambda_t - \theta^* a_t^*}.$$

B Empirical Evidence

B.1 The Treasury Basis and λ

In Jiang, Krishnamurthy and Lustig (2021), we present empirical evidence in support of Eq. (40) 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.

Let s_t denote the nominal exchange rate. For firm dollar bonds we had posited,

$$i_t + \mathbb{E}_t s_{t+1} - s_t = i_t^* - \lambda_t, \tag{A.6}$$

and used this equation to derive the U.I.P. condition in (26). For government bonds, we posit that,

$$i_t^T + \mathbb{E}_t s_{t+1} - s_t = i_t^* - (1+\phi)\lambda_t, \tag{A.7}$$

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

$$i_t - i_t^T = \phi\lambda_t. \tag{A.8}$$

So that the spread on the left is proportional to the convenience yield. In Jiang, Krishnamurthy and Lustig (2021), 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:

$$\left(i_t - i_t^T\right) - \left(i_t^* - i_t^{T,*}\right). \tag{A.9}$$

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 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 (Germany), 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.

This measure captures how an investor will profit from a buy-and-hold strategy in the U.S. and foreign markets. It is consistent with the notion in our model which captures the seigniorage revenue earned by the banks' capital in place, though we note that our measure does not reflect the new issuances in these asset classes.

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,

$$V(n^*_{t+1}, \lambda_{t+1}) = \sum_{k=t+1}^{\infty} (1-\sigma^*)^{k-(t+1)} \sigma^* n^*_k. \tag{A.10}$$

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,

$$\frac{n^*_{t+1}}{n^*_t} = \frac{a^*(1-\theta^*)}{1-\theta^* a^*(1+i^*-\lambda_t)^{-1}} \tag{A.11}$$

and we find that,

$$V(n^*_{t+1}, \lambda^*_{t+1}) = n^*_{t+1}\sigma^* \sum_{k=t+1}^{\infty} \left(((1-\sigma^*)a^*(1-\theta^*))^{k-(t+1)} \prod_{j=t+1}^{k-1} \frac{1}{1-\theta^* a^*(1+i^*-\lambda_j)^{-1}} \right) \tag{A.12}$$

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,

$$m(\lambda_{t+1}) = \sum_{k=t+1}^{\infty} \left(((1-\sigma^*)a^*(1-\theta^*))^{k-(t+1)} \prod_{j=t+1}^{k-1} \frac{1}{1-\theta^* a^*(1+i^*-\lambda_j)^{-1}} \right) \tag{A.13}$$

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:

$$\max_{\gamma} \mathbb{E}_t[(1-\sigma^*)n^*_{t+1} + \sigma^* n^*_{t+1} m(\lambda_{t+1})] \Rightarrow \max_{\gamma} \mathbb{E}_t[n^*_{t+1}]\mathbb{E}_t[(1-\sigma^*) + \sigma^* m(\lambda_{t+1})] + cov_t[n^*_{t+1}, \sigma^* m(\lambda_{t+1})] \tag{A.14}$$

where,

$$n^*_{t+1} = a^*_t n^*_t \left\{ (1-\gamma)\frac{1-\theta^*}{1-\theta^* a^*_t (1+i^*_t)^{-1}} + \gamma \left(\frac{(1-\theta^*) - \theta^*(s_{t+1} - \mathbb{E}_t[s_{t+1}])}{1-\theta^* a^*_t(1+i^*_t - \lambda_t)^{-1}} \right) \right\} \tag{A.15}$$

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

The term $\mathbb{E}_t[n^*_{t+1}]$ 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 parameterization. For lower values of λ_t, risk considerations enter the picture and the solution is at an interior where $\gamma < 1$. If risk is high enough, then it is possible that the solution sets $\gamma = 0$.

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