THE FLIGHT TO SAFETY AND INTERNATIONAL RISK SHARING

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ABSTRACT

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 U.S. 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 U.S. 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; U.S. external adjustment; and the international transmission of monetary and fiscal policies, including dollar swap lines.

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1   Introduction

The U.S. 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 U.S. international investment position. The U.S. 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 which can jointly capture these cyclical patterns and study their implications. One strand of the literature has emphasized the safety and liquidity value of U.S. 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 U.S. has a greater capacity to bear risk than the rest of the world. This can explain patterns in U.S. 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 which bridges these two perspectives. Our model features a time-varying demand for safe dollar bonds, greater risk-bearing capacity in the U.S. than the rest of the world, and nominal rigidities. A flight to safe dollar bonds — which we formalize as an increase in their non-pecuniary value — generates a stronger dollar and a decline in global output. Dollar bonds are thus an endogenous hedge and the U.S. 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 U.S. net foreign assets to excess equity returns. The model generates untargeted comovements between relative bond returns, equity returns, output, and U.S. net foreign assets quantitatively in line with the data. We then trace out its macroeconomic implications. Absent the time-varying demand for safe dollar bonds, global output would be roughly 15% less volatile, particularly so in the U.S. Absent the U.S.' greater capacity to bear risk, its net foreign assets

would be only as volatile as net exports, which in turn would bear a greater burden in external adjustment. Both the flight to safety and greater U.S. risk-bearing capacity played important roles in the Great Recession. We finally outline two of the model's policy implications. A monetary policy easing in the U.S. has disproportionate effects on global equities because it redistributes to risk tolerant agents and thus compresses risk premia. Government purchases of foreign-denominated bonds financed by the issuance of safe dollar bonds, such as via the dollar swap lines employed by central banks in recent crises, are globally stimulative.

We study a workhorse open-economy New Keynesian environment extended to feature a non-pecuniary 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 which are valued for their liquidity or safety beyond their pecuniary return. The equilibrium non-pecuniary 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 monetary and fiscal shocks at the end of the paper to shed light on policy transmission.

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 U.S. and a decline in its real interest rate. With nominal rigidity and U.S. monetary policy which 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. 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 U.S. are more risk tolerant than those abroad, this implies that U.S. net foreign assets fall on impact of the shock. In the periods which follow, the dollar depreciates, excess foreign bond and equity

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returns are high, global output recovers, and U.S. 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 U.S. Treasuries and G10 government bonds swapped into dollars constructed by Du, Im, and Schreger (2018a) 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 understate 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 U.S. 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 U.S. net foreign asset position which speak directly to the role of the dollar and U.S. economy in the international monetary system. As in the data, our model implies that (i) the year-over-year decline in U.S. 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 U.S. 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 U.S. 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 U.S. external adjustment. Safety shocks account for roughly 25% of output volatility in the U.S. and 10% of output volatility in the rest of the world. Heterogeneity in risk-bearing capacity accounts for virtually all of the excess volatility of U.S. net foreign assets relative to net exports. While the U.S. 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 U.S. external position. These insights are obtained using simulations of the model's driv-

ing forces over long time periods. We also feed in the observed sequence of safety and disaster risk innovations estimated by Du et al. (2018a) 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 U.S. output by 1.9%, Foreign output by 2.1%, and U.S. net foreign assets relative to output by 6.9% from the end of Q3 2007 through Q3 2009, versus 4.8%, 5.1%, and 10.0% in the data.

We finally use the model to trace out the global implications of U.S. monetary and fiscal policy. It first implies that monetary policy shocks in the U.S. have disproportionate effects on global asset prices, consistent with the growing empirical literature on the "global financial cycle".[1] A U.S. easing depreciates the dollar and thus redistributes wealth toward the risk tolerant (U.S. agents themselves) which are short dollars. As the risk tolerant seek to rebalance into capital, the expected excess return on capital falls. These effects are quantitatively small in the case of our baseline calibration in which all agents actively trade, implying small equilibrium price responses to portfolio flows. In an extension featuring a small fraction of active traders (such as financial intermediaries) in each country, they can be more substantial. For instance, if only 2.5% of agents rebalance each quarter, a Campbell-Shiller decomposition of the global stock market response to a U.S. (Foreign) monetary easing implies that roughly 60% (less than 0%) is due to news about lower future excess returns.

The model finally implies that a swap of foreign bonds for safe dollar bonds is globally stimulative. By increasing the supply of dollar liquidity to be absorbed by the private sector, such a swap reduces the convenience yield on safe dollar bonds like a negative safety shock. We consider the $450bn increase in swap line usage by May 2020 during the Covid-19 pandemic. We parameterize the effect on the convenience yield using evidence on the change in the swapped G10/Treasury bill spread during this period. In response to this policy, the model implies a peak dollar depreciation of $15bp$, increase in U.S. output by $60bp$, and increase in foreign output by $15bp$.

Related literature 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 (2020), Jiang, Krishnamurthy, and Lustig (2021a,b), and Valchev (2020) develop theories linking convenience yields with nominal exchange

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[1]See, for instance, the evidence in Rey (2013), Bruno and Shin (2015a), Rey (2016), Jorda, Schularick, Taylor, and Ward (2019), and Miranda-Agrippino and Rey (2020).

rates.[2] Jiang, Krishnamurthy, and Lustig (2020) argue that the effects of U.S. monetary policy on the dollar convenience yield can explain features of the global financial cycle. Relative to these papers, our contribution is to embed the convenience yield in a workhorse New Keynesian model with heterogeneity to trace out the implications for output, risk sharing, and risk premia. Del Negro, Eggertsson, Ferrero, and Kiyotaki (2017) study liquidity frictions in a New Keynesian model of the U.S. economy; our analysis is a natural open economy counterpart to theirs.

By accounting for differences in risk-bearing capacity across countries, we also build on a large literature studying international risk sharing in such an environment. As in Chien and Naknoi (2015), Dou and Verdelhan (2015), Gourinchas, Rey, and Govillot (2017), Maggiori (2017), and Sauzet (2021) we rationalize the U.S.' external position by calibrating U.S. agents to be effectively more risk tolerant than those abroad. Unlike these papers, our model accommodates a time-varying demand for safe dollar bonds, endogenous production, and nominal rigidity. These features interact to overcome the reserve currency paradox which has challenged this literature and allow us to rationalize the currency exposure of the U.S. in particular.[3] This in turn allows us to draw a novel link between the U.S.' role as world insurer and monetary policy asymmetries in the global financial cycle, applying our previous work on monetary policy, redistribution, and risk premia (Kekre and Lenel (2021)) to the global context.

By exploring the interactions between safe asset demand and international risk sharing, our paper also contributes to the large and growing literature studying exchange rates and risk premia in environments with asset demand shocks. The effects of safety shocks on exchange rates particularly echo the theories of exchange rate determination in Gabaix and Maggiori (2015) and Itskhoki and Mukhin (2021a,b).[4] Whereas these authors focus on shocks in the foreign exchange market which can rationalize exchange rate volatility which is "disconnected" from other aggregates, safety shocks also affect agents' portfolio choice between capital and bonds, and their intertemporal decisions between consumption and saving. In this sense, our analysis

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[2]See DiTella (2020), Drechsler, Savov, and Schnabl (2017), Greenwood, Hanson, and Stein (2015), He, Krishnamurthy, and Milbradt (2019), Krishnamurthy and Vissing-Jorgensen (2012), and Nagel (2016) for related analyses of convenience yields and the dollar as safe asset.

[3]The existing literature has proposed two other ways to potentially resolve the paradox: risk aversion shocks as in Gourinchas et al. (2017), and trade cost shocks as in Maggiori (2017). We contrast the effects of these shocks versus safety shocks in appendix C.

[4]See Alvarez, Atkeson, and Kehoe (2002, 2009) for seminal work on the link between portfolio flows, exchange rates, and risk premia.

perhaps builds most directly on Caballero and Farhi (2018) and Caballero, Farhi, and Gourinchas (2021), who demonstrate that an increase in the demand for safe assets raises risk premia and reduces output in the presence of nominal rigidities, heterogeneity, and a binding zero lower bound. We demonstrate that these insights apply under conventional Taylor rules even outside the zero lower bound and are quantitatively important contributors to cyclical fluctuations in the global economy.

Outline   In section 2 we outline the environment. In section 3 we characterize the main mechanisms analytically in a limiting case. In section 4 we calibrate the full model and in section 5 we study its impulse responses and untargeted comovements versus the data. Having validated the model, in section 6 we study its macroeconomic and policy implications. Finally, in section 7 we conclude.

2   Model

There are two countries, Home and Foreign, comprised of measure one and ζ^* 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 appendix A. Since we will calibrate the model so that Home captures the U.S., we refer to Home's nominal unit of account as the dollar.

The model adds several 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 are essential. Epstein-Zin preferences disentangle risk aversion from intertemporal substitution and allow us to isolate mechanisms. A rare disaster with time-varying probability generates meaningful variation in risk premia.

2.1   Households

The representative household at Home has recursive preferences

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

over consumption c_t, labor ℓ_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

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

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

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

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 non-pecuniary 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 γ, intertemporal elasticity of substitution as well as consumption-labor complementarity are jointly controlled by ψ, and discount rate is β. Home bias is controlled by ς and the trade elasticity by σ. Finally, $\bar{\nu}$ denotes the disutility of labor and ν 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 ι_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 Π_{t+1} per unit in $t+1$, and depreciates after its use at rate δ. 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

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

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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

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

where χ^W scales the adjustment costs and the aggregate wage bill $W_t \ell_t$ is defined below. 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 γ^* can differ from that of Home households. We also allow their discount factor β^* 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 ψ, home bias ς, trade elasticity σ, and Frisch elasticity ν as Home households. We further assume an identical degree of nominal wage rigidity ψ^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.

2.2 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 ϵ and sold at W_t to domestic firms. The labor packer thus earns

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

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

Production A representative Home producer hires ℓ_t units of labor from the domestic labor packer, rents κ_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

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

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 Π_t once expressed in dollars, reflecting the ability of households to freely deploy capital in either country, equating its rate of return.[5]

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

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

new units of capital, where χ^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

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

which will be zero in equilibrium.

2.3 Policy

Monetary policy is characterized by a Taylor rule

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

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[5]This simplifies the model computation, as there there is only a single aggregate capital state variable to keep track of $(\bar{k}_{t-1})$. Recently, Atkeson, Heathcote, and Perri (2021) have emphasized the importance of heterogeneous returns on equities in the U.S. versus the rest of the world when accounting for the dynamics of U.S. net foreign assets since 2010. It would be useful to extend the present environment to accommodate such heterogeneous returns.

where P_t is the ideal price index

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

An analogous Taylor rule in Foreign determines i_t^* with the same coefficient ϕ on inflation in the Foreign ideal price index P_t^*. We focus on CPI-targeting Taylor rules anticipating our calibration to the U.S. 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 bonds to global consumption

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

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

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

We abstract from the Home government's participation in asset markets other than safe dollar bonds because these do not provide non-pecuniary 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.

2.4 Non-pecuniary value of safe dollar bonds

The non-pecuniary 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

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

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 non-pecuniary value of safe dollar bonds must be equated across agents on the margin, which we denote ω_t:

$$\omega_t \equiv c_t \frac{\Omega'_t(B_{Ht,s}/P_t)}{\Omega_t(B_{Ht,s}/P_t)} = c^*_t \frac{\Omega^{*'}_t(B^*_{Ht,s}/(E_t^{-1}P^*_t))}{\Omega^*_t(B^*_{Ht,s}/(E_t^{-1}P^*_t))}. \tag{15}$$

Equation (14) makes clear how the convenience yield ω_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 Ω_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 ω_t^d is an exogenous driving force, ϵ^d is a parameter, and all variables with bars are aggregates which the representative household takes as given.[6] Given an analogous functional form in Foreign, appendix A proves that the second equality in (15) together with market clearing in safe dollar bonds implies

$$\frac{B_{Ht,s}}{P_t c_t} = \frac{B^*_{Ht,s}}{E_t^{-1}P^*_t c^*_t} = \frac{(-B^g_{Ht,s})}{P_t c_t + \zeta^* E_t^{-1}P^*_t c^*_t}. \tag{16}$$

The first equality in (15) thus implies

$$\omega_t = \omega_t^d - \frac{1}{\epsilon^d}\frac{(-B^g_{Ht,s})}{P_t c_t + \zeta^* E_t^{-1}P^*_t c^*_t}. \tag{17}$$

Intuitively, the convenience yield is rising in private demand for safe dollar bonds ω_t^d and decreasing in public supply $-B^g_{Ht,s}$. The relative strength of the latter depends on ϵ^d, the elasticity of demand to the non-pecuniary value. We treat ω_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

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[6]The rationale for this functional form is straightforward. Inside the parenthesis, the first term implies a time-varying non-pecuniary value of safe dollar bonds while the second term implies that this is diminishing in the household's position. The third and fourth terms ensure that in equilibrium $\Omega_t(B_{Ht,s}/P_t) = 1$, so that the equilibrium effects of a time-varying convenience yield do not arise from mechanical effects on households' stochastic discount factors.

stochastic properties of ω_t^d. At the end of section 6, we instead study shocks to $B_{Ht,s}^g$.

2.5 Driving forces

Global productivity follows a unit root process subject to rare disasters

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

where φ_t is equal to zero with probability $1 - p_t$ and $\underline{\varphi} < 0$ with probability p_t. The log disaster probability p_t follows an AR(1) process

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

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

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

This similarly captures the skewness of the convenience yield in the data, but we include the shift parameter Δ^ω so that the mean of ω_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

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

We assume that the innovations $\{\epsilon_t^z, \epsilon_t^p, \epsilon_t^\omega, \epsilon_t^F\}$ are each draws from a normal distribution with mean zero and variance one. We capture the correlation between disaster risk and the convenience yield in the data by allowing the shocks to each series to have correlation $\rho^{p\omega}$, and otherwise assume shock correlations are zero.

Later in the paper, we shed light on the transmission of monetary and fiscal policies by studying unanticipated, one-time policy shocks.

2.6 Equilibrium and solution

We provide the market clearing conditions in appendix A for brevity. The definition of equilibrium is standard and also provided in appendix A together with a characteri-

zation 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 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 ω_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 θ_t. After scaling in this way, global productivity shocks inclusive of disasters only govern the transition across states.

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

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

each of which earn return $1 + \iota_t = \frac{1+i_t}{1-\omega_t}$. The composition of households' dollar bond position is only relevant in determining the equilibrium seignorage earned by Home on the safe dollar debt held by Foreign which follows from (16).

2.7   Discussion of convenience yield and heterogeneity

As previously noted, two features of our environment are essential: a non-pecuniary value of safe dollar bonds and heterogeneity in risk tolerance. Before studying the equilibrium, we elaborate on our modeling choices.

Our modeling of safe dollar bonds in utility is a simple way to formalize the non-pecuniary value of these assets due to liquidity or safety. We maintain the "cash-less limit" commonly assumed in New Keynesian models and described in Woodford (2003). We show in appendix E that this is innocuous if money offers liquidity services which are neither substitutes nor complements with safe dollar bonds; the representative household's first-order conditions for money would simply describe the money

supply which implements the Taylor rule in each country. A more nuanced case is if dollar money and safe dollar bonds are perfect substitutes in liquidity provision. As Nagel (2016) argues, in this case (17) would effectively be replaced by a condition relating ω_t to Home's nominal rate, since changes in the supply of safe dollar bonds would be immediately undone by changes in the dollar money supply to implement a particular interest rate target. However, changes in the *relative* liquidity of safe dollar bonds versus money would still propagate like safety shocks in our baseline model.

Our modeling of cross-country differences in risk tolerance is similarly a parsimonious way to account for differences in risk-bearing capacity which emerge in richer models. Maggiori (2013) studies a model with balance sheet-constrained intermediaries in which U.S. intermediaries are able to deal with funding problems better. Chien and Naknoi (2015) study a model in which equity market participation rates are lower in the rest of the world than the U.S. We focus on a setting with cross-country differences in risk tolerance so that we can focus on the interaction between heterogeneity in risk-bearing capacity and safety shocks in the simplest possible way.[7]

3   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 U.S. finances a levered capital portfolio in dollars. Several features of safety shocks and of the U.S. economy render these shocks particularly special for the global economy.

3.1   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 ($\chi^x \to \infty$, $\delta \to 0$);*

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[7] We thus follow Dou and Verdelhan (2015) and Gourinchas et al. (2017), who also assume differences in preferences across countries.

- *a unitary IES ($\psi = 1$), complete home bias ($\varsigma \to \frac{\varsigma^*}{1+\varsigma^*}$), and an infinite Frisch elasticity ($\nu \to 0$);*

- *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.

3.2 Effects of a safety shock

We now describe the effects of a safety shock. We employ first-order approximations and use $\hat{\cdot}$ 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 ($b^g_{H,s} \equiv B^g_{H,s}/P = 0$) 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 $b^g_{H,s} = 0$ 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 ($\Delta \hat{P}_t = -\frac{1}{\phi} \hat{\omega}_t$); and*

- *the Home real exchange rate and employment in each country are unchanged ($\hat{q}_t = \hat{\ell}_t = \hat{\ell}_t = 0$).*

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

- *the Home real interest declines by less than above ($0 > \mathbb{E}_t \hat{r}_{t+1} > -\hat{\omega}_t$);*

- *the Home CPI declines by less than above ($0 > \Delta \hat{P}_t > -\frac{1}{\phi}\hat{\omega}_t$);*

- *the Home real exchange rate appreciates ($\hat{q}_t \propto \hat{\omega}_t$); and*

- *global employment falls, disproportionately so in Home ($\frac{1}{1+\zeta^*}\hat{\ell}_t + \frac{\zeta^*}{1+\zeta^*}\hat{\ell}_t^* \propto -\hat{\omega}_t$ and $\hat{\ell}_t - \hat{\ell}_t^* \propto -\hat{\omega}_t$).*

The proof of this proposition, like all others, is provided in 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 which 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.[8,9] The disproportionate recession borne by Home echoes the result in Caballero et al. (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 which 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, $\mathbb{E}_t\left[\hat{r}_{t+1}^k - \hat{r}_{t+1}\right] = \mathbb{E}_t\left[\hat{r}_{t+1}^* - \Delta\hat{q}_{t+1} - \hat{r}_{t+1}\right] = \hat{\omega}_t$).*

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 which raises the real return on dollar bonds (even absent nominal rigidity) and because of the decline in global production which 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 because of the real dollar appreciation (only with nominal rigidity). Going forward, expected excess returns on capital and Foreign bonds are high, ensuring that agents remain indifferent between safe dollar bonds and these other assets.

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[8]We note that these same results obtain if nominal prices rather than wages are sticky instead.

[9]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 σ is not too high.

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:

Proposition 3. *Consider the simplified environment and assume portfolios are initially not too different from the symmetric benchmark and $b^g_{H,s}$ 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*
$$\left(\hat{\theta}_t = \left(\frac{q^k k}{a} - 1 \right) (\hat{r}^k_t - \hat{r}_t) + \frac{b_F}{a} (\hat{r}^*_t - \Delta \hat{q}_t - \hat{r}_t) - \beta \frac{\zeta^*}{1+\zeta^*} \frac{b^g_{H,s}}{a} \hat{\omega}_t \right),$$

- *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 seignorage revenue Home earns on the share of this debt owned by the rest of the world.

3.3 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 Couerdacier 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 non-traded labor income, real exchange rate risk, and the disutility of labor. In 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 $\frac{\gamma^*}{\gamma}$, holding $\gamma + \frac{1}{\zeta^*}\gamma^*$ fixed.*

Intuitively, agents face two sources of risk: global productivity and safe asset demand.[10] 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 seignorage 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.[11] 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 U.S. 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:*

- $Cov_t\left(-\hat{m}_{t,t+1}, \hat{r}_{t+1}^* - \Delta\hat{q}_{t+1} - \hat{r}_{t+1}\right) \propto \gamma - \gamma^*$ *if $\sigma^\omega = 0$; and*

- $Cov_t\left(-\hat{m}_{t,t+1}, \hat{r}_{t+1}^* - \Delta\hat{q}_{t+1} - \hat{r}_{t+1}\right)$ *is rising in σ^ω.*

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, U.S. wealth rises (as it is levered in capital), and thus U.S. consumption rises. This indicates that the "reserve currency paradox" characterized

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[10]In appendix B, we provide the analogs of Propositions 1 and 2 for productivity shocks.

[11]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.

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.

3.4 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 non-pecuniary 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 U.S. economy renders the demand for safe dollar bonds particularly special vis-à-vis the bonds of other reserve issuers. In particular, consider augmenting the model with a third country which is an infinitesimal part of the global economy (for concreteness, Switzerland). An increase in the portfolio demand for safe dollar bonds and Swiss franc bonds would generate a global recession and appreciation in both currencies relative to others in the global economy, ascribing both a negative beta. However, only the portfolio demand for safe dollar bonds would be responsible for generating the recession; the Swiss franc deflation would drive a decline in Swiss production, but this would have a negligible effect on global demand and production. This echoes the message of Hassan (2013) that the U.S.' relative size in the global economy may be an important contributor to the dollar's reserve status.

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. In fact, the nominal dollar appreciation now is consistent with an unchanged real exchange rate, as the relative supply of U.S. goods is unchanged and thus the terms of trade are unaffected. Similar results are obtained when we model sticky prices rather than wages and assume dollar pricing of exports as in Gopinath (2015), Gopinath, Boz, Casas, Diez, Gourinchas, and Plagborg-Moller (2020), and Mukhin (2021). Our model thus suggests potentially rich interactions between the dollar's role in financial and goods markets.[12]

4   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 U.S. and Foreign with the G10 currency countries.[13] A period is one quarter.

4.1   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 OECD data on consumption, investment, real GDP, and the working age population to estimate quarterly per capita growth rates in those series. We use three-month government bond yields from Bloomberg as measures of nominal interest rates. We use the MSCI ACWI as our measure of the equity claim.

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, and we construct end-of-month real exchange rates using these data and the consumer price indices

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[12]See Gopinath and Stein (2021) for another model of these linkages.

[13]The G10 refers to Australia, Canada, Denmark, Germany, Japan, New Zealand, Norway, Sweden, Switzerland, and the United Kingdom, following common convention.

from the OECD. We measure net foreign assets using the Bureau of Economic Analysis International Investment Position (BEA IIP). 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.

4.2   Externally set parameters

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

Among the model's preference parameters, we set ψ to 0.75, consistent with evidence on the consumption responses to changes in interest rates as well as 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 ζ^* described in the next subsection) the expenditure share on domestically produced goods is 80% at Home, consistent with the U.S. evidence in Eaton, Kortum, and Neiman (2016). The Frisch elasticity of labor supply is set to $\nu = 0.9$, roughly consistent with the micro evidence for aggregate hours surveyed in Chetty, Guren, Manoli, and Weber (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%, 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 5 quarters, consistent with the U.S. 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% and the depth of the disaster to $\underline{\varphi} = -10\%$, consistent with Barro (2006) and Nakamura, Steinsson, Barro, and Ursua (2013). The quarterly autocorrelation of the log probability is 0.75 and the standard deviation of shocks is $\sigma^\rho = 0.55$, consistent with the autocorrelation of the probability in levels in Barro and Liao (2021) and the fact that its standard deviation is comparable to its mean.

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
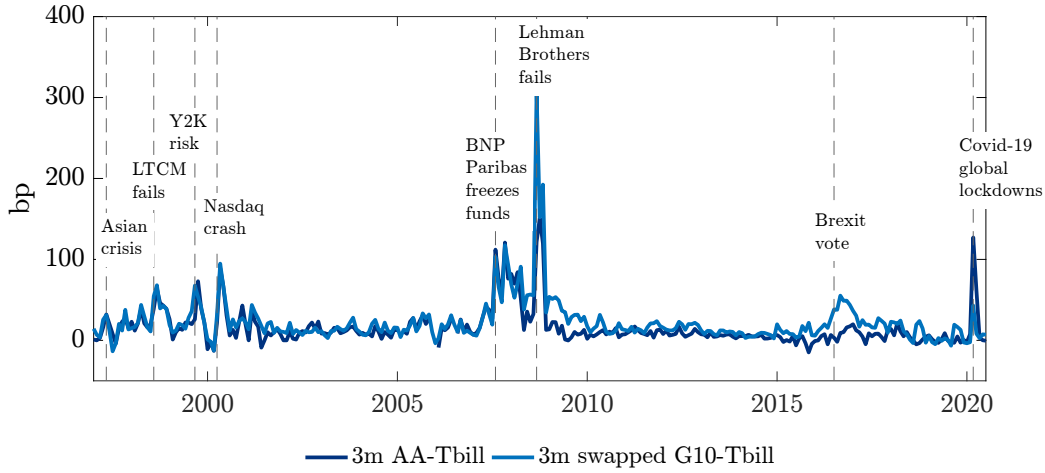
Figure 1: annualized spreads versus U.S. Treasuries

Notes: AA yield is from the Federal Reserve Board and swapped G10 yield is from Du et al. (2018a).

Treasury bills and three-month government bonds in the G10 currencies swapped into dollars, as constructed by Du et al. (2018a).[14,15] As is evident in Figure 1, both series comove and spike in times of market turmoil. We calibrate the stochastic properties of ω^d to match the swapped G10/T-bill spread given our global focus.[16] 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 $\rho^{p\omega} = 0.4$ to match the correlation with the Barro and Liao (2021) series. We calibrate σ^ω in the next subsection to match the conditional correlation between equity returns and excess foreign bond returns; following Jiang et al. (2021b), the standard deviation of the swapped G10/T-bill spread may understate the volatility of ω if swapped G10 bonds are also partially valued for their liquidity or safety.

4.3   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

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[14]We refrain from calling this a deviation from covered interest parity (CIP) because private agents cannot borrow at the U.S. 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 (2018b)).

[15]We use an updated series through 2020 and thank Wenxin Du for sharing it with us.

[16]We assume that variation in the convenience yield arises solely from changes in safe asset demand (except in section 6.5), 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 ω_t is consistent with the observed properties of the convenience yield.

	Description	Value	Notes
ψ	IES	0.75	
σ	trade elasticity	1.5	Backus et al. (1994)
ς	home bias	0.4	Eaton et al. (2016)
ν	Frisch elasticity	0.9	Chetty et al. (2011)
α	1 - labor share	0.33	
δ	depreciation rate	0.025	
ϵ	elast. of subs. across workers	20	
χ^W	Rotemberg wage adj. costs	400	$\approx \mathbb{P}(\text{adjust}) = 5$ qtrs
ϕ	Taylor coeff. on inflation	1.5	Taylor (1993)
$\underline{\varphi}$	disaster shock	-0.10	Nakamura et al. (2013)
p	disaster risk	0.4%	$E[p] = 0.5\%$ (Barro (2006))
ρ^p	dis. risk persistence	0.75	$\rho(p) = 0.7$
σ^p	dis. risk std. dev.	0.55	$\sigma(p)/E[p] = 1$
ω^d	safety skewness	0.002	$skew(\omega) = 6.1$
ρ^ω	safety persistence	0.4	$\rho(\omega) = 0.3$
$\rho^{p\omega}$	corr. safety, disaster	0.4	$\rho(p,\omega) = 0.4$

Table 1: externally set parameters

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 sum of G10 currency countries' GDP was on average 1.6 times that of the U.S. over 1995-2019. The standard deviation of global productivity shocks is set to 0.1% to target U.S. quarterly consumption growth volatility of 0.5%. The capital adjustment cost is set to 2 to match the quarterly volatility of investment growth volatility of 1.6%. The standard deviation of relative productivity shocks is set to 0.7% to match the average output growth volatility of the G10 countries of 0.8%. The autocorrelation is set to 0.9 to match the average year-over-year autocorrelation of G10 countries' GDP relative to U.S. GDP of 0.6.

In terms of asset prices, wealth, and portfolios, Foreign households' discount factor is set to 0.988 to target a 2% annualized real interest rate, and Home households' discount factor is very slightly lower at 0.9876 to target the U.S.' average net foreign asset position relative to annual GDP of -23% over 1995-2019. The volatility of safety shocks is set to match the conditional correlation of the MSCI ACWI equity return

	Description	Value	Moment	Target	Model
ζ^*	rel. pop.	1.6	$y^*/(sy)$	1.6	1.6
σ^z	std. dev. prod.	0.001	$\sigma(\Delta \log c)$	0.5%	0.5%
σ^F	std. dev. rel. prod.	0.007	$\sigma(\Delta \log y^*)$	0.8%	0.8%
ρ^F	persist. rel. prod.	0.9	$\rho(y^*/y, y^*_{-4}/y_{-4})$	0.6	0.7
χ^x	capital adj cost	2	$\sigma(\Delta \log x)$	1.6%	1.7%
β^*	disc. fac. Foreign	0.988	$4\mathbb{E}r$	2.0%	2.0%
β	disc. fac. Home	0.9876	$nfa/(4y)$	-23%	-18%
σ^ω	std. dev. safety	0.91	$\rho_{-1}(r^e, r^* + \Delta \log q - r)$	0.5	0.5
γ^*	RRA Foreign	25	$4\mathbb{E}[r^e - r]$	6.5%	6.8%
γ_*	RRA Home	23	$\beta((\Delta nfa)/y, r^e - r)$	0.5	0.6
$-\bar{b}^g$	safe debt/agg. cons.	0.12	$b^*_{H,s}/(4y)$	3.8%	3.7%
$\bar{\nu}$	ℓ disutility	0.72	ℓ	1	1.0
$\bar{\nu}^*$	ℓ^* disutility	0.72	ℓ^*	1	1.0

Table 2: targeted moments and calibrated parameters

Notes: second moments are reported over a quarterly frequency. Data moments are estimated over Q1 1995 – Q4 2019. Model moments are estimated over 50,000 quarters after a burn-in period of 5,000 quarters, with no disaster realizations in sample.

and excess foreign bond return of 0.5.[17],[18] The resulting parameter implies that ω_t has a quarterly standard deviation of 0.45% in levels. Foreign households have risk aversion of 25 to target the excess annualized real returns on the MSCI ACWI index of 6.5% over this period. Home households have risk aversion of 23 to target the 0.5pp by which U.S. net foreign assets to GDP rises when excess equity returns rise by 1pp.[19] That is, Home agents must be more risk tolerant than Foreign to match the

[17]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 appendix D, we estimate the conditional correlation following Maggiori (2013).

[18]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 $\frac{1}{1+\zeta^*}$ 5-year dollar bonds and $\frac{\zeta^*}{1+\zeta^*}$ 5-year Foreign bonds. The 5-year duration of debt is consistent with maturity of outstanding U.S. 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.

[19]In this regression, we also condition on the contemporaneous excess foreign bond return so that we can isolate the marginal exposure to equity returns.

U.S.' 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% of annual Home output. This is the average ratio of foreign-owned Treasury bills plus central bank liquidity swaps relative to annual U.S. GDP over 2003-2019.

Lastly, we set agents' disutility of labor $\bar{\nu}$ and $\bar{\nu}^*$ to target average labor supply of one in each country, a convenient normalization.

5 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 U.S. net foreign assets in the data.

5.1 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 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 which 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 on Foreign bonds falls when disaster risk is elevated. On the production side, as demonstrated in the third panel of the bottom row, 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
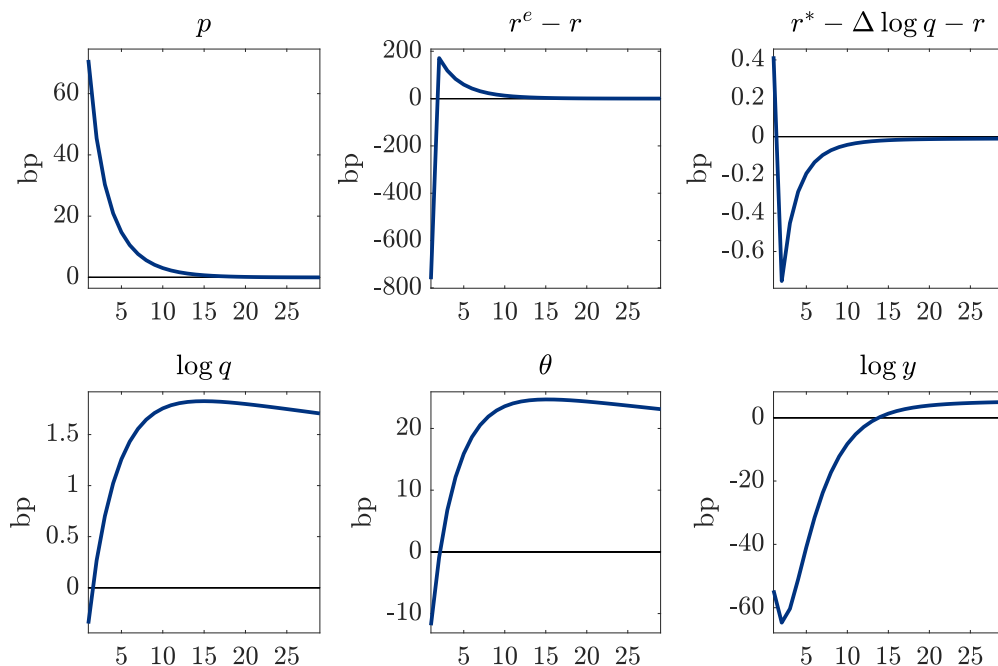
Figure 2: effects of increase in disaster probability

returns comove *negatively* with output, equity returns, and U.S. wealth.

These dynamics extend Maggiori (2017)'s "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 appendix C we demonstrate that this holds not just for disaster risk but also other productivity shocks.

5.2 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 which help to isolate the role of nominal rigidity and heterogeneity in risk-bearing capacity; a full set of impulse responses is again provided in appendix C. When there are no nominal frictions and no heterogeneity in risk tolerance across countries (the light blue responses), the expected real interest rate at Home simply falls to accommodate the increase in safe asset demand, consistent
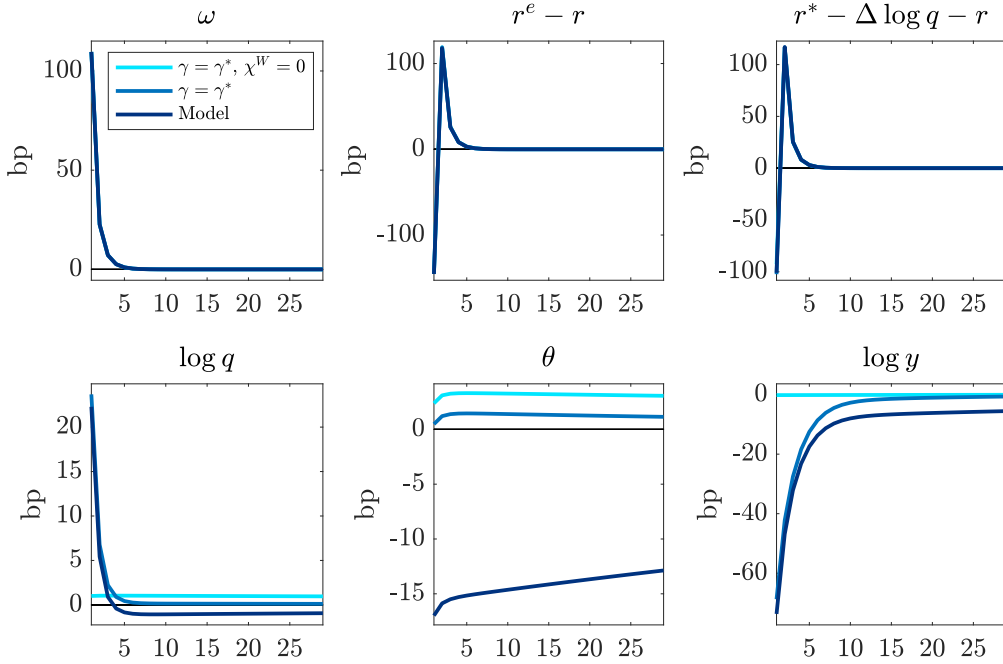
Figure 3: effects of increase in safety

with Proposition 1.[20] This is achieved by an immediate Home deflation and resulting negative excess equity and Foreign bond return on impact. Home experiences an increase in wealth due to the higher seignorage revenues it earns on its safe dollar debt, and 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. 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 as in the calibrated model (the dark blue responses), Home now takes a more substantial levered position in capital and Foreign bonds, so it suffers an immediate valuation loss followed by wealth accumulation over time, as in Proposition 3.

Safety shocks thus provide a resolution to the reserve currency paradox: following

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[20]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 $\gamma = \gamma^*$.

a safety shock, excess foreign bond returns are high as excess equity returns are high, output rises, and U.S. wealth and thus net foreign assets rise. In appendix D we estimate the effects of a shock to the swapped G10/T-bill spread in the data, finding effects which are consistent with these responses.

5.3   Comovements in the international monetary system

The previous subsections demonstrated that safety shocks as well as greater risk tolerance in the U.S. 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. In the data, a $1pp$ year-over-year decline in U.S. industrial production forecasts a $0.2pp$ higher quarterly 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, Maggiori, Neiman, and Schreger (2020);[21] and a $1pp$ higher excess return on foreign bonds is associated with a $1.4pp$ rise in U.S. net foreign assets to GDP, consistent with the exposure of the U.S. to the dollar exchange rate estimated by Tille (2003) and Gourinchas and Rey (2007a).[22] These patterns imply that dollar bonds are a hedge and the U.S. 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, the desire to hedge the real exchange rate risk induced by relative productivity shocks induces Home to take a (large) positive position in dollar bonds and short position in Foreign bonds.

Heterogeneity in risk tolerance is also quantitatively important for the last mo-

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[21]As these authors note, the comovement between the equity return and excess foreign bond return is particularly pronounced after 2008. Our model would generate at least this qualitative pattern if it were extended to match a binding zero lower bound beginning in 2008, as this would amplify the effects of safety shocks on the real economy and thus price of capital.

[22]Consistent with footnote 19, in this regression we also condition on the contemporaneous excess equity return so that we can isolate the marginal exposure to relative bond returns.

	Data	Model	No ω	$\gamma = \gamma^*$
$\beta(r^*_{t+1} - \Delta \log q_{t+1} - r_{t+1}, \log y_t - \log y_{t-4})$	-0.2	-0.1	0.0	-0.1
	(0.1)			
$\beta(r^*_{t+1} - \Delta \log q_{t+1} - r_{t+1}, r^e_{t+1})$	0.2	0.1	-0.0	0.1
	(0.04)			
$\beta((\Delta nfa_{t+1})/y_t, r^*_{t+1} - \Delta \log q_{t+1} - r_{t+1})$	1.4	1.5	-4.1	0.4
	(0.3)			
$Memo$: $(k - \kappa)/(4y)$		67%	66%	1%
$b_H/(4y)$		-108%	164%	6%
$b_F/(4y)$		23%	-239%	-7%

Table 3: comovements in the international monetary system

Notes: data moments estimated over 1995 - 2019. Standard errors are given in parenthesis. First two rows use monthly data and thus Hansen and Hodrick (1980) standard errors with 4 lags to correct for overlapping observations. Model moments are estimated over 50,000 quarters after a burn-in period of 5,000 quarters, with no disaster realizations in sample.

ment. The fourth column of Table 3 assumes identical risk tolerance across countries. Relative to the baseline model, there would be substantially less trade in nominal bonds across countries, evident again from the bottom panel. The seignorage earned by Home on impact of a (persistent) positive safety shock would still induce a positive comovement between Home net foreign assets and excess Foreign bond returns, but this alone would not match the degree of comovement observed in the data.

5.4 Additional untargeted second moments

The previous subsection focused on moments which speak directly to the role of the U.S. in the international monetary system. Here we summarize additional moments of interest regarding returns and exchange rates.

The first panel of Table 4 demonstrates that the model successfully generates excess equity return volatility which is several times that of real interest rate volatility, which in turn is close to the data.[23] In contrast, the model substantially undershoots

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[23]The remaining gap in excess equity return volatility between model and data could be closed if we assume a higher elasticity of intertemporal substitution (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.

	Data	Model	No ω	$\gamma = \gamma^*$
$\sigma(4r_{t+1})$	2.9%	4.2%	2.4%	4.2%
$\sigma(4\left[r^e_{t+1} - r_{t+1}\right])$	33.4%	17.9%	12.9%	17.9%
$\sigma(4\left[r^*_{t+1} - \Delta \log q_{t+1} - r_{t+1}\right])$	20.5%	2.0%	0.4%	2.0%
$\sigma(\Delta \log q_t)$	3.8%	0.3%	0.3%	0.3%
$\rho(\Delta \log q_t)$	0.09	0.07	0.35	0.07
$\sigma(\Delta \log E_t)$	3.8%	0.4%	0.2%	0.4%
$\rho(\Delta \log E_t)$	0.12	0.04	-0.31	0.04
$\rho(\Delta \log q_t, \Delta \log c^*_t - \Delta \log c_t)$	0.1	0.8	0.6	0.9

Table 4: additional second moments

Notes: data moments are estimated over Q1 1995 – Q4 2019. Standard errors are given in parenthesis. Model moments are estimated over 50,000 quarters after a burn-in period of 5,000 quarters, with no disaster realizations in sample.

the volatility of excess foreign bond returns, which the second panel demonstrates is because it undershoots the volatility of exchange rates.

Rationalizing the volatility of exchange rates is a challenge for the literature. In recent contributions, Gabaix and Maggiori (2015) and Itskhoki and Mukhin (2021a) have demonstrated that pure shifts in the demand for bonds in different currencies can amplify exchange rate volatility without affecting macroeconomic aggregates. This would also push toward zero the correlation between real exchange rate movements and relative consumption growth, which the third panel demonstrates is too high in the model.[24] Similar shocks may also amplify the volatility of equity returns. We conjecture that enriching the model with such shocks could improve the model fit in these dimensions without affecting the comovements which are our focus.

6   Macroeconomic and policy implications

Having used asset price data to validate the model, we now quantify its macroeconomic and policy implications. Safety shocks are an important contributor to global

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[24]In the data, the correlation of the log differenced average real exchange rate with the average consumption growth differential between the G10 countries and U.S. is 0.1 during this period. Standard models imply it should be one (the "Backus and Smith (1993) puzzle"). In our model, it is 0.8. As is evident from the third column, safety do not resolve the puzzle because they have the form of a "supply" shock which cause the dollar to appreciate when relative U.S. consumption falls.

	Data	Model	No ω	$\gamma = \gamma^*$
$\sigma(\Delta \log y_t)$	0.59%	0.61%	0.45%	0.59%
$\sigma(\Delta \log y_t^*)$	0.81%	0.78%	0.73%	0.79%

Table 5: output volatility

Notes: data moments estimated over Q1 1995 - Q4 2019. Model moments are estimated over 50,000 quarters after a burn-in period of 5,000 quarters, with no disaster realizations in sample.

macroeconomic volatility. Greater risk tolerance in the U.S. has both destabilizing and stabilizing effects on U.S. external adjustment. Both of these features played important roles in the Great Recession. U.S. monetary policy has disproportionate effects on global asset prices via risk premia. Dollar swap lines are globally stimulative by mitigating the flight to safety.

6.1 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 slightly more than 25% of the output volatility at Home and slightly less than 10% of the volatility in Foreign. In other words, safety shocks are meaningful contributors to global volatility, especially so in the U.S. 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 U.S. external adjustment.

6.2 U.S. external adjustment

Absent heterogeneity in risk-bearing capacity, the model implies that U.S. net foreign assets would be substantially less volatile. At the same time, net exports would bear

	Data	Model	No ω	$\gamma = \gamma^*$
$\sigma((\Delta nfa_t)/y_t)$	11.0%	3.4%	1.9%	0.8%
$\sigma(nx_t/y_t)$	1.0%	1.0%	0.7%	0.8%
$\sigma((\Delta nfa_t - nx_t)/y_t)$	10.9%	3.2%	2.1%	0.2%

Table 6: U.S. net foreign asset volatility

Notes: data moments estimated over Q1 1995 - Q4 2019. Model moments are estimated over 50,000 quarters after a burn-in period of 5,000 quarters, with no disaster realizations in sample.

a greater burden in external adjustment.

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

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

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

Table 6 first summarizes the unconditional volatility 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, but even in their absence the U.S. would still experience more volatility in net foreign assets than net exports. By contrast, the fourth column indicates that greater risk tolerance in the U.S. is essential to explain the relative volatilities of net foreign assets and net exports. Absent its greater risk tolerance, the U.S. would not take large balance sheet exposure to relative returns, and thus net foreign asset volatility would track that of net exports.

We can dig deeper using the model to understand the process of U.S. external adjustment. Iterating on (22) and evaluating news at any date t, we have that

$$(\mathbb{E}_t - \mathbb{E}_{t-1})nfa_t = -(\mathbb{E}_t - \mathbb{E}_{t-1}) \sum_{h=1}^{H} \left(\prod_{i=1}^{h} \frac{1}{1 + r_{t+i}^k} \right) nx_{t+h}$$

	Model	$\gamma = \gamma^*$
As share of $Var\left((\mathbb{E}_t - \mathbb{E}_{t-1})nfa_t\right)$:		
$Cov\left(-(\mathbb{E}_t - \mathbb{E}_{t-1})\sum_{h=1}^{200}\left(\prod_{i=1}^{h}\frac{1}{1+r_{t+i}^k}\right)nx_{t+h}, (\mathbb{E}_t - \mathbb{E}_{t-1})nfa_t\right)$	10%	102%
$Cov\left(-(\mathbb{E}_t - \mathbb{E}_{t-1})\sum_{h=1}^{200}\left(\prod_{i=1}^{h}\frac{1}{1+r_{t+i}^k}\right)val_{t+h}, (\mathbb{E}_t - \mathbb{E}_{t-1})nfa_t\right)$	89%	-4%
$Cov\left((\mathbb{E}_t - \mathbb{E}_{t-1})\left(\prod_{i=1}^{200}\frac{1}{1+r_{t+i}^k}\right)nfa_{t+200}, (\mathbb{E}_t - \mathbb{E}_{t-1})nfa_t\right)$	1%	2%

Table 7: understanding U.S. external adjustment

Notes: moments are estimated over 50,000 quarters after a burn-in period of 5,000 quarters.

$$- (\mathbb{E}_t - \mathbb{E}_{t-1})\sum_{h=1}^{H}\left(\prod_{i=1}^{h}\frac{1}{1+r_{t+i}^k}\right)val_{t+h} + (\mathbb{E}_t - \mathbb{E}_{t-1})\left(\prod_{i=1}^{H}\frac{1}{1+r_{t+i}^k}\right)nfa_{t+H}$$

up to any horizon H periods. 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 U.S. 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.

Applying this decomposition clarifies that, in the absence of greater risk tolerance in the U.S., net exports would bear a greater burden in external adjustment. The first column of Table 7 reports that a substantial fraction of U.S. external adjustment in the model occurs via the valuation channel.[25] This primarily reflects that the U.S. 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, U.S. net foreign assets decline but subsequently rise rapidly as the U.S. earns higher excess returns on its capital position. Absent heterogeneity in risk-bearing capacity in the second column of Table 7, the U.S. would not have disproportionate balance sheet exposure to disaster risk and net exports would bear essentially all of the burden in external adjustment.

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[25]Quantitatively, the role of the valuation channel in our model exceeds the roughly 30% 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.

6.3 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 ω (via ω^d) we feed in the series estimated by Du et al. (2018a). We assume zero innovations to global productivity z and relative productivity z_F and initialize the economy in Q1 1995 in its stochastic steady-state. Figure 4 focuses on the 2006-2011 period when, as we verify, these initial conditions are innocuous.

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 1.9%, Foreign output of 2.1%, and net foreign assets relative to output of 6.9% from the end of Q3 2007 through Q3 2009.[26] These compare with 4.8%, 5.1%, and 10.0% (not detrended) in the data. Moreover, as the last two panels of the figure make clear, as in the data the change in net foreign assets is not primarily due to net exports but rather returns on the U.S. external position.

6.4 Monetary policy

We turn now from macroeconomic outcomes to policy. We begin with monetary policy. The model implies asymmetric risk premium effects of monetary policy shocks originating in the U.S. versus abroad, providing a structural account of a key feature of the recent empirical literature on the "global financial cycle."

A Campbell and Shiller (1988) decomposition of the global equity market return permits a useful summary measure of the risk premium response to a monetary shock which we can compare to the data. We can decompose the real global equity market response to monetary policy shocks in any country using the first order approximation

$$r_t^e - \mathbb{E}_{t-1} r_t^e = (\mathbb{E}_t - \mathbb{E}_{t-1}) \sum_{j=0}^{\infty} \rho^j \Delta \log d_{t+j}^e$$

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[26]Interestingly, while safety shocks alone generate a larger decline in U.S. output, the increase in disaster risk generates a more persistent decline in Foreign output because of the relative increase in U.S. consumption in subsequent periods owing to higher risk premia.
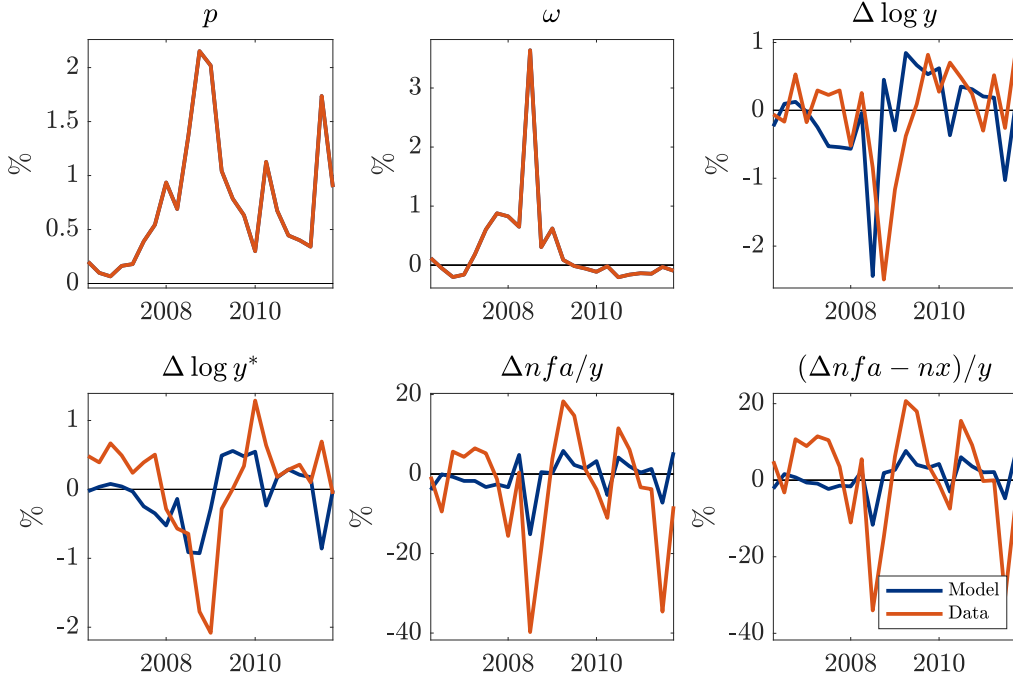
Figure 4: simulation using observed p and ω series

Notes: p is from Barro and Liao (2021) and ω is from Du et al. (2018a) (demeaned). Both are scaled to match the volatilities of p and ω in the model.

$$- (\mathbb{E}_t - \mathbb{E}_{t-1}) \sum_{j=1}^{\infty} \rho^j r_{t+j} - (\mathbb{E}_t - \mathbb{E}_{t-1}) \sum_{j=1}^{\infty} \rho^j (r_{t+j}^e - r_{t+j}), \qquad (23)$$

where d^e denotes dividends, $\rho \equiv \frac{1}{1+\frac{d^e}{p^e}}$, and $\frac{d^e}{p^e}$ is the steady-state dividend yield.

In the data, we perform this decomposition for U.S. and Euro area monetary policy shocks using a structural VAR instrumental variables approach. The details are provided in appendix D and the results are summarized in the first column of Table 8. Accounting for estimation uncertainty, in response to a U.S. monetary policy shock at least 20% and perhaps all of the increase in the MSCI ACWI is due to news about lower excess returns. In contrast, in response to the Euro area monetary policy shock we cannot reject the hypothesis that there is no change in future excess returns. The disproportionate effect of U.S. monetary policy on global risk premia is consistent with a central finding of the literature on the global financial cycle.

Our model generates this asymmetry because a U.S. easing redistributes to relatively risk tolerant agents who are endogenously short dollars. Starting from the

	Data	Model	Model, 2.5% rebal.
U.S. / Home monetary policy shock			
Share excess return news	58%	4%	62%
	[19%, 100%]		
$d\theta/di$		-1.1	-1.2
Euro area / Foreign monetary policy shock			
Share excess return news	-22%	1%	-13%
	[−105%, 54%]		
$d\theta/di^*$		0.2	0.2

Table 8: effects of monetary policy shocks

Notes: for each shock, first line reports share of global equity return due to news about future excess returns given the decomposition in (23) and $\rho = 0.9981$ as estimated on the MSCI ACWI index over 1/1995-11/2016. Second line reports elasticity of wealth share of risk tolerant agents to nominal interest rate.

model's stochastic steady-state, we simulate an unexpected, one-time monetary shock in each country's Taylor rule.[27] Both a Home and Foreign monetary easing raise the price of capital, but the Home easing also implies a dollar inflation and depreciation. Thus, a U.S. monetary easing revalues more wealth in favor of Home ($d\theta/di < d\theta/di^*$). In fact, a Foreign easing revalues wealth away from Home ($d\theta/di^* > 0$).[28]

Since Home agents wish to hold more of the marginal dollar in capital — they have a higher *marginal propensity to take risk*, in the language of Kekre and Lenel (2021) — asset market clearing requires that the risk premium falls by more on impact of a Home easing. As the second column of Table 8 makes clear, however, the risk premium effects are tiny in our baseline model: all agents are actively trading, the aggregate response to changes in expected excess returns is large, and thus there is a small response of the equilibrium risk premium. In a model extension in which only 2.5% of agents (randomly selected) are able to adjust their portfolios each period,

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[27]That is, assuming the economy is in its stochastic steady-state in period 0, we consider a shock to m_0 in the Taylor rule $1 + i_0 = (1 + \bar{i})(P_0/P_{-1})^\phi m_0$, and analogously in Foreign.

[28]If we extended our model to feature heterogeneity in risk tolerance within each country, it would similarly predict that a U.S. easing redistributes more wealth to risk tolerant agents globally who would endogenously borrow in dollars. These could be interpreted as global banks, consistent with their dollar funding as emphasized in Adrian, Etula, and Shin (2010) and Bruno and Shin (2015a,b).

with the remainder following a rule of thumb, the risk premium response becomes substantially larger.[29] In this case, the third column of Table 8 demonstrates that roughly 60% of the increase in the global equity return following a Home monetary easing is due to news about lower future excess returns, whereas news about future excess returns is negative following a Foreign monetary easing.

In this way, the present model extends the risk premium effects of monetary policy via redistribution characterized in Kekre and Lenel (2021) to the global economy.[30] In doing so, it demonstrates that the U.S.' role as world's insurer is in fact structurally linked to the global financial cycle — a connection which, to our knowledge, has not previously been made in the literature.

6.5 Fiscal policy

We finally turn to fiscal policy — in particular, the swap of Foreign bonds for safe dollar bonds, as through the dollar swap lines employed by central banks in recent crises. By (17), an increase in safe dollar bond supply can mitigate the effects of a flight to safety. In this subsection, we quantify the effects on the global economy.

To do so, we need an estimate of the elasticity of safe asset demand ϵ^d in (17). The ideal experiment is an exogenous change in the supply of safe dollar bonds, holding fixed safety shocks which would confound the effect on the convenience yield. We focus on the two-week period beginning in March 19, 2020 when the Federal Reserve announced it would expand from 5 to 14 the number of central banks which could access its swap lines. During this period, the annualized G10/Tbill spread fell by roughly $50bp$ while swap line usage rose by $\$350bn$.[31] Since the volatility of the G10/Tbill spread is roughly one fifth that of ω_t (recalling that swapped G10 currency

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[29]Appendix E discusses this model extension in further detail. It builds on the literature featuring infrequent portfolio rebalancing, as in Alvarez et al. (2002), Bacchetta and van Wincoop (2010), Chien, Cole, and Lustig (2012), and Gabaix and Koijen (2021).

[30]There are no asymmetric effects of monetary policy between Home and Foreign operating via liquidity premia because of our implicit assumption that bonds and money are neither substitutes nor complements in liquidity provision. As discussed in appendix E, this allows us to study the "cashless limit" of Woodford (2003) without loss of generality. If we instead assume bonds and money are substitutes in liquidity provision, a U.S. monetary easing itself would endogenously lower the convenience yield ω_t. Jiang et al. (2020) study an environment without aggregate risk but in which there are asymmetric effects of monetary policy in the U.S. versus rest of the world through asymmetric effects on the dollar convenience yield.

[31]Appendix D provides both series. As the Federal Reserve reports swap line usage on Wednesdays, we use the nearest dates — March 18 and April 1 — to estimate the latter moment.
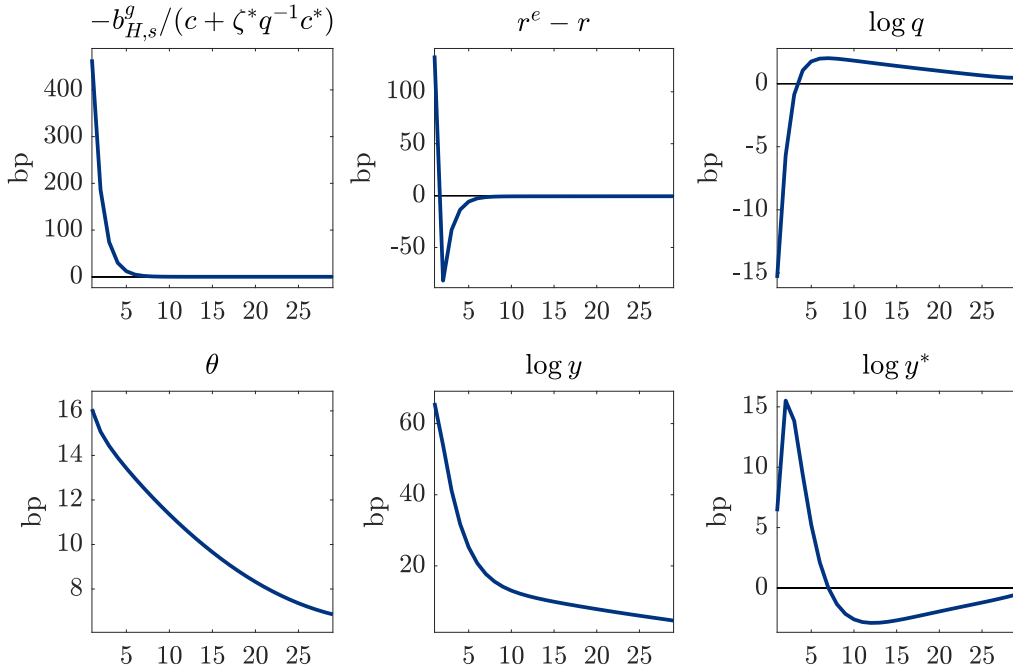
Figure 5: effects of increase in supply of safe dollar bonds

Notes: increase in safe debt supply on impact corresponds to roughly \$450bn in 2020 dollars. Simulation assumes $\epsilon^d = 6$ as motivated in the main text.

bonds may also be valued for their liquidity or safety); the swap line usage of \$350bn is roughly 1.75% of annual U.S. GDP; and annual Home GDP in the model is roughly 2 times quarterly global consumption, equation (17) implies that ϵ^d is approximately 6. This is an overestimate (and thus the results which follow are an underestimate) if this two-week period also featured positive safety shocks which raised the convenience yield despite the expansion in safe dollar debt. This is an underestimate (and thus the results which follow are an overestimate) if this two-week period featured additional increases in safe dollar bond supply beyond the increase in swap line usage.

Given $\epsilon^d = 6$, we can use our model to quantify the effect of the \$450bn total increase in swap line usage by May 2020 during the Covid-19 pandemic. We start for simplicity from the model's stochastic steady-state and consider an unexpected, one-time shock to $\bar{b}^g$ consistent with 2.25% of annual U.S. GDP, assuming it has the same persistence as ω^d in the model (0.4). In a reversal of Figure 3, the resulting lower convenience yield is globally stimulative, disproportionately so at Home, with an accompanying dollar depreciation. Quantitatively, the swap line usage generates

a peak depreciation of the dollar by roughly $15bp$, a peak increase in output by $60bp$ in the U.S., and a peak increase in output by $15bp$ in the rest of the world.

7 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 U.S. 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 U.S. 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 U.S. net foreign asset volatility but mitigates the relative role of net exports in external adjustment. Both safety shocks and heterogeneity in risk-bearing capacity were important during the Great Recession. Monetary and fiscal policies in the U.S. are disproportionately powerful via their effects on global risk and liquidity premia.

There are three natural directions to build on the framework of this paper. First, it would be interesting to extend our analysis beyond a two-country environment. Safety shocks may provide a structural account for the "dollar factor" in the cross-section of carry trade returns.[32] The model would also be a natural laboratory to study why advanced and emerging markets experience asymmetric policy spillovers from the U.S. through risk and liquidity premia in the data.[33] Second, it would be valuable to introduce global banks into our model. Shocks in the interbank market may provide a deeper microfoundation of the flight to safe dollar bonds.[34] Currency intermediation by these banks, together with shocks to the demand for various currencies, could bring the volatilities of exchange rates closer in line with the data. Finally, it would be useful to consider alternative pricing paradigms in our framework, most notably dominant currency (dollar) pricing. Our analytical results suggest potentially rich interactions between the demand for safe dollar bonds and the dollar's use in invoicing, but we

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[32]See Lustig, Roussanov, and Verdelhan (2011) and Verdelhan (2018) for analyses of this factor.
[33]See Kalemli-Ozcan (2020) for estimates of these spillovers in the data.
[34]See Bianchi, Bigio, and Engel (2020) for one recent analysis in this direction.

have neither endogenized these invoicing decisions nor explored these interactions in our quantitative analysis. We leave these exciting questions for future work.

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