

# The Flight to Safety and International Risk Sharing<sup>†</sup>

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*We study a business cycle model of the international monetary system featuring a time-varying demand for safe dollar bonds, greater risk-bearing capacity in the United States than the rest of the world, and nominal rigidities. A flight to safety generates a dollar appreciation and decline in global output. Dollar bonds thus command a negative risk premium, and the United States holds a levered portfolio of capital financed in dollars. We quantify the effects of safety shocks and heterogeneity in risk-bearing capacity for global macroeconomic volatility, US external adjustment, and policy transmission, as of dollar swap lines. (JEL E32, E43, E44, E52, F44, G11, G15)*

The United States sits at the center of the international monetary system. At business cycle frequencies, there are two defining features of this role. The first concerns its currency. Relative to bonds denominated in the currencies of equally high-income countries, dollar bonds pay well when equities pay poorly, and have low expected returns when output has been declining. These imply that dollar bonds are a hedge whose value rises in bad times. The second concerns the US international investment position. The United States is positively exposed to equities and negatively exposed to the dollar exchange rate. As such, it serves as the “world’s insurer” and transfers wealth to the rest of the world in bad times.

Despite substantial advances, the literature lacks a model of the international monetary system that can jointly capture these cyclical patterns and study their implications. One strand of the literature has emphasized the safety and liquidity value of US Treasuries. While these features can rationalize patterns in currency markets, this literature has not yet traced out the implications for global business cycles, risk sharing, or risk premia. Another strand of the literature has argued that the United States has a greater capacity to bear risk than the rest of the world. This can explain

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<sup>†</sup> Go to <https://doi.org/10.1257/aer.20211319> to visit the article page for additional materials and author disclosure statements.

patterns in US net foreign assets but has counterfactual asset pricing implications: given consumption home bias, the dollar should depreciate in bad times.

In this paper, we propose a business cycle model of the international monetary system that bridges these two perspectives. Our model features a time-varying demand for safe dollar bonds, greater risk-bearing capacity in the United States than the rest of the world, and nominal rigidities. A flight to safe dollar bonds—which we formalize as an increase in their nonpecuniary value—generates a stronger dollar and a decline in global output. Dollar bonds are thus an endogenous hedge, and US finances a levered portfolio of capital in dollars. We discipline the time-varying demand for safe dollar bonds to match spreads in financial markets, and differences in risk tolerance across countries to match the sensitivity of US net foreign assets to excess equity returns. The model generates untargeted comovements between relative bond returns, equity returns, output, and US net foreign assets quantitatively in line with the data. We then trace out its macroeconomic and policy implications. Absent the time-varying demand for safe dollar bonds, global output would be roughly 15 percent less volatile, particularly so in the United States. Absent the United States' greater capacity to bear risk, its net foreign assets would be only as volatile as net exports, but net exports would in turn bear a greater burden in external adjustment, and the United States would no longer earn positive average returns on its external position. Both the flight to safety and greater US risk-bearing capacity played important roles in the Great Recession. Finally, the creation of safe dollar liquidity, such as via the dollar swap lines employed by central banks in recent crises, is globally stimulative but revalues wealth in the United States' favor.

We study a workhorse open economy New Keynesian environment extended to feature a nonpecuniary value of dollar bonds and heterogeneity in risk aversion. Agents consume subject to home bias and supply labor domestically subject to adjustment costs in nominal wages. They trade safe dollar bonds, other dollar bonds, foreign bonds, and capital, which can be deployed in either country. We associate safe dollar bonds with Treasury bills and other money-like assets that are valued for their liquidity or safety beyond their pecuniary return. The equilibrium nonpecuniary value—described in the literature as a “convenience yield”—reflects both the latent demand for these securities as well as their supply. We treat demand as a driving force and term the associated shocks *safety shocks*. The model features three other sets of shocks: to global productivity (including a rare disaster), to the disaster probability, and to relative productivity across countries. We study unexpected shocks to the supply of safe dollar bonds at the end of the paper.

Safety shocks and heterogeneity in risk aversion together generate a distinctive pattern of comovements between excess foreign bond returns, equity returns, output, and wealth in the global economy. A positive safety shock implies that the expected return on all assets must rise relative to safe dollar bonds to keep agents indifferent across assets. Absent nominal rigidity, this is achieved by deflation in the United States and a decline in its real interest rate. With nominal rigidity and US monetary policy that does not lower nominal interest rates sufficiently in response, this instead is achieved by a decline in global consumption and investment as well as immediate dollar appreciation. The goods market and foreign exchange market responses are linked by a larger fall in US output than output abroad, appreciating the US terms of

trade. As dollar bonds thus pay well in endogenously “bad” times, they earn a negative risk premium versus foreign bonds, and relatively risk-tolerant agents insure the risk averse against such a shock. If agents in the United States are more risk tolerant than those abroad, this implies that US net foreign assets fall on impact of the shock. In the periods that follow, the dollar depreciates, excess foreign bond and equity returns are high, global output recovers, and US net foreign assets improve. Consistent with the “reserve currency paradox” elucidated by Maggiori (2017), productivity and disaster risk shocks are unable to deliver these comovements.

We calibrate the model to match observed portfolios and second moments in asset prices and real quantities. We use the yield spread between US Treasuries and G10 government bonds swapped into dollars constructed by Du, Im, and Schreger (2018) as a direct measure of safety shocks, up to its volatility; if swapped foreign government bonds are also partially valued for their liquidity or safety, the volatility of their yield difference versus Treasury bills will underestimate the volatility of safety shocks. We thus calibrate the volatility of safety shocks to match the observed (negative) risk premium on dollar bonds. We calibrate the volatility of global and relative productivity shocks to target volatilities in aggregate consumption and output. We calibrate the stochastic properties of disaster risk shocks to match the disaster risk series estimated by Barro and Liao (2021). The risk tolerance of Foreign is set to match the global equity premium. The risk tolerance of Home is set to match the positive exposure of US net foreign assets to excess equity returns.

The model generates untargeted comovements quantitatively in line with the data. We focus on comovements involving excess foreign bond returns and the US net foreign asset position, which speak directly to the role of the dollar and US economy in the international monetary system. As in the data, our model implies that (i) the year-over-year decline in US output forecasts high future excess foreign bond returns, (ii) high global equity returns are accompanied by high excess foreign bond returns, and (iii) an increase in US net foreign assets is accompanied by high excess foreign bond returns. Safety shocks are crucial for all of these, while greater risk-bearing capacity in the United States is crucial for the third.

We then use the model to quantify the roles of safety shocks and heterogeneity in risk-bearing capacity for global macroeconomic volatility and US external adjustment. Safety shocks account for more than 25 percent of output volatility in the United States and 5 percent of output volatility in the rest of the world. Heterogeneity in risk-bearing capacity accounts for essentially all of the positive average return on the US external position and the excess volatility of US net foreign assets relative to net exports. While the US external position would thus be less volatile if it did not serve as the world’s insurer, the share of innovations to net foreign assets rebalanced by future net exports would rise, as valuation effects would no longer stabilize the US external position. These insights are obtained using simulations of the model’s driving forces over long time periods. We also feed in the observed sequence of safety and disaster risk innovations estimated by Du, Im, and Schreger (2018) and Barro and Liao (2021) during the Great Recession. Together with the calibrated differences in risk tolerance across countries, these shocks alone generate a cumulative decline in US output by 1.3 percent, Foreign output by 1.5 percent, and US

net foreign assets relative to output by 8.6 percent from the end of 2007:III through 2009:III, versus 4.8 percent, 5.1 percent, and 10.0 percent in the data.

We finally use the model to trace out the transmission of shocks to the supply of safe dollar assets, as via dollar swap lines. An increased supply reduces the convenience yield like a negative safety shock. We simulate the Federal Reserve's announcements to expand the availability and frequency of its swap line operations on March 19 and 20, 2020. The model generates a 100bp dollar depreciation and increase in the global equity return of 135bp on impact, comparable to the estimates obtained by Kekre and Lenel (2023) around the swap line announcements in the data. We then use the model to quantify the implications for real activity and wealth. The model implies an increase in US output of 80bp, foreign output of 20bp, and US net foreign assets relative to output of 440bp. We conclude that in recent crises, dollar swap lines have played a meaningful stabilization role and relaxed the US external budget constraint by mitigating the flight to safety.

*Related Literature.*—Our model sits between and integrates two literatures. Our focus on the time-varying demand for safe dollar bonds builds on the rapidly growing literature studying convenience yields and safe assets (Engel 2016; Engel and Wu 2023; Jiang, Krishnamurthy, and Lustig 2021, 2023; Jiang et al. 2022; and Valchev 2020).<sup>1</sup> Relative to this literature, our contribution is to embed the convenience yield in a workhorse open economy New Keynesian model to trace out the implications for output, risk sharing, and risk premia. By accounting for greater risk-bearing capacity in the US than in the rest of the world, we also build on a large literature studying international risk sharing in such an environment (Chien and Naknoi 2015; Dou and Verdelhan 2015; Gourinchas, Rey, and Govillot 2017; Maggiori 2017; and Sauzet 2023). Relative to this literature, our model accommodates a time-varying demand for safe dollar bonds, production, and nominal rigidity, which together provide a resolution to the “reserve currency paradox” that has challenged this literature.

Our account of the cyclical properties of the dollar and the US external balance sheet is distinct from others in the literature. Gourinchas, Rey, and Govillot (2017) propose an increase in foreign risk aversion in times with elevated uncertainty, driving a higher demand for insurance from the United States. Maggiori (2017) proposes an increase in trade costs, which shifts demand to US goods in crises. We instead emphasize an increase in the demand for safe dollar assets, disciplined by convenience yields and with distinct implications for policy, such as dollar swap lines. Jiang, Krishnamurthy, and Lustig (2023) emphasize that the seigniorage revenues earned by the United States upon a flight to safety drive an increase in US wealth, such that there may be no paradox in accounting for a dollar appreciation after all. Our model also features this channel, but we relax the assumptions on risk neutrality and binding financial constraints made in their analysis, and we provide a quantitative evaluation. We find that the seigniorage gains of the United States upon

<sup>1</sup> See Del Negro et al. (2017); DiTella (2020); Drechsler, Savov, and Schnabl (2017); Farhi and Maggiori (2018); Greenwood, Hanson, and Stein (2015); He, Krishnamurthy, and Milbradt (2019); Krishnamurthy and Vissing-Jorgensen (2012); Lenel, Piazzesi, and Schneider (2019); and Nagel (2016) for related analyses of convenience yields and safe assets.

a flight to safety are more than offset by losses on capital and foreign bonds. The dollar appreciation remains consistent with a fall in relative US wealth because the flight to safety induces a larger reduction in the supply of US goods. In Lucas tree environments, Dahlquist et al. (2023) and Sauzet (2023) also associate crises with a fall in the relative supply of US goods, generating a dollar appreciation. Our model identifies a shock that endogenously has this feature in a production economy with nominal rigidities, the flight to safe dollar assets.<sup>2</sup>

The effects of safety shocks in our model build most directly on Caballero and Farhi (2018) and Caballero, Farhi, and Gourinchas (2021). These authors demonstrate that an increase in the demand for safe assets reduces output and appreciates the exchange rate of safe asset issuers in the presence of nominal rigidities and a binding zero lower bound. We build on their work by demonstrating that these insights apply under conventional Taylor rules even if the zero lower bound is not binding; characterizing the *ex ante* currency risk premia and international portfolios that arise in response; and quantifying the implications of the time-varying demand for safe dollar bonds for international business cycles, asset prices, and portfolios.

The effects of safety shocks contrast with the effects of other asset demand shocks in the literature that are “disconnected” from aggregates. Gabaix and Maggiori (2015) and Itsikhoki and Mukhin (2021, 2023) study shocks to the demand for specific currencies that have to be intermediated by a subset of risk-averse agents, resulting in fluctuations in the exchange rate that may have little relationship to macroeconomic quantities.<sup>3</sup> Our analysis differs from these papers in three ways. First, safety shocks pertain to the demand for a particular type of asset within a given currency, as reflected in a time-varying convenience yield, whereas the “UIP shocks” studied in these papers reflect the demand for all assets of a given currency, as reflected in a time-varying currency risk premium.<sup>4</sup> Second, safety shocks affect not only agents’ portfolio choice between bonds of different currencies but also their portfolio choice between bonds and capital and their intertemporal decisions between consumption and saving. Third, we study an environment in which all agents can trade the same assets, whereas the aforementioned papers emphasize segmented financial markets in which only a small measure of agents trade the menu of assets. The latter two features combine to imply that safety shocks affect not only exchange rates and other asset prices but also macroeconomic quantities and country-level portfolios.

*Outline.*—In Section I we outline the environment. In Section II we characterize the main mechanisms analytically in a limiting case. In Section III we calibrate the full model, and in Section IV we study its impulse responses and untargeted comovements versus the data. Having validated the model, in Section V we study its macroeconomic and policy implications. Finally, in Section VI we conclude.

<sup>2</sup> In our analytical and quantitative results, we also speak to the empirical analyses in Dahlquist et al. (2023) and Sauzet (2023) concerning the dynamics of the US wealth share over 2008–2009.

<sup>3</sup> See Alvarez, Atkeson, and Kehoe (2002, 2009) for seminal work on the link between portfolio flows, exchange rates, and risk premia.

<sup>4</sup> In this sense, our analysis relates to the emerging literature on preferred habitats and exchange rates (Gourinchas, Ray, and Vayanos 2022 and Greenwood et al. 2023), which studies how shocks to the demand for specific assets (maturities) within a given currency transmit to exchange rates. The focus of these papers, however, remains on the quantity of risk borne by a subset of arbitrageurs in segmented markets. In our case, it is on the transmission of such asset demand shocks in general equilibrium in the presence of nominal rigidity.

## I. Model

There are two countries, Home and Foreign, comprised of measure one and  $\zeta^*$  households, respectively. We use asterisks to denote variables chosen by or endowed to Foreign households. For brevity, we focus on the optimization problems and policy at Home and only summarize the analogs in Foreign; a complete description is in online Appendix A. Since we will calibrate the model so that Home captures the United States, we refer to Home's nominal unit of account as the dollar.

We add two essential ingredients to a workhorse open economy New Keynesian model with sticky nominal wages and capital: cross-country heterogeneity in risk-bearing capacity and a time-varying convenience yield on dollar-denominated government bonds. We model these via differences in risk tolerance and bonds in utility so that we can focus on their implications and interactions in the simplest possible environment. We expect our insights would extend to richer models of differences in risk-bearing capacity and convenience yields.

In addition to these essential ingredients, we add several features to isolate mechanisms and improve the model's quantitative fit. In particular, Epstein-Zin preferences disentangle risk aversion from intertemporal substitution. A rare disaster with time-varying probability generates meaningful variation in risk premia.

### A. Households

The representative household at Home has recursive preferences,

$$(1) \quad v_t = \left\{ (1 - \beta) \left[ c_t \Phi(\ell_t) \Omega_t (B_{Ht,s}/P_t) \right]^{1-1/\psi} + \beta \mathbb{E}_t \left[ (v_{t+1})^{1-\gamma} \right]^{1-1/\psi} \right\}^{\frac{1}{1-1/\psi}},$$

over consumption  $c_t$ , labor  $\ell_t$ , and the real value of “safe” dollar bonds  $B_{Ht,s}/P_t$ . Consumption  $c_t$  is a CES aggregator of Home- and Foreign-produced goods,

$$(2) \quad c_t = \left[ \left( \frac{1}{1 + \zeta^*} + \varsigma \right)^{\frac{1}{\sigma}} (c_{Ht})^{\frac{\sigma-1}{\sigma}} + \left( \frac{\zeta^*}{1 + \zeta^*} - \varsigma \right)^{\frac{1}{\sigma}} (c_{Ft})^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}.$$

The disutility of labor follows Shimer (2010) and Trabandt and Uhlig (2011),

$$(3) \quad \Phi(\ell_t) = \left[ 1 + (1/\psi - 1) \bar{\nu} \frac{(\ell_t)^{1+1/\nu}}{1 + 1/\nu} \right]^{\frac{1/\psi}{1-1/\psi}}.$$

The utility provided by safe dollar bonds is analogous to the voluminous literature with money in the utility function since Sidrauski (1967). It captures the nonpecuniary value agents receive from the liquidity or perceived safety of these assets and follows Krishnamurthy and Vissing-Jorgensen (2012) among many other papers in the recent literature on convenience yields. The household's risk aversion is denoted by  $\gamma$ , intertemporal elasticity of substitution as well as consumption-labor complementarity are jointly controlled by  $\psi$ , and discount rate is  $\beta$ . Home bias is controlled by  $\varsigma$ , and the trade elasticity by  $\sigma$ . Finally,  $\bar{\nu}$  denotes the disutility of labor,

and  $\nu$  controls the Frisch elasticity of labor supply. Each household supplies a continuum of labor varieties  $j \in [0, 1]$ , so  $\ell_t = \int_0^1 \ell_t(j) dj$ .

The household chooses one-period safe dollar bonds  $B_{Ht,s}$  paying  $i_t$  dollars at  $t + 1$ ; one-period other dollar bonds  $B_{Ht,o}$  paying  $\iota_t$  dollars at  $t + 1$ ; one-period Foreign nominal bonds  $B_{Ft}$  paying  $i_t^*$  in Foreign's unit of account at  $t + 1$ ; and capital  $k_t$ , which trades at price  $Q_t^k$  at  $t$ , pays dividends  $\Pi_{t+1}$  per unit in  $t + 1$ , and depreciates after its use at rate  $\delta$ . Without loss of generality, the price and return on the capital claim are written here in dollars. The rare disaster scales the capital stock by the stochastic term  $\exp(\varphi_{t+1})$ . We describe the effects of a disaster in more detail below.

Each period, the household supplies labor and chooses consumption and its portfolio subject to the resource constraint,

$$(4) \quad P_{Ht} c_{Ht} + E_t^{-1} P_{Ft}^* c_{Ft} + B_{Ht,s} + B_{Ht,o} + E_t^{-1} B_{Ft} + Q_t^k k_t \\ \leq (1 + i_{t-1}) B_{Ht-1,s} + (1 + \iota_{t-1}) B_{Ht-1,o} + E_t^{-1} (1 + i_{t-1}^*) B_{Ft-1} \\ + [\Pi_t + (1 - \delta) Q_t^k] k_{t-1} \exp(\varphi_t) + \int_0^1 W_t(j) \ell_t(j) dj \\ - \int_0^1 AC_t^W(j) dj + T_t,$$

where  $P_{Ht}$  and  $P_{Ft}^*$  denote the prices of Home- and Foreign-produced goods in their domestic unit of accounts;  $E_t$  is the nominal exchange rate in terms of Foreign's unit of account per dollar; and we assume producer-currency pricing, implying that the law of one price holds. Each labor variety  $j$  in the household earns a wage rate  $W_t(j)$ . Following Rotemberg (1982), the household pays a cost of setting such a wage,

$$(5) \quad AC_t^W(j) = \frac{\chi^W}{2} W_t \ell_t \left[ \frac{W_t(j)}{W_{t-1}(j) \exp(\varphi_t)} - 1 \right]^2,$$

where  $\chi^W$  scales the adjustment costs and the aggregate wage bill  $W_t \ell_t$  is defined below.<sup>5,6</sup> Finally, the household receives a government transfer  $T_t$ .

Households in Foreign face an analogous problem. Importantly, Foreign households also receive utility  $\Omega_t^* (B_{Ht,s}^* / (E_t^{-1} P_t^*))$  from safe dollar bonds, and their risk aversion  $\gamma^*$  can differ from that of Home households. We also allow their discount factor  $\beta^*$  to differ from that in Home so that we can match the level of net foreign assets in our calibration. Otherwise, they share the same intertemporal elasticity cum consumption-labor complementarity  $\psi$ , home bias  $\varsigma$ , trade elasticity  $\sigma$ , and Frisch elasticity  $\nu$  as Home households. We further assume an identical degree of nominal wage rigidity  $\chi^W$  as in Home. We allow the disutility of labor  $\bar{\nu}^*$  to differ from that in Home, only to normalize labor supply to one when calibrating the model.

<sup>5</sup>We assume the adjustment cost is paid to the government and then rebated lump-sum so it does not mechanically affect our quantitative results (as on output volatility) later in the paper.

<sup>6</sup>The disaster enters into the denominator of the wage adjustment cost for computational simplicity, as it reduces the size of the grid of prior period real wages we need to consider in our numerical algorithm. We further view this as realistic, as richer models of nominal rigidity would imply that in response to large shocks, prices and wages indeed may be more flexible.

### B. Supply Side

*Labor Unions.*—Home union  $j$  represents each variety  $j$  in Home households. Each period, it chooses the wage  $W_t(j)$  and labor supply  $\ell_t(j)$  to maximize the utilitarian social welfare of members. An analogous problem faces each Foreign union  $j^*$ .

*Labor Packer.*—A representative Home labor packer purchases varieties supplied by each union and combines them to produce a CES aggregate with elasticity of substitution  $\epsilon$  and sold at  $W_t$  to domestic firms. The labor packer thus earns

$$(6) \quad W_t \left[ \int_0^1 \ell_t(j)^{(\epsilon-1)/\epsilon} dj \right]^{\epsilon/(\epsilon-1)} - \int_0^1 W_t(j) \ell_t(j) dj.$$

An analogous problem faces the representative Foreign labor packer, and we assume that the elasticity of substitution across labor varieties is also  $\epsilon$ .

*Production.*—A representative Home producer hires  $\ell_t$  units of labor from the domestic labor packer, rents  $\kappa_t$  units of capital on the international market, and produces the consumption good with productivity  $z_t$  and a constant-returns-to-scale technology with labor share  $1 - \alpha$ . The producer thus earns

$$(7) \quad P_{Ht} (z_t \ell_t)^{1-\alpha} (\kappa_t)^\alpha - W_t \ell_t - \Pi_t \kappa_t.$$

A symmetric problem faces the representative Foreign producer. Relative productivity in Foreign is stochastic and given by  $z_{Ft}$ . We note that the return per unit capital used in Foreign will still be  $\Pi_t$  once expressed in dollars, reflecting the ability of households to freely deploy capital in either country, equating its rate of return.<sup>7</sup>

Finally, a representative global capital producer uses  $\left\{ \bar{k}_t / [\bar{k}_{t-1} \exp(\varphi_t)] \right\}^{\chi^x} x_{Ht}$  units of the Home consumption good and  $\left\{ \bar{k}_t / [\bar{k}_{t-1} \exp(\varphi_t)] \right\}^{\chi^x} x_{Ft}$  units of the Foreign consumption good to produce

$$(8) \quad x_t = \left[ \left( \frac{1}{1 + \zeta^*} \right)^{\frac{1}{\sigma}} (x_{Ht})^{\frac{\sigma-1}{\sigma}} + \left( \frac{\zeta^*}{1 + \zeta^*} \right)^{\frac{1}{\sigma}} (x_{Ft})^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}$$

new units of capital, where  $\chi^x$  controls adjustment costs, global capital  $\bar{k}_t$  is taken as given, and we assume investment is not subject to home bias. The producer earns

$$(9) \quad Q_t^k x_t - \left\{ \bar{k}_t / [\bar{k}_{t-1} \exp(\varphi_t)] \right\}^{\chi^x} (P_{Ht} x_{Ht} + E_t^{-1} P_{Ft}^* x_{Ft}),$$

which will be zero in equilibrium.

<sup>7</sup>This simplifies the model computation, as there is only a single aggregate capital state variable to keep track of  $(\bar{k}_{t-1})$ . Recently, Atkeson, Heathcote, and Perri (2023) and Dahlquist et al. (2023) have emphasized the importance of heterogeneous returns on US versus foreign equities. In Section II, we describe a model extension featuring distinct capital stocks in each country.

### C. Policy

Monetary policy is characterized by a Taylor (1993) rule,

$$(10) \quad 1 + i_t = (1 + \bar{i}) \left( \frac{P_t}{P_{t-1}} \right)^\phi,$$

where  $P_t$  is the ideal price index

$$(11) \quad P_t = \left[ \left( \frac{1}{1 + \zeta^*} + \varsigma \right) P_{Ht}^{1-\sigma} + \left( \frac{\zeta^*}{1 + \zeta^*} - \varsigma \right) (E_t^{-1} P_{Ft}^*)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}.$$

An analogous Taylor rule in Foreign determines  $i_t^*$  with the same coefficient  $\phi$  on inflation in the Foreign ideal price index  $P_t^*$ . We focus on CPI-targeting Taylor rules anticipating our calibration to the US and G10 currency countries.

Fiscal policy at Home is characterized by participation in the safe dollar bond market  $B_{Ht,s}^g$  and lump-sum transfers. We assume that the government maintains a constant ratio of safe dollar debt to global consumption,

$$(12) \quad -B_{Ht,s}^g = \bar{b}^g (P_t c_t + \zeta^* E_t^{-1} P_t^* c_t^*),$$

a specification we motivate in the next subsection. The empirically relevant case features  $\bar{b}^g > 0$ : the Home government borrows in safe dollar bonds, namely Treasury bills. The Home government then makes transfers to each household,

$$(13) \quad T_t = \int_0^1 AC_t^W(j) dj + (1 + i_{t-1}) B_{Ht-1,s}^g - B_{Ht,s}^g.$$

We abstract from the Home government's participation in asset markets other than safe dollar bonds because these do not provide nonpecuniary benefits and the government finances itself with lump-sum taxes, so Ricardian equivalence will apply. The Foreign government similarly provides wage subsidies and makes lump-sum transfers, but we abstract from its participation in asset markets because it is assumed to be unable to create safe dollar liquidity, and thus, Ricardian equivalence holds.

### D. Nonpecuniary Value of Safe Dollar Bonds

The nonpecuniary value of safe dollar bonds is reflected in a wedge between the returns on safe dollar bonds and all other assets—a “convenience yield.” Among dollar-denominated bonds, this is particularly clear because both bonds pay in the same unit of account and are risk free. Thus, investor indifference in Home requires

$$(14) \quad \frac{1 + i_t}{1 - c_t \Omega_t'(B_{Ht,s}/P_t) / \Omega_t(B_{Ht,s}/P_t)} = 1 + \iota_t.$$

The left-hand side is the effective return on safe dollar bonds. The right-hand side is the return on other dollar bonds. Since an analogous condition must hold for Foreign

agents, the nonpecuniary value of safe dollar bonds must be equated across agents on the margin, which we denote  $\omega_t$ :

$$(15) \quad \omega_t \equiv c_t \frac{\Omega_t'(B_{Ht,s}/P_t)}{\Omega_t(B_{Ht,s}/P_t)} = c_t^* \frac{\Omega_t^{*'}(B_{Ht,s}^*/(E_t^{-1}P_t^*))}{\Omega_t^*(B_{Ht,s}^*/(E_t^{-1}P_t^*))}.$$

Equation (14) makes clear how the convenience yield  $\omega_t$  can be estimated using spreads in financial markets, which we make use of in our quantitative analysis.

We now assume a particularly convenient functional form for  $\Omega_t$ :

$$\Omega_t\left(\frac{B_{Ht,s}}{P_t}\right) = \exp\left(\omega_t^d \frac{B_{Ht,s}}{P_t \bar{c}_t} - \frac{1}{2} \frac{1}{\epsilon^d} \left(\frac{B_{Ht,s}}{P_t \bar{c}_t}\right)^2 - \left[\omega_t^d \frac{\bar{B}_{Ht,s}}{P_t \bar{c}_t} - \frac{1}{2} \frac{1}{\epsilon^d} \left(\frac{\bar{B}_{Ht,s}}{P_t \bar{c}_t}\right)^2\right]\right),$$

where  $\omega_t^d$  is an exogenous driving force,  $\epsilon^d$  is a parameter, and all variables with bars are aggregates that the representative household takes as given.<sup>8</sup> Given an analogous functional form in Foreign, online Appendix A proves that the second equality in (15), together with market clearing in safe dollar bonds, implies

$$(16) \quad \frac{B_{Ht,s}}{P_t c_t} = \frac{B_{Ht,s}^*}{E_t^{-1} P_t^* c_t^*} = \frac{(-B_{Ht,s}^g)}{P_t c_t + \zeta^* E_t^{-1} P_t^* c_t^*}.$$

The first equality in (15) thus implies

$$(17) \quad \omega_t = \omega_t^d - \frac{1}{\epsilon^d} \frac{(-B_{Ht,s}^g)}{P_t c_t + \zeta^* E_t^{-1} P_t^* c_t^*}.$$

Intuitively, the convenience yield is rising in private demand for safe dollar bonds  $\omega_t^d$  and decreasing in public supply  $-B_{Ht,s}^g$ . The relative strength of the latter depends on  $\epsilon^d$ , the elasticity of demand to the nonpecuniary value. We treat  $\omega_t^d$  as a driving force and refer to its innovations as “safety shocks.” Given our assumed supply of safe dollar debt (12), the convenience yield is effectively exogenous and inherits the stochastic properties of  $\omega_t^d$ . At the end of Section V, we instead study shocks to  $B_{Ht,s}^g$ .<sup>9</sup>

### E. Driving Forces

Global productivity follows a unit root process subject to rare disasters,

$$(18) \quad \log(z_t) = \log(z_{t-1}) + \sigma^z \epsilon_t^z + \varphi_t,$$

<sup>8</sup> The rationale for this functional form is straightforward. Inside the parenthesis, the first two terms imply a time-varying nonpecuniary value of safe dollar bonds diminishing in the household’s position. The second two terms ensure that in equilibrium  $\Omega_t(B_{Ht,s}/P_t) = 1$ , so that the effects of a time-varying convenience yield do not arise from mechanical effects on stochastic discount factors.

<sup>9</sup> We maintain the “cashless limit” of Woodford (2003). If money offers liquidity services that are neither substitutes nor complements with safe dollar bonds, this is innocuous. If dollar money and safe dollar bonds are perfect substitutes in liquidity provision, (17) would effectively be replaced by a condition relating  $\omega_t$  to Home’s nominal rate. However, changes in the *relative* liquidity of safe dollar bonds versus money would still propagate like safety shocks in our baseline model.

where  $\varphi_t$  is equal to zero with probability  $1 - p_t$  and  $\varphi_t < 0$  with probability  $p_t$ . The log disaster probability  $p_t$  follows an AR(1) process,

$$(19) \quad \log p_t - \log p = \rho^p (\log p_{t-1} - \log p) + \sigma^p \epsilon_t^p,$$

which we specify in terms of the log series to capture its skewness in the data. Similarly, the demand for safe dollar bonds is given by  $\omega_t^d = \Delta^\omega + \tilde{\omega}_t^d$ , where

$$(20) \quad \log \tilde{\omega}_t^d - \log \omega^d = \rho^\omega (\log \tilde{\omega}_{t-1}^d - \log \omega^d) + \sigma^\omega \epsilon_t^\omega.$$

This similarly captures the skewness of the convenience yield in the data, but we include the shift parameter  $\Delta^\omega$  so that the mean of  $\omega_t$  is zero, allowing us to make clear that all of the paper's insights only rely on time variation in the convenience yield. Finally, log relative productivity at Foreign  $z_{Ft}$  follows

$$(21) \quad \log z_{Ft} = \rho^F \log z_{Ft-1} + \sigma^F \epsilon_t^F.$$

We assume that the innovations  $\{\epsilon_t^z, \epsilon_t^p, \epsilon_t^\omega, \epsilon_t^F\}$  are each drawn from a normal distribution with mean zero and variance one. We allow the shocks to disaster risk and the convenience yield to have correlation  $\rho^{p\omega}$ ; a positive value (as we later estimate in the data) allows us to capture that the flight to safe dollar assets typically accompanies times of elevated global risk. We assume all other shock correlations are zero.

#### F. Equilibrium and Solution

We provide the market-clearing conditions in online Appendix A for brevity. The definition of equilibrium is standard and also provided in online Appendix A, together with a characterization of agents' first-order conditions. Since labor varieties are symmetric,  $\ell_t(j) = \ell_t$ ,  $\ell_t(j^*) = \ell_t^*$ , and we drop the indices  $j$  and  $j^*$  going forward.

We globally solve a stationary transformation of the economy obtained by dividing all real variables (except labor) by  $z_t$  and nominal variables by  $P_t z_t$ . As shown in online Appendix A, we obtain a recursive representation of equilibrium in which the aggregate state in period  $t$  is given by the disaster probability  $p_t$ , convenience yield  $\omega_t$ , relative Foreign productivity  $z_{Ft}$ , scaled aggregate capital  $\bar{k}_{t-1}/z_t$ , scaled real wages  $W_t/(P_t z_t)$  and  $W_t^*/(E_t P_t z_t)$ , and Home financial wealth share  $\theta_t$ . After scaling in this way, global productivity shocks inclusive of disasters only govern the transition across states.

Online Appendix A also defines additional variables used in the remainder of the paper, including the real exchange rate  $q_t$  (so that an increase corresponds to a Home appreciation), real interest rates  $r_t$  and  $r_t^*$ , real return on capital  $r_t^k$  (expressed in terms of the Home consumption bundle), Home's real value of aggregate saving  $a_t$ , and Home's real net foreign assets  $nfa_t$ . All of these definitions are standard. The

online Appendix further defines the total positions of the Home and Foreign representative agents in dollar-denominated bonds,

$$B_{Ht} \equiv (1 - \omega_t)(B_{Ht,s} + B_{Ht,s}^g) + B_{Ht,o},$$

$$B_{Ht}^* \equiv (1 - \omega_t)B_{Ht,s}^* + B_{Ht,o}^*,$$

each of which earn return  $1 + \iota_t = (1 + i_t)/(1 - \omega_t)$ . The composition of households' dollar bond position is only relevant in determining the equilibrium seigniorage earned by Home on the safe dollar debt held by Foreign, which follows from (16).<sup>10</sup>

## II. Analytical Insights

We first characterize the interactions between safety shocks, greater risk tolerance at Home, and nominal rigidities in a version of the model admitting analytical results. A positive safety shock generates a dollar appreciation and global recession. Dollar bonds earn a negative risk premium, and the US finances a levered capital portfolio in dollars. Several features of safety shocks and of the US economy render these shocks particularly special for the global economy. We discuss the role of key model features in shaping our main results.

### A. Parametric Assumptions

We first describe the simplifying assumptions made in this section alone.

**DEFINITION 1:** *The simplified environment features*

- *flexible wages or wages set one period in advance;*
- *a fixed global capital stock ( $\chi^x \rightarrow \infty, \delta \rightarrow 0$ );*
- *a unitary IES ( $\psi = 1$ ), complete home bias ( $\varsigma \rightarrow \zeta^*/(1 + \zeta^*)$ ), and an infinite Frisch elasticity ( $\nu \rightarrow 0$ );*
- *no disaster risk ( $p = 0, \sigma^p = 0$ ), constant relative productivity ( $\sigma^F = 0$ ), and transitory safety ( $\rho^\omega = 0$ );*
- *identical per capita wealth across countries in the deterministic steady state;*
- *identical discount factors ( $\beta = \beta^*$ ).*

The first assumption departs from the Rotemberg (1982) adjustment costs in the full model; together with the second assumption, this simplifies the dynamics. The next three assumptions simplify the algebra in the proofs. The final assumption ensures that the deterministic steady state is well defined. We study this environment using a perturbation approach around this steady state. We emphasize that in the quantitative analysis in the subsequent sections, none of the above assumptions are made, and a global solution of the model is employed.

<sup>10</sup>In particular, as derived in online Appendix A, Foreign transfers  $\omega_t \left[ (\zeta^* q_t^{-1} c_t^*) / (c_t + \zeta^* q_t^{-1} c_t^*) \right] (-b_{Ht,s}^g)$  units of the Home consumption basket to Home in each period  $t$ , reflecting the Home government's borrowing from Foreign at an interest rate below that on privately issued dollar bonds.

### B. Effects of a Safety Shock

We now describe the effects of a safety shock. We use first-order approximations and  $\hat{\cdot}$  to denote log/level deviations from the deterministic steady state and variables without time subscripts to denote the deterministic steady state.

We begin with the effects on prices and production, in which case the role of nominal rigidity is crucial. To most cleanly see this, we assume identical portfolios and zero safe debt issued by the Home government ( $b_{H,s}^g \equiv B_{H,s}^g/P = 0$ ) in steady state, eliminating any revaluation of wealth on impact of a safety shock.

**PROPOSITION 1:** *Consider the simplified environment and assume identical portfolios and  $b_{H,s}^g = 0$  in the deterministic steady state. If wages are flexible, then on impact of a positive safety shock,*

- the Home real interest rate declines ( $\mathbb{E}_t \hat{r}_{t+1} = -\hat{\omega}_t$ );
- the Home CPI declines ( $\Delta \hat{P}_t = -(1/\phi)\hat{\omega}_t$ ); and
- the Home real exchange rate and employment in each country are unchanged ( $\hat{q}_t = \hat{\ell}_t = \hat{\ell}_t = 0$ ).

*If wages are set one period in advance, then on impact of a positive safety shock,*

- the Home real interest rate declines by less than above ( $0 > \mathbb{E}_t \hat{r}_{t+1} > -\hat{\omega}_t$ );
- the Home CPI declines by less than above ( $0 > \Delta \hat{P}_t > -(1/\phi)\hat{\omega}_t$ );
- the Home real exchange rate appreciates ( $\hat{q}_t \propto \hat{\omega}_t$ ); and
- global employment falls, disproportionately so in Home ( $[1/(1 + \zeta^*)]\hat{\ell}_t + [\zeta^*/(1 + \zeta^*)]\hat{\ell}_t^* \propto -\hat{\omega}_t$  and  $\hat{\ell}_t - \hat{\ell}_t^* \propto -\hat{\omega}_t$ ).

The proof of this proposition, like all others, is provided in online Appendix B. Intuitively, consider a positive safety shock  $\hat{\omega}_t > 0$  in the Euler equation

$$\mathbb{E}_t m_{t,t+1} \left( \frac{1 + r_{t+1}}{1 - \omega_t} \right) = 1,$$

where  $m_{t,t+1}$  denotes the real pricing kernel of a Home household between  $t$  and  $t+1$ . Analogous conditions hold for Foreign households. Absent nominal rigidity, the flight to safe dollar bonds is met with a one-for-one decline in the Home expected real interest rate. With nominal bonds, this is achieved by an immediate dollar deflation, which, under the assumed Taylor rule, results in a fall in the nominal interest rate. With nominal prices and interest rates at Home fully absorbing the increase in safe asset demand, there is no required adjustment in Foreign prices or interest rates to ensure that uncovered interest parity,

$$\mathbb{E}_t m_{t,t+1} \left[ \frac{q_t}{q_{t+1}} (1 + r_{t+1}^*) - \left( \frac{1 + r_{t+1}}{1 - \omega_t} \right) \right] = 0,$$

remains satisfied. There is thus no required adjustment in relative prices nor in production across countries.

In the presence of nominal rigidity and a monetary policy rule that does not sufficiently lower the nominal interest rate (as in the case of the conventional Taylor rule), real interest rates exceed those in the natural allocation and consumption demand is depressed, driving a global recession. In the foreign exchange market, the limited adjustment in real interest rates implies that the dollar must appreciate on impact so that it can be expected to depreciate going forward, ensuring uncovered interest parity holds. These goods market and foreign exchange market responses are linked by the relative supply response: the deflationary pressure particularly at Home implies that product wages rise and output thus falls especially at Home, driving the appreciation in Home's terms of trade and thus real exchange rate.<sup>11,12</sup> The disproportionate recession borne by Home echoes the result in Caballero, Farhi, and Gourinchas (2021) that reserve asset issuers bear the disproportionate cost of "safety traps." We demonstrate that this insight does not rely on the zero lower bound and is a consequence of any monetary policy rule that does not react one-for-one to safe asset demand.

We now turn to the predictions for realized and expected excess returns.

**PROPOSITION 2:** *Consider the simplified environment and assume identical portfolios and  $b_{H,s}^g = 0$  in the deterministic steady state. Then on impact of a positive safety shock,*

- *the real return on dollar bonds rises ( $\hat{r}_t \propto \omega_t$ );*
- *the real return on capital is unaffected if wages are flexible ( $\hat{r}_t^k = 0$ ) but falls if wages are set in advance ( $\hat{r}_t^k \propto -\hat{\omega}_t$ );*
- *the real return on Foreign bonds is unaffected if wages are flexible ( $\hat{r}_t^* - \Delta \hat{q}_t = 0$ ) but falls if wages are set in advance ( $\hat{r}_t^* - \Delta \hat{q}_t \propto -\hat{\omega}_t$ );*
- *expected excess returns on capital and Foreign bonds are positive (up to first order,  $\mathbb{E}_t[\hat{r}_{t+1}^k - \hat{r}_{t+1}] = \mathbb{E}_t[\hat{r}_{t+1}^* - \Delta \hat{q}_{t+1} - \hat{r}_{t+1}] = \hat{\omega}_t$ ).*

Consider the excess returns on capital and Foreign bonds relative to safe dollar bonds. The realized excess returns on capital are negative due to a positive safety shock, both because of the deflation that raises the real return on dollar bonds (even absent nominal rigidity) and the decline in global production that reduces the return to capital (only with nominal rigidity). The realized excess returns on Foreign bonds are negative, again because of the higher real return on dollar bonds (even absent nominal rigidity) and the real dollar appreciation (only with nominal rigidity). Going forward, expected excess returns on capital and Foreign bonds are high, so agents remain indifferent between safe dollar bonds and these other assets.

Finally, we turn to the predictions for wealth and net foreign assets, in which case the interaction between these dynamics of excess returns and heterogeneity in portfolios is crucial.

<sup>11</sup> We note that these same results obtain if nominal prices rather than wages are sticky instead.

<sup>12</sup> In the limit of complete home bias, Foreign output is in fact unaffected by a safety shock. Away from this limit, Foreign output will also fall on impact of a positive safety shock provided the trade elasticity  $\sigma$  is not too high.

**PROPOSITION 3:** *Consider the simplified environment, and assume portfolios are initially not too different from the symmetric benchmark and  $b_{H,s}^g$  is not too different from zero. Then on impact of a positive safety shock,*

- *Home's wealth share falls in its leverage in capital and Foreign bonds but rises in the safe debt issued by the Home government,*

$$\hat{\theta}_t = \left( \frac{q^k k}{a} - 1 \right) (\hat{r}_t^k - \hat{r}_t) + \frac{b_F}{a} (\hat{r}_t^* - \Delta \hat{q}_t - \hat{r}_t) - \beta \frac{\zeta^*}{1 + \zeta^*} \frac{b_{H,s}^g}{a} \hat{\omega}_t,$$

- *revaluing Home's net foreign assets in the same way.*

The fact that Home's wealth falls in its capital and Foreign bond positions is a straightforward consequence of Proposition 2. The fact that its wealth rises in the safe debt issued by the Home government reflects the seigniorage revenue Home earns on the share of this debt owned by the rest of the world.

### C. Portfolios and Risk Premia

We now characterize the equilibrium portfolios actually chosen by agents and the risk premium on Foreign bonds versus dollar bonds. Following Devereux and Sutherland (2011), these can be characterized using a second-order approximation around the deterministic steady state. Because the simplified environment is only subject to global productivity and safety shocks, the three available assets implement efficient risk sharing around the steady state (it is “locally complete,” as defined by Coeurdacier and Gourinchas 2016). We focus on the case with wages set one period in advance.

The equilibrium portfolios reflect the issuance of safe dollar debt by the Home government; differences in risk tolerance between Home and Foreign; and agents' hedging demands given nontraded labor income, real exchange rate risk, and the disutility of labor. In online Appendix B, we characterize each of these forces in closed form. We focus here on comparative statics with respect to Home's safe debt supply and heterogeneity in risk tolerance alone.

**PROPOSITION 4:** *Consider the simplified environment with wages set one period in advance and the same, positive steady-state labor wedge in each country. At least around the case with symmetric country portfolios,*

- *Home's portfolio share in capital (dollar bonds) is unaffected (falls) with  $-b_{H,s}^g$ , and*
- *Home's portfolio share in capital (dollar bonds) rises (falls) with  $\gamma^*/\gamma$ , holding  $\gamma + (1/\zeta^*)\gamma^*$  fixed.*

Intuitively, agents face two sources of risk: global productivity and safe asset demand. The former affects consumption holding fixed labor, and both affect labor in the presence of nominal rigidity. As Home's government borrows more in safe dollar bonds, Home receives more seigniorage on impact of a positive safety shock,

rendering it a natural insurer of this shock. It can do so without loading up on productivity risk by borrowing more in dollar bonds to hold Foreign bonds. In contrast, as Home gets more risk tolerant than Foreign, it will provide insurance against *both* negative productivity shocks and positive safety shocks.<sup>13</sup> It does so by holding more capital and borrowing more in dollar bonds. It is in this sense that greater risk tolerance is necessary to explain why the United States takes a disproportionate exposure to equity returns.

The risk premium on Foreign bonds versus dollar bonds reflects these risk factors and country-level portfolios. As our final analytical result makes clear, the presence of safety shocks has a crucial effect on the sign of the risk premium.

**PROPOSITION 5:** *Consider the same environment as in Proposition 4 and suppose safety and productivity shocks are independent. Then at least around the case with symmetric country portfolios,*

- $\text{cov}_t(-\hat{m}_{t,t+1}, \hat{r}_{t+1}^* - \Delta \hat{q}_{t+1} - \hat{r}_{t+1}) \propto \gamma - \gamma^*$  if  $\sigma^\omega = 0$ , and
- $\text{cov}_t(-\hat{m}_{t,t+1}, \hat{r}_{t+1}^* - \Delta \hat{q}_{t+1} - \hat{r}_{t+1})$  is rising in  $\sigma^\omega$ .

*This result holds as well for the pricing kernel of a Foreign household.*

The first part of this result indicates that, absent safety shocks, Foreign bonds would earn a negative risk premium versus dollar bonds if Home is more risk tolerant than Foreign. This is because the dollar would appreciate in “good” times, when productivity is high, US wealth rises (as it is levered in capital), and thus, US consumption rises. This indicates that the “reserve currency paradox” characterized in Maggiori (2017) is robust to endogenous production and nominal rigidities. The second part of this result indicates that safety shocks can provide a resolution to this paradox. Because safety shocks instead imply that the dollar appreciates in “bad” times, when safe asset demand is high and global employment declines, sufficiently volatile safety shocks imply that Foreign bonds instead earn a positive risk premium.

We finally emphasize where safety shocks and cross-country heterogeneity in risk tolerance interact in our results. The propagation of safety shocks to output and asset prices in Propositions 1 and 2 holds even in the absence of differences in risk tolerance. As a result, the variance of safety shocks raises the ex ante risk premium on Foreign bonds versus dollar bonds in Proposition 5 even in the absence of differences in risk tolerance. Where these model ingredients interact is in the determination of international portfolios and the associated valuation effects. In particular, because safety shocks induce a negative beta of dollar bonds, the United States borrows more in dollar bonds as it grows more risk tolerant as a means to insure the rest of the world (Proposition 4). This in turn implies a larger loss in wealth upon a flight to safety (Proposition 3). In the absence of safety shocks, the United States would still be levered in capital as the more risk-tolerant investor, but there would be no reason to finance this portfolio in dollar bonds as opposed to Foreign bonds. In the absence of differences in risk aversion, the United States would remain the natural

<sup>13</sup>The latter result relies on a positive labor wedge in steady state: only in this case will risk-tolerant agents insure risk-averse agents against states of the world in which labor falls.

insurer of safety shocks owing to the seigniorage it earns, but its wealth share and net foreign assets would not fall upon these shocks because the seigniorage gains would offset the losses on its Foreign bond portfolio, and it would not take a levered position in global capital.

#### *D. The Specialness of Safe Dollar Bonds*

Extensions of the model clarify several dimensions in which the demand for safe dollar bonds may be particularly special relative to the demand for other assets.

*Zero Net Supply.*—The demand for safe dollar bonds triggers a Keynesian recession because these assets are in zero net supply. If agents' demand for capital instead increases—formally, capital also enters into utility, and its nonpecuniary value increases on the margin—this would induce an increase in the price of capital, a rise in household wealth, and thus an increase in consumption demand and aggregate output. Relaxing the assumption of a fixed global capital stock, the demand for capital would also stimulate output via increased investment. This underscores the importance of distinguishing between dollar convenience yields in bond versus equity markets, as in the work of Koijen and Yogo (2020), to understand their macroeconomic effects.

*Country Size.*—The large size of the US economy renders the demand for safe dollar bonds particularly special vis-à-vis the demand for bonds of other reserve issuers. In particular, consider augmenting the model with a third country that is an infinitesimal part of the global economy (for concreteness, Switzerland). An increase in the portfolio demand for Swiss franc bonds would generate an appreciation in its currency and decline in Swiss production but would have negligible spillovers on global demand and production. This echoes the message of Hassan (2013) that the United States' relative size in the global economy may be an important contributor to the dollar's negative beta.

*Currency of Invoicing.*—The widespread use of the dollar in pricing further renders the demand for safe dollar bonds particularly special vis-à-vis the currencies of other large countries. For instance, suppose nominal wages even in Foreign are denominated and sticky in dollars. Then the global decline in employment following a positive safety shock is exacerbated relative to the baseline model. Intuitively, the dollar deflation now implies that product wages in both countries are too high, generating a more severe and uniform global recession. Similar results are obtained when we assume dollar pricing of exports as in Gopinath (2015); Gopinath et al. (2020); and Mukhin (2022). Indeed, dollar pricing in trade flows among countries not involving the United States is analogous to an internal price in Foreign (such as the nominal wage) being denominated in dollars in our two-country setup. Our model thus suggests potentially rich interactions between the dollar's role in financial and goods markets.

#### *E. Discussion of Key Model Features*

We finally provide additional discussion of the role of several model features in shaping the effects of safety shocks, greater risk tolerance at Home, and their interaction.

*Efficient Risk Sharing and the Law of One Price.*—Our results imply that the dollar appreciation in bad times is induced by a shock (a safety shock) that reduces output more in Home than Foreign.<sup>14</sup> Here, we demonstrate that this result is a natural consequence of efficient risk sharing and the law of one price.

Consider in particular the  $\gamma = \gamma^* = 1$  case, which is convenient to make preferences time separable recalling our maintained assumption in this section of unitary elasticities of intertemporal substitution. Then efficient risk sharing requires

$$\hat{c}_t^* - \hat{c}_t = \hat{q}_t,$$

assuming no shocks prior to period  $t$  for simplicity. Intratemporal optimality between Home- and Foreign-produced goods in each country, together with goods market clearing, requires

$$\varsigma \frac{1 + \zeta^*}{\zeta^*} (\hat{c}_t^* - \hat{c}_t) + \left(1 + \varsigma \frac{1 + \zeta^*}{\zeta^*}\right) \left(1 - \varsigma \frac{1 + \zeta^*}{\zeta^*}\right) \frac{1}{\varsigma \frac{1 + \zeta^*}{\zeta^*} \sigma} \hat{q}_t = \hat{y}_t^* - \hat{y}_t,$$

where we allow an arbitrary degree of home bias  $\varsigma$  to emphasize the generality of the result. Combining these implies

$$\hat{q}_t = \frac{1}{\varsigma \frac{1 + \zeta^*}{\zeta^*} + \left(1 + \varsigma \frac{1 + \zeta^*}{\zeta^*}\right) \left(1 - \varsigma \frac{1 + \zeta^*}{\zeta^*}\right) \frac{1}{\varsigma \frac{1 + \zeta^*}{\zeta^*} \sigma}} (\hat{y}_t^* - \hat{y}_t).$$

Thus, given consumption home bias  $\varsigma > 0$ , any shock that appreciates the Home real exchange rate must be reflected in a relative fall in Home output, both because efficient risk sharing calls for relative Home consumption to fall and because the associated appreciation of Home's terms of trade will lead to a global expenditure switch away from Home-produced goods. Relaxing the law of one price, as in the case of sticky local currency prices, can decouple the Home real exchange rate from the relative price of goods faced by consumers, eliminating the second effect. But the first will remain provided that risk sharing is efficient.

This result helps to relate our paper to others in the literature. Sauzé (2023) demonstrates that a fall in relative US output in crises can resolve the reserve currency paradox precisely following the logic above. Our paper identifies a shock in a production economy that will have this feature, namely the flight to safe dollar assets. Maggiore (2017) proposes instead to resolve the paradox by considering an expenditure shift toward US goods in crises. This introduces a shock in the second equation above, implying that the dollar can appreciate in crises even if relative output is unchanged. Dahlquist et al. (2023) generate a dollar appreciation from a fall in US output as in Sauzé (2023) but augment the model with deep habits. This implies that the decline in US output also generates a relative demand shift toward US goods, further appreciating the dollar as in Maggiore (2017).

<sup>14</sup>We emphasize that this does not require that Home output is more volatile than Foreign output in an unconditional sense; indeed, in our quantitative analysis, Home output is less volatile.

The effect of safety shocks on relative output also has implications for the US wealth share. Proposition 4 focuses on the comparative statics of efficient portfolios with respect to heterogeneity in risk tolerance and US safe dollar debt issuance. But it is useful to also note that, in the benchmark with identical risk tolerance across countries, efficient risk sharing calls for the Home wealth share to increase upon a flight to safety provided risk aversion exceeds unity. This is a standard implication of the motive to hedge real exchange rate risk in response to relative supply shocks: when risk aversion exceeds unity, the domestic wealth share should rise in response to shocks that cause the local currency to appreciate.<sup>15</sup> Away from the limit of complete home bias and with a trade elasticity above one, the Home wealth share should also rise upon this shock to hedge the relative decline in Home labor income. Hence, if the United States is only slightly more risk tolerant than the rest of the world, it is ambiguous whether its wealth share will rise or fall upon a flight to safety. This relates to the mixed empirical findings in Dahlquist et al. (2023) and Sauzet (2023) regarding the US wealth share dynamics in 2008–2009. Our analysis clarifies that the sign of the wealth share response in the data cannot, on its own, validate or reject the hypothesis that the United States provides insurance to the rest of the world, to the extent that this period was characterized by relative supply shocks as induced by the flight to safety.

*Monetary Policy Response.*—Essential to the nonneutrality of safety shocks for macroeconomic quantities is that US monetary policy does not sufficiently respond to these shocks. This will be true not only for the conventional Taylor rule assumed in our paper but any monetary policy rule that does not respond with a unitary coefficient on the safety shock itself. Of course, ignoring the seigniorage effects of safety shocks and assuming that the flexible wage allocation is efficient (as in the absence of steady-state markups), the globally optimal response of US monetary policy in our model would be to fully neutralize the effects of safety shocks.

Our focus on conventional Taylor rules rather than optimal monetary policy follows in the tradition of business cycle models seeking to describe the conduct of actual monetary policy, particularly among the US and G10 currency countries, which are our focus. We note that our analysis is particularly consistent with the large New Keynesian literature studying risk premium shocks,<sup>16</sup> in which the important role of risk premium fluctuations in business cycle dynamics owes to an inadequate response of monetary policy to track the natural rate.

*Capital Mobility and Relative Capital Returns.*—Our model assumes for computational simplicity that capital can be deployed in either country, implying that the returns to capital used in Home and Foreign are equated at all dates and states.

<sup>15</sup>The intuition is easiest to see in the case with CRRA preferences with risk aversion  $\gamma$ , in which case efficient risk sharing requires  $\gamma(\hat{c}_t^* - \hat{c}_t) = \hat{q}_t$ , again assuming no shocks prior to  $t$  for simplicity. It follows that  $\hat{c}_t + \hat{q}_t - \hat{c}_t^* = (1 - 1/\gamma)\hat{q}_t$ . Thus, if  $\gamma > 1$ , relative US expenditures must rise when the dollar appreciates. Online Appendix B demonstrates that the same conclusion holds for the US wealth share (which is closely related to relative US expenditures) under Epstein-Zin preferences with a unitary intertemporal elasticity of substitution.

<sup>16</sup>This is both true of models introducing such shocks as ad hoc wedges, as in Smets and Wouters (2007), as well as those tracing them to underlying changes in the price or quantity of risk, as in Ilut and Schneider (2014); Fernandez-Villaverde et al. (2015); Basu and Bundick (2017); Caballero and Simsek (2020); and Kekre and Lenel (2022).

With sticky wages, having distinct capital stocks at Home and Foreign turns out not to matter for our results. Consider for concreteness the case with symmetric portfolios at Home and Foreign, as assumed in Propositions 1–3. Then the returns to capital at Home and Foreign are still equated in response to safety shocks; in other words, capital would not be reallocated across borders even if it could. Intuitively, any increase in Foreign output relative to Home output induces an appreciation of the Home real exchange rate, which fully offsets the increase in the Foreign return to capital. This sharp result is no longer obtained away from the limit of complete home bias (provided the trade elasticity  $\sigma \neq 1$ ), but it illustrates that our assumptions on capital mobility are not crucial for our results. With sticky prices, we can obtain richer results with distinct capital stocks at Home and Foreign.<sup>17</sup> Most results, such as the propagation of safety shocks to macroeconomic quantities, remain unchanged. But now, a positive safety shock raises the return to Home capital relative to Foreign capital. This is because a positive safety shock induces a rise in Home markups under sticky prices. This can help to account for the rise in relative US equity returns in crises documented in Dahlquist et al. (2023).

*Global Demand for Safe Dollar Bonds.*—We finally comment on the assumption that the demand for safe dollar bonds enters symmetrically for Home and Foreign households. Up to seigniorage effects, this assumption does not affect the propagation of safety shocks as well as the *ex ante* implications for risk premia or portfolios.

Concretely, suppose only Foreign households receive utility from safe dollar bonds, and we augment the model with the (realistic and now relevant) constraint that Home households cannot short safe dollar bonds.<sup>18</sup> In equilibrium, Home households will be at the corner of holding zero safe dollar bonds, and the equilibrium convenience yield in (17) will now reflect only the marginal valuation of Foreign households (and still the supply of these bonds by the Home government). Considering for concreteness the case with  $b_{H,s}^g = 0$  so that we can abstract from seigniorage, an increase in Foreign demand for safe dollar bonds propagates exactly like a safety shock in our baseline model. Intuitively, at unchanged interest rates and prices, Foreigners would seek to borrow in non-safe dollar bonds to hold safe dollar bonds, allowing them to capture the convenience benefits of safe dollar bonds without changing their currency risk exposure. This would induce an increase in the interest rate  $\iota_t$  in the absence of a decline in the policy rate  $i_t$ , making saving more attractive for Home households and inducing the same effects on quantities and relative prices as in the baseline model.<sup>19</sup>

<sup>17</sup> See online Appendix B for a full description of this environment and formal statements of these results.

<sup>18</sup> See online Appendix B for formal statements of the results that follow.

<sup>19</sup> It is useful to relate this discussion to the finding in Eichenbaum, Johannsen, and Rebelo (2021) that shocks to the foreign demand for dollar-denominated bonds can generate fluctuations in exchange rates disconnected from aggregates. This reflects the absence of a distinction between safe and other dollar-denominated bonds in their analysis. If they modeled shocks to the foreign demand for safe dollar bonds in particular, these shocks would affect output as described here.

### III. Parameterization

In the rest of the paper, we return to the full model and quantify the effects of safety shocks and heterogeneity in risk-bearing capacity in the global economy. In this section, we parameterize the model. We associate Home with the United States and Foreign with the G10 currency countries.<sup>20</sup> A period is one quarter.

#### A. Data Sources

Unless otherwise noted, we use data over 1995–2019, and we estimate moments for Foreign using a simple average of moments for each of the G10 currency countries.

In terms of business cycle moments, interest rates, and equity prices, we use Bureau of Economic Analysis, Bureau of Labor Statistics, and OECD data on consumption, investment, real GDP, and the working-age population to estimate quarterly per capita growth rates in those series.<sup>21</sup> We use industrial production data from the Federal Reserve Board and OECD.<sup>22</sup> We use three-month government bond yields from Bloomberg and the Center for Research in Security Prices as measures of nominal interest rates.<sup>23</sup> We use the MSCI ACWI as our measure of the equity claim.<sup>24</sup>

In terms of exchange rates, wealth, and portfolios, we use end-of-month nominal exchange rates vis-à-vis the dollar from the Federal Reserve Board,<sup>25</sup> and we construct end-of-month real exchange rates using these data and the consumer price indexes from the OECD.<sup>26</sup> We measure net foreign assets using the Bureau of Economic Analysis International Investment Position (BEA IIP).<sup>27</sup> Foreign-owned Treasury bills and central bank liquidity swap line usage are reported by the Treasury International Capital (TIC) System and Federal Reserve Board, respectively.<sup>28</sup>

#### B. Externally Set Parameters

A subset of model parameters summarized in Table 1 are first set externally.

Among the model's preference parameters, we set  $\psi$  to 0.75, consistent with evidence on the consumption responses to changes in interest rates as well as

<sup>20</sup>These countries are Australia, Canada, Denmark, Germany, Japan, New Zealand, Norway, Sweden, Switzerland, and the United Kingdom, following common convention. Emerging markets differ from these advanced economies in their conduct of monetary policy (Calvo and Reinhart 2002) and in the nature of shocks affecting these economies (Aguiar and Gopinath 2007). We leave to future work a three-country extension exploring the transmission of safety shocks and international risk sharing between the United States, other advanced economies, and emerging markets.

<sup>21</sup>The sources are US Bureau of Economic Analysis (n.d.b,c); US Bureau of Labor Statistics (n.d.b); and OECD (n.d.a,d,e).

<sup>22</sup>The sources are Board of Governors of the Federal Reserve System (n.d.d) and OECD (n.d.c).

<sup>23</sup>The sources are Center for Research in Security Prices (n.d.a,b), and we use the consumer price index for all urban consumers from US Bureau of Labor Statistics (n.d.a) to construct real interest rates.

<sup>24</sup>The sources are Bloomberg (n.d.a).

<sup>25</sup>The source is Board of Governors of the Federal Reserve System (n.d.c).

<sup>26</sup>The source for consumer price indexes is OECD (n.d.b).

<sup>27</sup>The sources are US Bureau of Economic Analysis (n.d.a,d).

<sup>28</sup>The sources are Treasury International Capital Reporting System (n.d.) and Board of Governors of the Federal Reserve System (n.d.b).

TABLE 1—EXTERNALLY SET PARAMETERS

	Description	Value	Notes
$\psi$	IES	0.75	
$\sigma$	Trade elasticity	1.5	Backus, Kehoe, and Kydland (1994)
$\varsigma$	Home bias	0.4	Eaton, Kortum, and Neiman (2016)
$\nu$	Frisch elasticity	0.75	Chetty et al. (2011)
$\alpha$	1-labor share	0.33	
$\delta$	Depreciation rate	0.025	
$\epsilon$	Elast. of subs. across workers	20	
$\chi^W$	Rotemberg wage adj. costs	400	$\approx \text{Pr}(\text{adjust}) = 5 \text{ qtrs}$
$\phi$	Taylor coeff. on inflation	1.5	Taylor (1993)
$\varphi$	Disaster shock	-0.10	Nakamura et al. (2013)
$p$	Disaster risk	0.4%	$\mathbb{E}[p] = 0.5\%$ (Barro 2006)
$\rho^p$	Dis. risk persistence	0.75	$\rho(p) = 0.7$
$\sigma^p$	Dis. risk std. dev.	0.55	$\sigma(p)/\mathbb{E}[p] = 1$
$\omega^d$	Safety skewness	0.002	$skew(\omega) = 6.1$
$\rho^\omega$	Safety persistence	0.4	$\rho(\omega) = 0.3$
$\rho^{p\omega}$	Corr. safety, disaster	0.5	$\rho(p, \omega) = 0.4$

consumption-labor complementarity. We set  $\sigma = 1.5$ , consistent with the trade elasticity estimated by Backus, Kehoe, and Kydland (1994) and widely used in the literature. We set a home bias parameter of  $\varsigma = 0.4$  so that (given our calibration of  $\zeta^*$  described in the next subsection) the expenditure share on domestically produced goods is 80 percent at Home, consistent with the US evidence in Eaton, Kortum, and Neiman (2016). The Frisch elasticity of labor supply is set to  $\nu = 0.75$ , consistent with the micro evidence for aggregate hours surveyed in Chetty et al. (2011).

Among the model's technology and policy parameters, we choose  $\alpha = 0.33$  for the capital share of production and a quarterly depreciation rate of 2.5 percent, standard values in the literature. We choose an elasticity of substitution across worker varieties  $\epsilon = 20$  and, absent compelling evidence on heterogeneity in wage stickiness across countries, Rotemberg wage adjustment costs in each country of  $\chi^W = \chi^{W^*} = 400$ . Together, these imply a Calvo (1983)-equivalent frequency of wage adjustment around five quarters, consistent with the US evidence in Grigsby, Hurst, and Yildirmaz (2021). We assume a standard Taylor coefficient on inflation in each country of 1.5.

Finally, in terms of driving forces, we set  $p$  so that the average quarterly global disaster probability is 0.5 percent and the depth of the disaster to  $\varphi = -10\%$ , consistent with Barro (2006) and Nakamura et al. (2013). The quarterly autocorrelation of the log probability is 0.75, and the standard deviation of shocks is  $\sigma^p = 0.55$ , consistent with the autocorrelation and standard deviation of the probability in levels in Barro and Liao (2021).

Following (14), the convenience yield is given by the spread between safe and other dollar bonds. One natural measure is the spread between three-month Treasury bills and three-month AA commercial paper. Another is the spread between three-month Treasury bills and three-month government bonds in the G10 currencies swapped

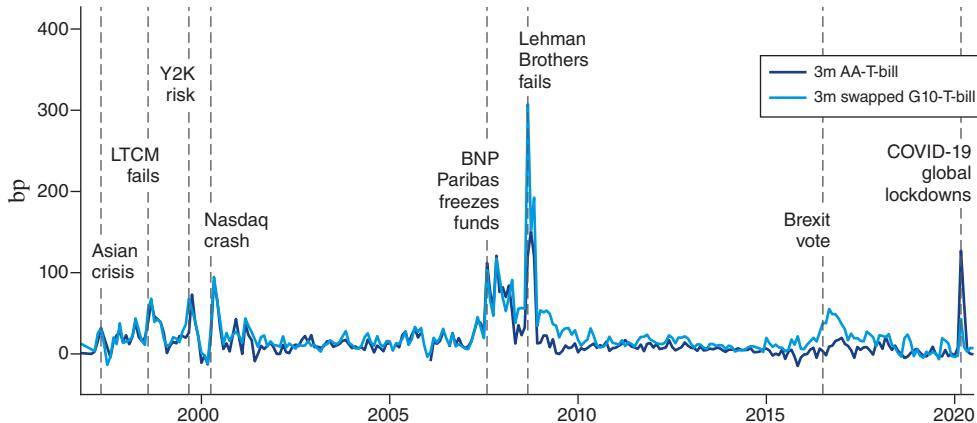


FIGURE 1. ANNUALIZED SPREADS VERSUS US TREASURIES

Note: AA yield is from Board of Governors of the Federal Reserve System (n.d.a), and swapped G10 yield is from Du, Im, and Schreger (2018).

into dollars, as constructed by Du, Im, and Schreger (2018).<sup>29,30</sup> As is evident in Figure 1, both series comove and spike in times of market turmoil. We calibrate the stochastic properties of  $\omega_t^d$  to match the swapped G10/T-bill spread given our global focus.<sup>31</sup> We set  $\omega^d = 0.002$  to match the skewness of 6.1,  $\rho^\omega = 0.4$  to match the autocorrelation (in levels) of 0.3, and  $\rho^{p\omega} = 0.5$  to match the correlation with the Barro and Liao (2021) series. We calibrate  $\sigma^\omega$  in the next subsection to match the conditional correlation between equity returns and excess foreign bond returns; following Jiang, Krishnamurthy, and Lustig (2021), the standard deviation of the swapped G10/T-bill spread understates the volatility of  $\omega$  if swapped G10 bonds are also partially valued for their liquidity or safety. The conditional correlation between equity and excess foreign bond returns disciplines the magnitude of safety shocks because these shocks, unlike others in the model, imply that the dollar appreciates when equity returns fall on impact.

### C. Calibrated Parameters

We calibrate the remaining model parameters to match evidence on the business cycle, asset prices, and cross-border wealth and portfolios. Table 2 reports the moment in model and data that each parameter is most closely linked to.

In terms of output and the business cycle, the population in Foreign is set to 1.6 to match the fact that the G10 plus other euro area countries' GDP was on average 1.6

<sup>29</sup> We refrain from calling this a deviation from covered interest parity (CIP) because private agents cannot borrow at the US Treasury bill rate and, relatedly, this spread is distinct from Libor-based CIP deviations, which exhibited a structural break in 2008 (see Du, Tepper, and Verdelhan 2018).

<sup>30</sup> We use an updated series through 2020 and thank Wenxin Du for sharing it with us.

<sup>31</sup> We assume that variation in the convenience yield arises solely from changes in safe asset demand (except in Section VD), while in the data it may also arise from shocks to supply. This source of misspecification would have minimal effects on our quantitative results: all that matters is that the equilibrium  $\omega_t$  is consistent with the observed properties of the convenience yield.

TABLE 2—TARGETED MOMENTS AND CALIBRATED PARAMETERS

	Description	Value	Moment	Target	Model
$\zeta^*$	Rel. pop.	1.6	$y^*/(sy)$	1.6	1.6
$\sigma^z$	Std. dev. prod.	0.002	$\sigma(\Delta \log c)$	0.5%	0.5%
$\sigma^F$	Std. dev. rel. prod.	0.005	$\sigma(\Delta \log y^*)$	0.8%	0.8%
$\rho^F$	Persist. rel. prod.	0.9	$\rho(y^*/y, y_{-4}/y_{-4})$	0.6	0.5
$\chi^x$	Capital adj. cost	3	$\sigma(\Delta \log x)$	1.6%	1.6%
$\beta^*$	Disc. fac. Foreign	0.9892	$4r$	2.0%	2.0%
$\beta$	Disc. fac. Home	0.9887	$nfa/(4y)$	-23%	-23%
$\sigma^\omega$	Std. dev. safety	0.91	$\rho_{-1}(r^e, r^* + \Delta \log q - r)$	0.5	0.5
$\gamma^*$	RRA Foreign	24	$4(r^e - r)$	5.1%	5.2%
$\gamma$	RRA Home	21	$\beta((\Delta nfa)/y, r^e - r)$	0.5	0.6
$\bar{b}^g$	Safe debt/agg. cons.	0.13	$b_{H,S}^*/(4y)$	3.8%	3.8%
$\bar{\nu}$	$\ell$ disutility	0.73	$\ell$	1	1.0
$\bar{\nu}^*$	$\ell^*$ disutility	0.71	$\ell^*$	1	1.0
$\bar{i}$	Taylor intercept Home	0.49%	$\log P/P_{-1}$	0%	0.0%
$\bar{i}^*$	Taylor intercept Foreign	0.47%	$\log P^*/P_{-1}^*$	0%	0.0%

Notes: Second moments are reported over quarterly frequency. Data moments are estimated over 1995:I–2019:IV. Model moments are computed by (i) simulating model for 20,000 quarters and discarding first 10,000 quarters; (ii) drawing 100 starting points from remaining 10,000 quarters; (iii) simulating 100 samples beginning from these starting points, with no disaster realizations in sample; (iv) computing moments for each sample and averaging across samples.

times that of the United States over the sample period.<sup>32</sup> The standard deviation of global productivity shocks is set to 0.2 percent to target US quarterly consumption growth volatility of 0.5 percent. The capital adjustment cost is set to 3 to match US investment growth volatility of 1.6 percent. The standard deviation of relative productivity shocks is set to 0.5 percent to match the average output growth volatility of the G10 countries of 0.8 percent. The autocorrelation is set to 0.9 to match the average year-over-year autocorrelation of G10 countries' GDP relative to US GDP, linearly detrended, of 0.6.

In terms of asset prices, wealth, and portfolios, Foreign households' discount factor is set to 0.9892 to target a 2 percent annualized real interest rate,<sup>33</sup> and Home households' discount factor is very slightly lower at 0.9887 to target the United States' average net foreign asset position relative to annual GDP of -23 percent over 1995–2019.<sup>34</sup> The volatility of safety shocks is set to match the conditional correlation of the MSCI ACWI equity return and excess foreign bond return of

<sup>32</sup> The other euro area countries included besides Germany are Austria, Belgium, Spain, Finland, France, Greece, Ireland, Italy, Luxembourg, Netherlands, and Portugal. We use the annual GDP measures in dollars reported by Lane and Milesi-Ferretti (2018).

<sup>33</sup> Throughout the rest of the paper, we work with log returns in both data and model, though in a slight abuse of notation, we continue to write these as  $r_i$ ,  $r_i^e$ , and so on.

<sup>34</sup> To ensure the ergodic wealth distribution is well centered and does not require an excessively large grid, we further assume that the discount factors are a shallow function of Home's wealth share ( $\beta_t = \beta - 0.001(\theta_t - \theta)$  and  $\beta_t^* = \beta^* + 0.001(\theta_t - \theta)$ ) not internalized by agents in their optimization.

0.5.<sup>35,36</sup> The resulting parameter implies that  $\omega_t$  has a quarterly standard deviation of 0.4 percent in levels. Foreign households have risk aversion of 24 to target the excess annualized real returns on the MSCI ACWI index of 5.1 percent over this period. Home households have risk aversion of 21 to target the 0.5pp by which US net foreign assets to GDP rises when excess equity returns rise by 1pp.<sup>37</sup> That is, Home agents must be more risk tolerant than Foreign to match the United States' levered position in capital, consistent with Proposition 4. Finally,  $\bar{b}^g$  is set so that the level of safe dollar debt owned by Foreign (given by (16)) is 3.8 percent of annual Home output. This is the average ratio of foreign-owned Treasury bills plus central bank liquidity swaps relative to annual US GDP over 2003–2019.

Lastly, we set agents' disutility of labor  $\bar{v}$  and  $\bar{v}^*$  to target average labor supply of one in each country, and the Taylor rule intercepts  $\bar{i}$  and  $\bar{i}^*$  to target average inflation rates of zero in each country, convenient normalizations.

#### IV. Impulse Responses and Validation

We now summarize the model's key impulse responses and demonstrate that it matches a number of untargeted comovements between excess foreign bond returns, excess equity returns, output, and US net foreign assets in the data.

##### A. Impulse Responses to Disaster Risk Shock

We begin by evaluating the responses to a disaster probability shock to provide a benchmark against which to compare the effects of safety shocks.

Figure 2 summarizes a subset of the impulse responses; a full set of responses is provided in online Appendix C. As demonstrated in the second panel of the top row, realized excess equity returns are negative on impact and then high in the quarters that follow, reflecting a decline in the price of capital on impact and an increase in the risk premium. Because Home agents are more risk tolerant than in Foreign, on aggregate they hold a levered portfolio in capital. The dynamics of excess equity returns thus lower Home's wealth share initially but then lead to an increase over time, as shown in the second panel of the bottom row. With home bias in consumption, these same dynamics are reflected in relative consumption demand for Home goods and thus the Home real exchange rate in the first panel of the bottom row. In the third panel of the top row, the realized excess return on Foreign bonds is thus positive on impact, while it is negative in the subsequent months: since a disaster would similarly induce a positive excess return on Foreign bonds, the risk premium

<sup>35</sup>This conditional correlation is closely related to risk premium on foreign bonds versus dollar bonds. We prefer to match it rather than the average realized excess return because the latter is highly sensitive to the time period used, given the large volatility of realized excess returns. As further described in online Appendix D, we estimate the conditional correlation following Maggiori (2013).

<sup>36</sup>The model counterpart to the real MSCI ACWI return,  $r^e$ , is the real return on a levered claim on capital with a debt/equity ratio of 0.5, and where the debt is comprised of a fraction  $1/(1 + \zeta^*)$  5-year dollar bonds and  $\zeta^*/(1 + \zeta^*)$  5-year Foreign bonds. The five-year duration of debt is consistent with maturity of outstanding US and European corporate debt in S&P Global (2021). We price a 5-year bond in each currency, even though such assets are not traded, by defining the price at each point in the state space to be what the highest-valuation agent would be willing to pay.

<sup>37</sup>In this regression, we also condition on the contemporaneous excess foreign bond return so that we can isolate the marginal exposure to equity returns.

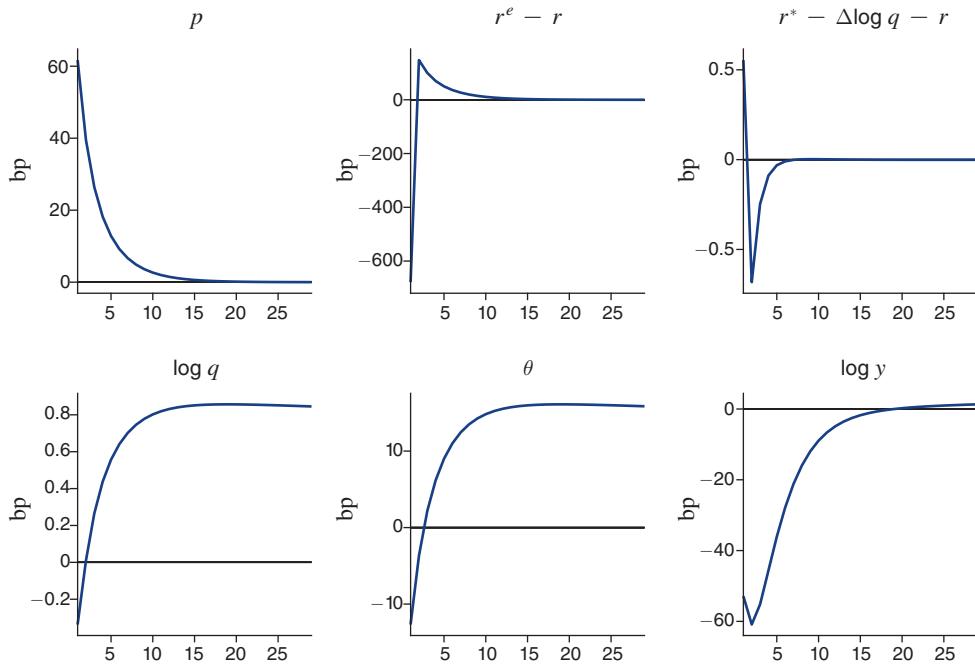


FIGURE 2. EFFECTS OF INCREASE IN DISASTER PROBABILITY

Note: Impulse responses are average responses starting from 100 points drawn from ergodic distribution, as described in the notes to Table 2.

on Foreign bonds falls when disaster risk is elevated. On the production side, as demonstrated in the third panel of the bottom row of Figure 2, Home output falls (as it does in Foreign, not shown) because the increase in precautionary savings is not met with a sufficient decline in real interest rates. Taken together, the disaster probability shock implies that excess foreign bond returns comove *negatively* with output, equity returns, and US wealth.

These dynamics extend Maggiori's (2017) "reserve currency paradox" to a setting with endogenous production and nominal frictions: as in his endowment economy, in the presence of home bias, the relatively risk-tolerant country's currency must depreciate in bad times because equilibrium risk sharing implies that its consumption must disproportionately fall. In online Appendix C we demonstrate that this holds not just for disaster risk but also global and Foreign productivity shocks.

### B. Impulse Responses to Safety Shock

We now turn to the impulse responses to a safety shock.

Figure 3 summarizes a subset of impulse responses in the calibrated model as well as two alternative parameterizations that help to isolate the role of nominal rigidity and heterogeneity in risk-bearing capacity; a full set of impulse responses is again provided in online Appendix C. When there are no nominal frictions and no heterogeneity in risk tolerance across countries (the light blue responses), the

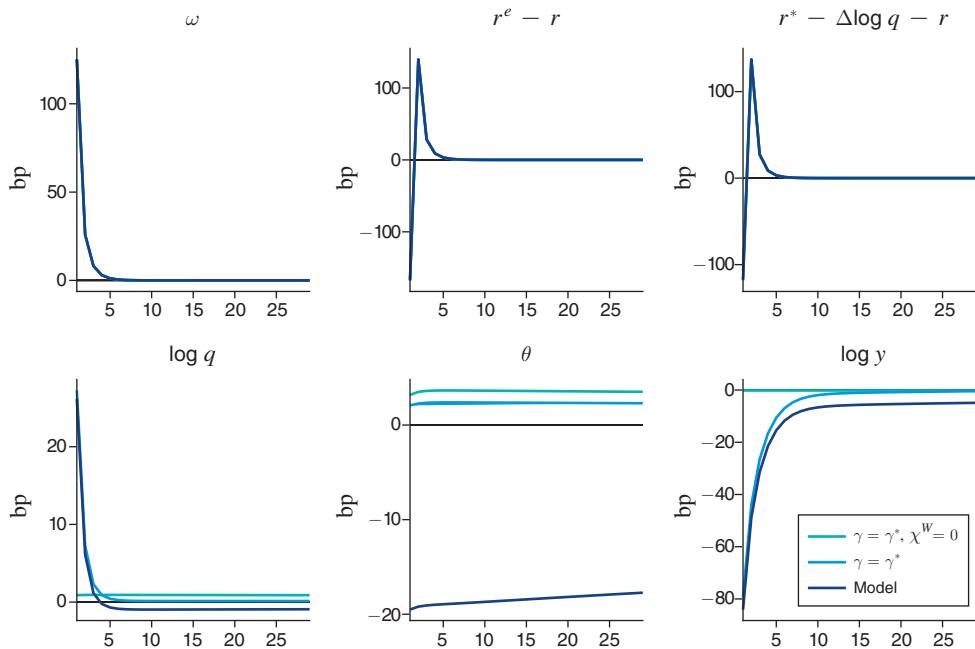


FIGURE 3. EFFECTS OF INCREASE IN SAFETY

*Note:* Impulse responses are average responses starting from 100 points drawn from ergodic distribution, as described in the notes to Table 2.

expected real interest rate at Home simply falls to accommodate the increase in safe asset demand, consistent with Proposition 1.<sup>38</sup> This is achieved by an immediate Home deflation and resulting negative excess equity and Foreign bond return on impact. Since Home is actually long dollar bonds and short Foreign bonds in this case—which hedges the relative labor income and real exchange rate effects of Foreign productivity shocks—it experiences an increase in wealth. This implies a persistent but mild real appreciation of the dollar due to home bias in consumption. Next, we introduce nominal rigidity (the medium blue responses), in which case the deflationary pressure underlies a global recession, more severe at Home than Foreign (not shown for brevity), as in Proposition 1. Indeed, the relative decline in Home output is what rationalizes a more dramatic immediate appreciation in Home's terms of trade and real exchange rate, which absorbs the safety shock when the response of real interest rates is muted due to nominal rigidity.<sup>39</sup> With identical risk tolerance, however, the implied patterns in excess returns have only small effects on Home wealth (and thus net foreign assets). With greater risk tolerance at Home (the dark

<sup>38</sup>In this figure and all subsequent tables, we also set  $\beta = \beta^*$  whenever we set  $\gamma = \gamma^*$ . Since the latter is crucial for the economics, whereas the former is not, we simply use the label  $\gamma = \gamma^*$ .

<sup>39</sup>Consistent with the discussion in Section II E, these responses to safety shocks are robust to two generalizations of the monetary policy rule (10) in online Appendix C: we allow the nominal rate in each country to respond to domestic output, and we consider inertia in the nominal rate. The first modification slightly dampens the exchange rate and output effects of safety shocks, while the second amplifies the effects on impact. The overall responses remain comparable to the baseline policy rule.

blue responses), the response of Home's wealth share (and net foreign assets) flips. Home now takes a levered position in capital and Foreign bonds financed by dollar bonds, so it suffers a valuation loss followed by wealth accumulation over time, as in Proposition 3.

Safety shocks thus provide a resolution to the reserve currency paradox: following a safety shock, excess foreign bond returns are high, as excess equity returns are high, output rises, and US wealth and thus net foreign assets rise. In online Appendix D we estimate the effects of a shock to the swapped G10/T-bill spread in the data, finding effects that are consistent with these responses.

### *C. Comovements in the International Monetary System*

The previous subsections demonstrated that safety shocks as well as greater risk tolerance in the United States generate a distinctive set of international comovements. We now demonstrate that, quantitatively, the model matches these in the data.

Table 3 summarizes the key moments. We first report these in the data, computed over our maintained sample but which are all consistent with existing findings in the literature. A 1pp year-over-year decline in US industrial production forecasts a 0.2pp higher quarterly excess return on foreign bonds, consistent with the evidence in Lustig, Roussanov, and Verdelhan (2014); a 1pp higher equity return is associated with a contemporaneous 0.2pp higher excess return on foreign bonds, consistent with the evidence in Lilley et al. (2022); and a 1pp higher excess return on foreign bonds is associated with a 1.4pp rise in US net foreign assets to GDP, consistent with the dollar exposure of the United States estimated by Tille (2003) and Gourinchas and Rey (2007a).<sup>40</sup> These patterns imply that dollar bonds are a hedge and the United States insures the rest of the world by being short the dollar. In model-generated data, these same coefficients are 0.1pp, 0.1pp, and 1.5pp, respectively.

Safety shocks are essential for the model's success in each dimension. The third column of Table 3 eliminates safety shocks from the model. In this case, excess Foreign bond returns are essentially unpredictable by output, and the reserve currency paradox implies that excess Foreign bond returns are high when equity returns are low. Moreover, Home net foreign assets comove negatively with excess Foreign bond returns. This is because, as is evident from the bottom panel of Table 3, the desire to hedge the relative labor income and real exchange rate risk induced by relative productivity shocks induces Home to go long dollar bonds financed by Foreign bonds.

Heterogeneity in risk tolerance is also quantitatively important for the last moment. The fourth column of Table 3 assumes identical risk tolerance across countries. Relative to the baseline model, there would be substantially less trade in assets across countries, evident again from the bottom panel. Home's net foreign assets

<sup>40</sup> Consistent with footnote 37, in this regression we also condition on the contemporaneous excess equity return so that we can isolate the marginal exposure to relative bond returns.

TABLE 3—COMOVEMENTS IN THE INTERNATIONAL MONETARY SYSTEM

	Data	Model	No $\omega$	$\gamma = \gamma^*$
$\beta(r_{t+1}^* - \Delta \log q_{t+1} - r_{t+1}, \log y_t - \log y_{t-4})$	-0.17 (0.11)	-0.11	0.00	-0.11
$\beta(r_{t+1}^* - \Delta \log q_{t+1} - r_{t+1}, r_{t+1}^e)$	0.23 (0.04)	0.06	-0.00	0.06
$\beta((\Delta nfa_{t+1})/y_t, r_{t+1}^* - \Delta \log q_{t+1} - r_{t+1})$	1.38 (0.30)	1.45	-3.39	0.25
<i>Memo:</i> $(k - \kappa)/(4y)$		60%	50%	0%
$b_H/(4y)$		-103%	151%	14%
$b_F/(4y)$		20%	-225%	-16%

*Notes:* Data moments estimated over 1995–2019. Standard errors are given in parentheses. First two rows use monthly data and thus Hansen and Hodrick (1980) standard errors with four lags to correct for overlapping observations. Model moments are computed as described in the notes to Table 2.

in this case comove positively with excess Foreign bond returns, but not enough to match the degree of comovement observed in the data.<sup>41</sup>

The fact that safety shocks alone are important for the first two moments, while their interaction with heterogeneity in risk tolerance is important for the last moment, is consistent with our analytical results in Section II. In particular, safety shocks alone imply that the dollar has a negative beta, but it is the interaction with heterogeneity in risk tolerance that shapes international portfolios and in particular means that the US net foreign assets deteriorate when excess Foreign bond returns fall.

Online Appendix C provides a decomposition of the role of individual model parameters beyond  $\sigma^\omega$  and  $\gamma$  in determining international portfolios and the currency risk premium. Consistent with Proposition 4, the safe dollar debt issued by the Home government  $\bar{b}^g$  pushes up the average Foreign bond holdings of Home since seigniorage revenues can offset the carry trade losses upon a safety shock. However, because the supply of Treasury bills relative to aggregate wealth is relatively small in the data, we find this channel to be modest. By contrast, the correlation between safety shocks and disaster risk  $\rho^{p\omega}$  is quantitatively quite important in accounting for the currency composition of the US external balance sheet and positive risk premium on Foreign bonds. It raises the risk premium because it makes a decline in excess Foreign bond returns more likely when disaster risk is elevated and thus global marginal utility is high. It also induces the United States as the relatively risk-tolerant investor to take a leveraged position in Foreign bonds to insure Foreign against such states of the world.

<sup>41</sup>The positive comovement reflects the decoupling of net foreign assets and wealth shares in response to relative productivity shocks given identical risk tolerance. A decline in Foreign productivity raises excess Foreign bond returns and raises Home's net foreign assets as it lends to Foreign so that the latter can smooth consumption intertemporally. This obtains even though Home's wealth share falls because it is long dollar bonds financed by Foreign bonds.

TABLE 4—ADDITIONAL SECOND MOMENTS

	Data	Model	No $\omega$	$\gamma = \gamma^*$
$\sigma(4r_{t+1})$	2.9%	4.1%	2.1%	4.1%
$\sigma(4[r_{t+1}^e - r_{t+1}])$	33.6%	17.2%	11.2%	17.5%
$\sigma(4[r_{t+1}^* - \Delta \log q_{t+1} - r_{t+1}])$	15.5%	1.9%	0.3%	1.9%
$\sigma(\Delta \log q_t)$	3.8%	0.3%	0.2%	0.3%
$\sigma(\Delta \log E_t)$	3.8%	0.4%	0.2%	0.4%
$\rho(\Delta \log q_t, \Delta \log c_t^* - \Delta \log c_t)$	0.1	0.9	0.9	1.0

Notes: Data moments are estimated over 1995:I–2019:IV. Standard errors are given in parentheses. Model moments are computed as described in the notes to Table 2.

#### D. Additional Untargeted Second Moments

The previous subsection focused on moments that speak directly to the role of the United States in the international monetary system. Here, we summarize additional moments of interest regarding returns and exchange rates.

The top panel of Table 4 demonstrates that the model successfully generates excess equity return volatility that is several times that of real interest rate volatility, which in turn is close to the data.<sup>42</sup> In contrast, the model substantially undershoots the volatility of excess foreign bond returns, which the middle panel demonstrates is because it undershoots the volatility of exchange rates. The bottom panel also demonstrates that the model does not resolve the “Backus and Smith (1993) puzzle,” the observation that the data feature a low correlation between real exchange rate movements and relative consumption growth, whereas efficient risk sharing in most models implies that this correlation is close to 1. Our model features recursive utility and markets that are not fully complete, but innovations in the real exchange rate remain tightly related to innovations in relative consumption.

Adding to the present framework a distinct set of asset demand shocks, pure shocks to the demand for bonds in different currencies as in Gabaix and Maggioli (2015) and Itsikhoki and Mukhin (2021), may be useful to resolve both shortcomings. Such shocks could induce additional exchange rate volatility disconnected from macroeconomic aggregates, pushing toward zero the correlation between real exchange rates and relative consumption. We leave it to future work to enrich our framework with these shocks, as the segmentation assumptions typically required to study them would substantially complicate the present analysis. But we note that, to the extent our model is missing such shocks generating disconnected fluctuations

<sup>42</sup>The remaining gap in excess equity return volatility between model and data could be closed if we assume a higher elasticity of intertemporal substitution (EIS) (above 1). This is the case in most other papers studying production economies with time-varying disaster risk, such as Gourio (2012). We prefer to keep the EIS below 1, both given microeconomic evidence and because an EIS above 1 breaks the comovement of consumption, investment, and output on impact of an increase in risk.

in exchange rates, this should not affect the macro-financial comovements that are our focus.<sup>43</sup>

## V. Macroeconomic and Policy Implications

Having used asset price data to validate the model's core comovements, we now quantify its macroeconomic and policy implications. Safety shocks are an important contributor to global macroeconomic volatility. Greater risk tolerance in the United States has both destabilizing and stabilizing effects on US external adjustment. Both of these features played important roles in the Great Recession. Dollar swap lines stimulate output globally and revalue wealth in the United States' favor by mitigating the flight to safety.

### A. Output Volatility

The model first implies that safety shocks are an important contributor to global macroeconomic volatility.

Table 5 summarizes the volatilities of Home and Foreign output. In both data and model, output volatility is higher in Foreign than Home. Comparing the third column with the second, the model implies that safety shocks account for more than 25 percent of the output volatility at Home and 5 percent of the volatility in Foreign. In other words, safety shocks are meaningful contributors to global volatility, especially so in the United States. The disproportionate effects of safety shocks on Home output are consistent with the mechanisms described around Proposition 1 and Figure 3: given nominal rigidities, the dollar deflation and appreciation on impact of a flight to safety induces a more severe Keynesian recession at Home. The fourth column indicates that, by contrast, heterogeneity in risk-bearing capacity has a minimal effect on output volatilities. As we show in the next subsection, however, this feature of the global economy is quite important for US external adjustment.

### B. US External Adjustment

Absent safety shocks and especially heterogeneity in risk-bearing capacity, the model implies that US net foreign assets would be substantially less volatile. At the same time, the United States would not earn such high returns on its external position, and net exports would bear a greater burden in external adjustment.

We can study these issues by focusing on the country-level budget constraint

$$(22) \quad \Delta nfa_t = nx_t + r_t^k nfa_{t-1} + val_t,$$

where  $nfa_t$  denotes the real value of Home net foreign assets at the end of period  $t$ ,  $nx_t$  denotes net exports during period  $t$ ,  $r_t^k nfa_{t-1}$  denotes net foreign income if all assets paid the return on capital, and  $val_t$  denotes the excess returns arising from

<sup>43</sup> See Fukui, Nakamura, and Steinsson (2023) for recent work accounting for properties of exchange rates using multiple types of financial shocks.

TABLE 5—OUTPUT VOLATILITY (PERCENT)

	Data	Model	No $\omega$	$\gamma = \gamma^*$
$\sigma(\Delta \log y_t)$	0.59	0.61	0.44	0.60
$\sigma(\Delta \log y_t^*)$	0.81	0.81	0.75	0.81

Notes: Data moments estimated over 1995:I–2019:IV. Model moments are computed as described in the notes to Table 2.

TABLE 6—US NET FOREIGN ASSET VOLATILITY AND MEANS (PERCENT)

	Data	Model	No $\omega$	$\gamma = \gamma^*$
$\sigma[(\Delta nfa_t)/y_t]$	11.0	3.3	1.6	0.8
$\sigma(nx_t/y_t)$	1.0	1.0	0.8	0.8
$\sigma[(\Delta nfa_t - nx_t)/y_t]$	10.9	3.1	1.8	0.2
$\Delta nfa/y$	-2.8	0.2	0.1	0.0
$nx/y$	-3.2	-0.6	-0.2	0.1
$(\Delta nfa - nx)/y$	0.4	0.7	0.3	-0.1

Notes: Volatilities in data estimated over 2006:I–2019:IV since BEA IIP data are available quarterly only after that date; means are estimated using annual data over 1995:I–2019:IV. Model moments are computed as described in the notes to Table 2.

relative returns and the composition of Home's net foreign assets. Online Appendix C defines each of these terms in our model environment.

The top panel of Table 6 summarizes the volatilities of the components in (22) after scaling by output. In both data and model, the volatility of the change in net foreign assets is substantially larger than the volatility of net exports, though the model understates the difference (because it understates the volatility of excess returns). The third column indicates that safety shocks are an important contributor to volatility in net foreign assets, operating largely through asset returns rather than net exports. The fourth column indicates that greater risk tolerance in the United States is especially important to volatility in net foreign assets. Absent its greater risk tolerance, the United States would not take large balance sheet exposure to relative returns, and thus, net foreign asset volatility would essentially equal that of net exports.

The counterpart to the higher volatility in US net foreign assets is the high returns it earns on its external balance sheet as a levered investor in equities and foreign bonds, related to the empirical literature on the “exorbitant privilege.”<sup>44</sup> The bottom panel of Table 6 demonstrates that in both data and model, the United States earns positive net foreign income despite running trade deficits on average.<sup>45</sup> In the absence of safety shocks, the third column indicates the average returns earned by

<sup>44</sup>See, for instance, Gourinchas and Rey (2007a) and Curcuru, Dvorak, and Warnock (2008).

<sup>45</sup>The average US trade deficit to output is of course larger in the data, reflecting the secular decline in net foreign assets, which is absent in the model. In the model, the average change in net foreign assets is in fact slightly positive because there are no disaster realizations in sample.

the United States would fall by half, as there would be less risk in the global economy. In the absence of greater risk tolerance in the United States, the fourth column indicates that the positive average returns earned by the United States would be eliminated altogether.

We can further use the model to understand the dynamics of US external adjustment arising from its levered international portfolio. Iterating on (22) and evaluating news at any date  $t$  (defining for brevity the operator  $\mathbb{E}_t^{t-1} \equiv \mathbb{E}_t - \mathbb{E}_{t-1}$ ), we have that

$$\begin{aligned}\mathbb{E}_t^{t-1} nfa_t = & -\mathbb{E}_t^{t-1} \sum_{h=1}^H \left( \prod_{i=1}^h \frac{1}{1+r_{t+i}^k} \right) nx_{t+h} - \mathbb{E}_t^{t-1} \sum_{h=1}^H \left( \prod_{i=1}^h \frac{1}{1+r_{t+i}^k} \right) val_{t+h} \\ & + \mathbb{E}_t^{t-1} \left( \prod_{i=1}^H \frac{1}{1+r_{t+i}^k} \right) nfa_{t+H}.\end{aligned}$$

This identity says that a negative innovation in net foreign assets at  $t$  must be rebalanced by news about future trade surpluses through period  $t+H$  (the trade channel), news about excess returns through period  $t+H$  (the valuation channel), or news about a higher net foreign asset position at  $t+H$ . Taking a large value of  $H$  and the covariance of both sides with innovations to net foreign assets, we can decompose US external adjustment into the trade and valuation channels. This is closely related to the decomposition in Gourinchas and Rey (2007b) but does not use linearizations.

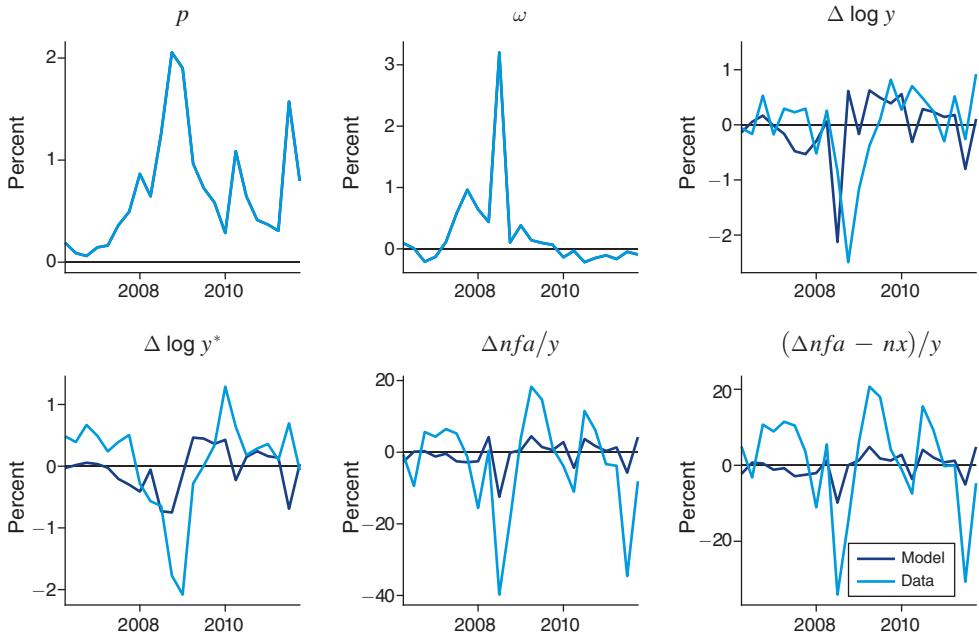
Table 7 decomposes the process of external adjustment in the model. The first column indicates that a substantial fraction of US external adjustment in the model occurs via the valuation channel.<sup>46</sup> This primarily reflects the role of excess capital returns: the United States is levered in capital financed by dollar bonds, and time-varying disaster risk induces time-varying expected excess returns on capital. On impact of an increase in disaster risk, US net foreign assets decline but subsequently rise rapidly as the United States earns higher excess returns on its capital position. Absent heterogeneity in risk-bearing capacity in the third column, the United States would not have disproportionate balance sheet exposure to disaster risk, and net exports would bear essentially all of the burden in external adjustment. Safety shocks play a secondary role in generating a valuation channel, through two mechanisms. First, a flight to safety generates a decline in US wealth, which is partially rebalanced in future periods through higher seigniorage revenues. Second, the existence of safety shocks implies that the United States is slightly more levered in capital (as demonstrated in the bottom panel of Table 3), implying stronger valuation effects resulting from disaster risk shocks.

<sup>46</sup> Quantitatively, the role of the valuation channel in our model exceeds the roughly 30 percent estimated by Gourinchas and Rey (2007b) and Gourinchas, Rey, and Sauzet (2019). Adding other standard business cycle shocks to our model, essentially all of which induce fluctuations without movements in expected excess returns, would bring the valuation channel in our model closer to these estimates.

TABLE 7—UNDERSTANDING US EXTERNAL ADJUSTMENT (PERCENT)

	Model	No $\omega$	$\gamma = \gamma^*$
<i>As share of var</i> ( $\mathbb{E}_t^{t-1} nfa_t$ )			
$\text{cov}\left(-\mathbb{E}_t^{t-1} \sum_{h=1}^{500} \left(\prod_{i=1}^h \frac{1}{1+r_{i+h}^k}\right) nx_{t+h}, \mathbb{E}_t^{t-1} nfa_t\right)$	32	76	99
$\text{cov}\left(-\mathbb{E}_t^{t-1} \sum_{h=1}^{500} \left(\prod_{i=1}^h \frac{1}{1+r_{i+h}^k}\right) val_{t+h}, \mathbb{E}_t^{t-1} nfa_t\right)$	68	24	1
$\text{cov}\left(\mathbb{E}_t^{t-1} \left(\prod_{i=1}^{500} \frac{1}{1+r_{i+h}^k}\right) nfa_{t+500}, \mathbb{E}_t^{t-1} nfa_t\right)$	0	0	0

Note: Moments are computed as described in the notes to Table 2 but including disaster realizations.

FIGURE 4. SIMULATION USING OBSERVED  $p$  AND  $\omega$  SERIES

Notes:  $p$  is from Barro and Liao (2021), and  $\omega$  is from Du, Im, and Schreger (2018) (de-meaned). Both are scaled to match volatilities of  $p$  and  $\omega$  in model. Given these shocks, the figure depicts average paths starting from 100 points drawn from ergodic distribution as described in the notes to Table 2.

### C. Great Recession

The previous two subsections use long, simulated time series to demonstrate the quantitative importance of safety shocks and greater risk-bearing capacity for macroeconomic outcomes in the global economy. We now use the model to quantify the importance of these features during the Great Recession.

For  $p$ , we feed in the series estimated by Barro and Liao (2021) and for  $\omega$  (via  $\omega^d$ ), we feed in the series estimated by Du, Im, and Schreger (2018). We assume zero innovations to global productivity  $z$  and relative productivity  $z_F$ . We begin the simulation in 1995 but focus in Figure 4 on the 2006–2011 period of interest.

Just with the observed disaster risk and safety series, the model generates sizable movements in output and net foreign assets relative to the data. In particular, these shocks and model features generate a cumulative decline in Home output of 1.3 percent, Foreign output of 1.5 percent, and net foreign assets relative to output of 8.6 percent from the end of 2007:III through 2009:III. These compare with 4.8 percent, 5.1 percent, and 10.0 percent (not detrended) in the data. Moreover, as the last two panels of Figure 4 make clear, as in the data the change in net foreign assets is not primarily due to net exports but rather returns on the US external position.

Online Appendix C decomposes the role of each driving force in generating these dynamics. Both play an important role. The flight to safety is important in generating output declines in late 2008, particularly for the United States. However, the increase in disaster risk is more important in accounting for the persistence of the output decline, particularly in Foreign. Relatedly, the flight to safety plays a key role in generating the US valuation losses in late 2008, but it is the elevated disaster risk thereafter that delivers high excess returns on the US external position.<sup>47</sup>

Online Appendix C also compares additional variables of interest between model and data. First, nominal interest rates globally (and especially in the United States) fall well below zero in the model, while they were constrained by the zero lower bound in the data. While this is consistent with the decline in “shadow rates” in practice, owing to policies such as quantitative easing that are outside the model, this suggests that the model may underestimate the effects of disaster risk and safety shocks during this period, if anything. Second, the US wealth share in fact slightly rises over 2008–2009 in the model. While both the increase in disaster risk and flight to safety lower the US wealth share on impact, the elevated disaster risk induces a rise in the wealth share thereafter, as the US earns high excess equity returns, while the flight to safety dissipates. This relates to the mixed empirical findings in Dahlquist et al. (2023) and Sauzet (2023) regarding the US wealth share dynamics during this period. Our model generates effects well within the range estimated by these papers and clarifies that it is fully consistent for the US wealth share to rise over the 2008–2009 period even if, on impact, both shocks reduce it.

#### D. Dollar Swap Lines

We finally turn from macroeconomic outcomes to policy. We focus on changes in the supply of safe dollar bonds, as through the swap of Foreign bonds for safe dollar bonds by central banks in recent crises.<sup>48</sup> By (17), such a policy would reduce the value of safety/liquidity  $\omega_t$ . In this subsection, we quantify its effects.

In particular, we compare the model predictions to the estimated effects of the March 19 and 20, 2020, announcements of expanded dollar swap lines studied in

<sup>47</sup> Our conclusion that the flight to safety played an important quantitative role in the Great Recession is consistent with other DSGE models studying this episode, which have emphasized financial shocks broadly and shocks to liquidity premia in particular (see, for instance, Del Negro et al. 2017). Here, we extend these analyses to the global economy.

<sup>48</sup> Strictly speaking, dollar swap lines by the Federal Reserve have involved the issuance of dollars, not safe dollar bonds. Extending the model to feature dollar money that provides liquidity services alongside safe dollar bonds, an increase in the supply of dollar money will reduce the convenience yield  $\omega_t$  like an increase in the supply of safe dollar bonds. For simplicity, we thus conceptualize swap lines as an increase in the supply of safe dollar bonds here.

Kekre and Lenel (2023). On March 19, the Federal Reserve announced it would temporarily expand from 5 to 14 the number of central banks that could access its swap lines, and on March 20, it announced it would increase the frequency of its standing swap line operations from weekly to daily. Kekre and Lenel (2023) use high-frequency event studies around the announcements to identify their asset pricing effects. In particular, they estimate that the (annualized) 3-month Libor rate fell by 12bp, the 3-month Treasury bill yield and current and 3-month-ahead Fed funds rates were essentially unchanged, the dollar depreciated by roughly 70bp versus the G7 currencies, and the S&P 500 rose by roughly 150bp, due to these announcements.

To simulate these announcements in the model, we first need to map the response of the three-month Libor rate into a decline in  $\omega_t$ . The announcement effect on the 3-month Libor amounts to a 12bp decline in the Libor/T-bill spread (the “Ted spread”). The volatility of  $\omega_t$  in the model is roughly 1.2 times the volatility of the (annualized) Ted spread in the data. Our interpretation of this moment is that intraday funds lent between financial institutions provide some liquidity services, so they underestimate the true volatility of the liquidity premium  $\omega_t$ .<sup>49</sup> We thus multiply the 12bp decline in the annualized Ted spread by 1.2 to obtain a 14bp decline in  $\omega_t$ .

We thus simulate a 14bp decline in  $\omega_t$  in the model resulting from the expanded dollar swap lines. Online Appendix D describes how the decline in  $\omega_t$  can be used to estimate a range for the elasticity of safe asset demand  $\epsilon^d$  in (17) given a plausible range for the news regarding the expanded supply of safe dollar assets in these announcements. We assume that the swap line usage implies the same persistence in  $\omega_t$  as safety shocks in the model (0.4), consistent with the fact that swap line usage fell back to roughly zero within a year after the announcements.

We consider two assumptions on the monetary policy response. Our baseline assumption is that the US nominal interest rate is fixed in the first quarter and follows the Taylor rule thereafter, consistent with the findings in Kekre and Lenel (2023) that near-term Fed funds futures do not respond to the announcements. We consider an alternative assumption that the US nominal interest rate follows the Taylor rule in all periods. In both cases, Foreign follows its standard Taylor rule.

The first two rows of Table 8 present the asset pricing effects of the swap line announcements in data and under these model scenarios. Kekre and Lenel (2023) estimate that the March 19–20 announcements generated a roughly 70bp nominal depreciation of the dollar versus G7 currencies and 150bp increase in the (nominal value of the) S&P 500. With a constant nominal rate in the first quarter, the present model implies a 100bp nominal dollar depreciation and 135bp increase in the dollar value of equities on impact, remarkably consistent with the estimated responses. The last column indicates that, with an active Taylor rule even in the first quarter, these asset pricing responses would be substantially diminished as the central bank tightens the policy rate upon the reduction in  $\omega_t$ .

<sup>49</sup>This is analogous to our interpretation that swapped G10 government bonds also provide some liquidity/safety, so the swapped G10/T-bill spread understates  $\omega_t$ . However, we acknowledge that the Ted spread may also reflect default risk, not just a liquidity premium. We would have preferred to use the response of the swapped G10/T-bill spread for this reason, but Kekre and Lenel (2023) are unable to measure this series intraday. Nonetheless, Kekre and Lenel (2023) document in lower-frequency data that the Ted spread and swapped G10/T-bill spread comove tightly.

TABLE 8—EFFECTS OF DOLLAR SWAP LINES

	Data	Model	
		Constant $i$	Active Taylor
<i>Impact effects</i>			
$\log E_t$	−72bp	−100bp	−18bp
$\log P_t r_t^e$	+151bp	+135bp	+29bp
$\Delta nfa_t / y_t$		+436bp	+67bp
$(\Delta nfa_t - nx_t) / y_t$		+351bp	+63bp
<i>Peak effects</i>			
$\log y_t$		+79bp	+11bp
$\log y_t^*$		+21bp	+4bp

*Notes:* Data column is cumulative estimates from Kekre and Lenel (2023) for March 19–20, 2020, announcements (Table 1 in that paper). Model columns simulate a decrease in  $\omega_t$  of 14bp starting from the average of the model's ergodic distribution.

The subsequent rows of Table 8 use our structural model to quantify the implied effects for the real economy, which the empirical analysis in Kekre and Lenel (2023) is unable to do. Focusing on the case with a constant nominal interest rate in the first quarter, the swap line announcements in the model generate a peak increase in US output of roughly 80bp and foreign output of roughly 20bp, indicating that the dollar swap lines played a meaningful macroeconomic stabilization role during the COVID-19 pandemic. The announcements further generate an increase in US net foreign assets to output of roughly 440bp, most of which is accounted for by valuation effects, indicating that the swap lines relaxed the US external budget constraint owing to their effects on asset prices and the exposures of the US balance sheet.

## VI. Conclusion

In this paper we have proposed a business cycle model of the international monetary system emphasizing a time-varying demand for safe dollar bonds, greater risk-bearing capacity in the United States than the rest of the world, and nominal rigidities.

A flight to safety triggers a dollar appreciation and decline in global output. Dollar bonds thus command a negative risk premium, and the United States insures the rest of the world against such shocks. Quantitatively, the model matches untargeted comovements between relative bond returns, equity returns, output, and wealth in the global economy. It in turn clarifies that safety shocks are an important driver of global macroeconomic volatility. Heterogeneity in risk-bearing capacity amplifies US net foreign asset volatility but raises the average return earned by the United States on its external position and reduces the required role of net exports in external adjustment. Both safety shocks and heterogeneity in risk-bearing capacity were important during the Great Recession. Dollar swap lines are globally stimulative and relax the US external budget constraint by mitigating the flight to safety.

We have deliberately made minimal departures from a workhorse two-country open economy model to focus on the consequences of a time-varying demand for safe dollar bonds and greater US risk-bearing capacity in this context. We view the

introduction of additional heterogeneity within countries, particularly in the form of financial intermediaries, as among the most fruitful ways to enrich this framework going forward. Shocks in the interbank market or to financial constraints facing banks may provide a deeper microfoundation of the flight to safe dollar bonds,<sup>50</sup> and currency intermediation by these banks could bring the volatilities of exchange rates closer to the data. The negative beta of the dollar could also help explain why dollar funding is an important feature of bank balance sheets.<sup>51</sup> The effects of the dollar exchange rate on intermediary wealth may in turn help to account for the effects of US monetary policy on global financial conditions and especially on emerging markets.<sup>52</sup> We leave these exciting questions for future work.

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<sup>50</sup> See Bianchi, Bigio, and Engel (2022) and Devereux, Engel, and Wu (2023) for recent work in this direction.

<sup>51</sup> See Adrian, Etula, and Shin (2010) and Bruno and Shin (2015a,b) for such evidence.

<sup>52</sup> See Rey (2013, 2016); Bruno and Shin (2015a); Jorda et al. (2019); Kalemli-Ozcan (2020); Miranda-Agrippino and Rey (2020); and Obstfeld and Zhou (2023).

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