A Model of Global Spillovers of U.S. Uncertainty Shocks*

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Abstract

We study the effects of an increase in uncertainty about U.S. asset returns on exchange rates and global asset prices using a two-country general equilibrium model with U.S. based financial intermediaries. Credit spreads rise globally, the dollar appreciates, expected excess foreign currency returns widen, and the U.S. safe rate falls in response to an identified uncertainty shock in the data. A standard open economy general-equilibrium model with incomplete markets cannot reproduce these data patterns. Our model can match the data under the assumption that U.S. banks hold and price risky and safe assets subject to a leverage constraint. Faced with uncertainty shocks, forward looking risk averse U.S. intermediaries adjust their portfolio due to higher future uncertainty about asset returns by shedding risky assets today. The appreciation of the dollar, lower U.S. safe rate, higher risk premia on foreign currencies, and capital flows out of foreign countries into the U.S. are all endogenous responses to higher volatility of U.S. asset returns.

Keywords: Financial Frictions; Risk premia; Time-varying uncertainty, Intermediary Asset Pricing, Global Financial Cycle.

JEL classification: E32; E44; F41.

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1 Introduction

What role U.S. financial intermediaries play in driving returns to risky assets, exchange rates and capital flows around the world? What is the most important model ingredient to explain observed comovements of these variables with measures of U.S. uncertainty? To study these questions, we build a two country general equilibrium model with long-lived U.S-based financial intermediaries. These financial intermediaries are investors in global markets with pricing power and subject to endogenous leverage constraints. Because they are long-lived, their future net worth is important in their global portfolio allocation decisions today. Using the model we quantify effects on global financial markets of an increase in U.S. volatility, and compare it with the observed effects in response to an identified uncertainty (VIX) shock in the data.

Figure 1 illustrates some key comovements of global financial variables in the data. Panel (a) shows the time series of the VIX (an index of expected U.S. stock market volatility), along with series for 5-year BBB bond spreads issued by corporations in the U.S. (in green), in a set of advanced foreign economies (AEs) (blue), and in emerging markets (EMs) (red). All three spread series are highly correlated with the VIX. Panel (b) shows that the VIX moves together with the dollar exchange rate *vis-à-vis* EM currencies: the dollar is strong against emerging market currencies whenever the VIX is elevated. Panel (c) shows a very tight positive correlation between the VIX and UIP premia on foreign currencies.

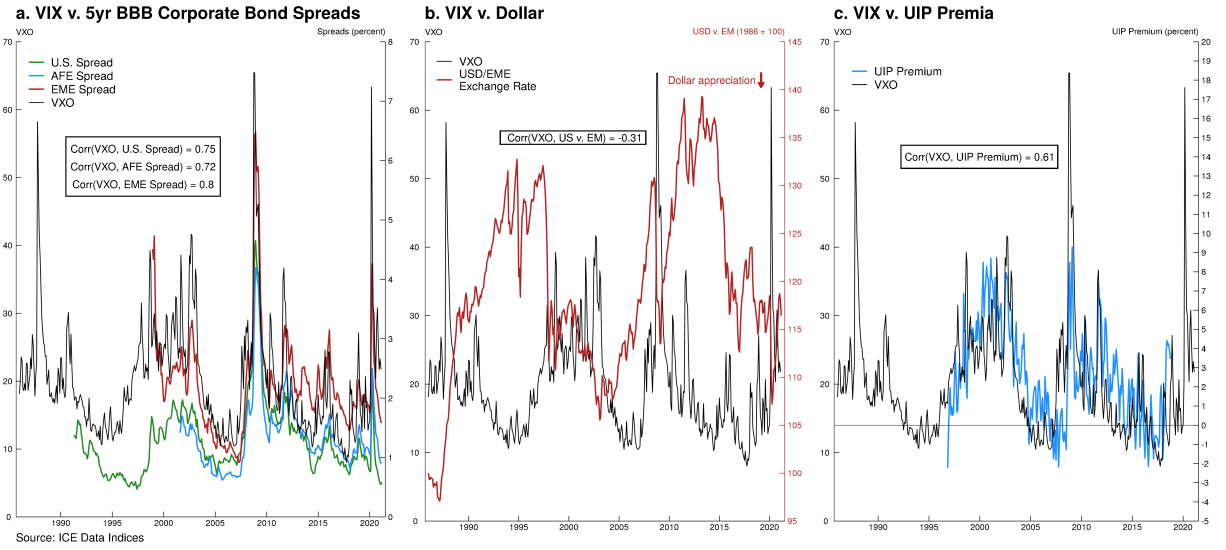
In this paper we quantify the empirical effects of U.S. uncertainty on global financial markets, and we develop an open-economy intermediary asset pricing model that we show rationalizes the evidence. We identify uncertainty shocks in the data as an exogenous increase in the expected volatility of future stock returns, an identification strategy that is consistent with the theoretical model we propose. A one standard deviation increase in uncertainty produces a peak rise in U.S. and foreign credit spreads of about 25 basis points, an increase in UIP premium on foreign currencies of 50 basis points, and leads to an appreciation of the broad real dollar on impact by about 0.5 percent. We also document that higher uncertainty is associated with lower U.S. real risk-free interest rates over the medium term. All told, these results are consistent with the global financial cycle facts documented in the empirical literature.[1]

Standard open economy general-equilibrium models with incomplete markets cannot reproduce this comovement. Instead, we develop here a model based on constrained U.S.-based financial intermediaries that can. The model's key elements are (i) U.S.-based financial intermediaries who are marginal investors in global assets, and (ii) Balance sheet frictions that effectively make intermediaries behave "as if" they were highly risk averse, in a way that magnifies the effects of uncertainty shocks on risk premiums, helping the model rationalize the evidence.

We next provide further details on our model setup. Our model is a two-country framework consisting of the U.S. and a foreign economy or region (e.g. a set of emerging market economies).

[1]Earlier research also documented the importance of U.S. investors' "risk sentiment" measured by the VIX in driving international risky asset prices, capital flows, and bank leverage (e.g. Rey (2013), Miranda-Agrippino and Rey (2021)). These effects are stronger for EMs (Kalemli-Özcan (2019), Kalemli-Özcan and Varela (2021)).

Figure 1: U.S. Stock Market Volatility, Global Credit Spreads, the Dollar, and UIP Premia



The key exogenous driving force in our model is a shock to the volatility of the future productivity (or dividend) of U.S. physical capital. This shock generates time variation in uncertainty about intermediaries' prospective returns on their holdings of U.S. risky assets. Our modeling of these "uncertainty shocks" is similar to that in Basu and Bundick (2017). We believe this approach captures the reality that part of the uncertainty involving future returns is outside the control of intermediaries due to unexpected exogenous disturbances and hence cannot be diversified away ex-ante. Crucially, while uncertainty fluctuations are exogenous in our model, risk premia are fully endogenous, and hence our results do not rely on assuming an unrealistically high risk aversion parameter.

Global financial intermediaries in our model can hold claims to productive risky capital both at home and abroad, as well safe domestic government bonds and foreign government bonds denominated in foreign currency. Households can hold these assets too, but they are subject to management costs or intermediation fees (capturing the relatively lower expertise of households compared to intermediaries)—making financial intermediaries the marginal investors. Our work thus follows the literature on intermediary asset pricing (e.g. He and Krishnamurthy (2013)) in that through intermediaries' pricing of claims on assets, asset prices and risk premia are both linked to frictions in financial intermediation. The key differences of our paper relative to the existing intermediary asset pricing literature are that (i) we focus on international variables such as foreign credit spreads, foreign currencies, and UIP premiums, and (ii) we focus on the effects of time-varying uncertainty on these and other variables. These features also distinguish our work from recent literature on international financial frictions (Itskhoki and Mukhin, 2021; Gabaix and Maggiori, 2015). In our model, the interaction between risk-aversion and financial frictions is key

since this interaction leads to both risk premia and UIP deviations that are highly responsive to changes in U.S. uncertainty.

Arbitrage deviations are sizeable in our quantitative model, that is failures of UIP due to movements in the "risk term" (i.e. the conditional covariance between intermediaries' SDF and the exchange rate) can match the UIP deviations in the data. Notice the difference from the literature: our large UIP failures come from from fluctuations in uncertainty. Hence we have a SDF that is endogenous to changes in risk sentiment.[2] Although we do not assume that global intermediaries face limits to arbitrage in pricing foreign-currency bonds, our model generates UIP deviations—a sizable foreign currency depreciation and a dollar appreciation in the wake of increased U.S. uncertainty. The reason is that these intermediaries are highly exposed to U.S. dividend risk, in a way that makes the UIP premium on foreign currencies highly elastic to U.S. uncertainty. When U.S. uncertainty rises, the UIP premium of foreign currencies shoots up, and the foreign currency depreciates sharply. By contrast, in a model without intermediary frictions, the dollar *depreciates* following higher uncertainty (though the magnitude is small as long as risk aversion is low). We show that the data indicates a stronger dollar, an a higher UIP premia on EM, together with EM capital outflows into U.S., following higher uncertainty, fully consistent with the implications of our model.[3]

The presence of constrained intermediaries is crucial to obtain our results. A rise in uncertainty triggers a reduction in the discounted excess returns that intermediaries expect to obtain from holding the risky asset. Such reduction implies, everything else equal, that intermediaries must operate with a lower leverage cap. This occurs endogenously in our model: the leverage cap is linked to an explicit agency friction between intermediaries and their creditors. This friction endogenously worsens when uncertainty rises. In effect, intermediaries face deleveraging pressure. In equilibrium, as all intermediaries face this deleveraging pressure simultaneously, the asset price has to fall. Turning to the effects on the risk premium, note that because the asset is held by constrained intermediaries, the relevant stochastic discount factor depends not only on the marginal utility of a unit of consumption, but also contains a term that reflects the marginal effect of a unit of wealth on the tightness of financial constraints. Because constraints are tighter in bad times, the latter term is highly countercyclical, and is also highly elastic to the dividend shock, due to the presence of "financial accelerator" feedback effects between asset prices and net worth (which amplifies the response of both variables to a given dividend shock). As a consequence, the risk premium moves up sharply when uncertainty rises, orders of magnitude more than it would absent

[2] A similar approach to us is taken by Bai et al. (2025), though their modeling strategy is very different from ours, relying on long-run risk.

[3] Notice that our model is not subject to standard criticism of generating UIP premia via covariance of returns with SDF, as that premia can be generated without any risk premium. Similarly one can also generate UIP premia without risk aversion by constrained intermediaries and segmented markets where risk neutral intermediaries act as if they are risk averse due to non-convexities in intermediation. Problems with these models is that model implied interest rate is high, which does not fit the fact that U.S. enjoys a convenience yield. Since our UIP premia is not generated this way, we can also match low safe rate and U.S. convenience yield. Another approach is Devereux et al. (2023) where convenience yield is endogenous to liquidity of U.S. dollar assets but that approach requires nominal rigidities.

financial constraints. In this way, our model can generate large movements in risk premia following uncertainty shocks—as observed in the data—without relying on a high risk aversion parameter.

In effect, financial constraints work to make intermediaries endogenously more risk averse, despite a modest value of risk aversion parameter in the utility function. To illustrate this point, we turn off the friction and apply the same uncertainty shock. Given a standard value of just 3 for households' risk aversion (which is equal to intermediaries' risk aversion in the frictionless case), the magnitudes of the effects of uncertainty shocks are very small, as expected; but, importantly, asset values following an increase in uncertainty go up, while they go down in the data. Thus, the intermediary friction is crucial in generating responses both qualitatively and quantitatively consistent with the evidence.

The presence of these global intermediaries imparts a strong comovement in risky asset prices in the two countries, even if the dividends on the underlying assets evolve independently. This occurs through the optimal portfolio condition of these intermediaries, which states that they must be indifferent between holding assets of either country, and therefore implies that differences in expected returns between domestic and foreign capital are quickly arbitraged away. As an example, assume that the economy is hit by a disturbance that drives U.S. excess returns up and the U.S. asset price down. Without any chance in foreign asset prices, global intermediaries would want to shift away from foreign assets and into U.S. assets. To restore equilibrium, the foreign asset price must fall.[4]

Overall, we find that a U.S. uncertainty shock drives asset prices and intermediary capital down, as well as risk premia up, in both countries. What is important here is that the shock originates in the U.S., but *spills over* to the foreign country since U.S. financial intermediaries price both countries' assets. As the required return on emerging market assets rises, there is pressure for capital to flow *out* of the emerging market to satisfy the equilibrium pricing condition. We believe our model is the first to show that an uncertainty shock that originates in the financial center of the world (the U.S.) can spill over strongly to emerging markets, and therefore have properties that resemble a global risk aversion shock. The two will be observationally equivalent in the data given the GFC—that is, the co-movement in risky asset prices and capital flows.

Literature. There is a large literature studying the effects of uncertainty shocks. Well-known examples include Bloom (2009) and Basu and Bundick (2017). This literature focuses on closed economies and mostly frameworks without financial frictions. We on the other hand, study the global effects of fluctuations in uncertainty and try to understand how financial constraints shapes this process. Recently, few papers also introduced financing frictions into closed economy models such as Arellano et al. (2019) and Fernández-Villaverde and Guerrón-Quintana (2020). Alfaro et al. (2018) and Alessandri and Mumtaz (2019) present direct evidence that financial frictions amplify the impact of uncertainty shocks, mainly in closed economies.

[4]A similar form of propagation across markets has also been emphasized by Dedola and Lombardo (2012) and Perri and Quadrini (2018) in open economies, and by Gertler et al. (2016) in a closed economy with two sectors. Differently from these papers, we study spillover effects of second-moment uncertainty shocks, while they focus on first-moment financial or dividend shocks.

The recent work by Itskhoki and Mukhin (2021), Gabaix and Maggiori (2015), Basu et al. (2020) show that shocks to currency intermediation can generate volatile exchange rates and predictable deviations from UIP. There are also papers by Kekre and Lenel (2024) and Devereux et al. (2023), with price stickiness, who focus only on dollar exchange rate and demand shocks together with intermediation shocks. We argue that a shock to uncertainty of risky asset returns can do the same job with shock to currency intermediation in terms of matching exchange rate fluctuations and UIP premia. Since we also do not assume price stickiness and our shocks are about future asset returns, we are closer to papers such as Alvarez et al. (2002) and Heathcote and Perri (2002). Our results on the exchange rate and UIP premium effects of uncertainty do *not* rely on limits to arbitrage in financing foreign bond positions. Instead, the critical feature of our model is the presence of *long-lived* financial intermediaries that face leverage constraints. This feature plays a key role in determining how the conditional covariance between intermediaries' SDFs and the exchange rate reacts following a rise in uncertainty about the future. By contrast, the papers just mentioned generally do not feature long-lived intermediaries.

There is also work by Kekre and Lenel (2021) and Jiang et al. (2021) that employ an exogenous time-varying demand for safe dollar bonds, which can jointly account for greater tolerance in the U.S. for risky portfolios and the appreciation of the dollar in bad times due to increased demand for U.S. Treasuries in those periods. These frameworks are designed to explain CIP deviations (convenience yield) since these deviations are directly tied to safety preference (low hedged return). However these setups cannot explain the high UIP premia in foreign countries (high unhedged return). In our setup, UIP premia on foreign bonds rise sharply when U.S.-based uncertainty rises, because the marginal investors pricing the EM currencies are constrained intermediaries that are exposed to U.S. risk. Through this mechanism, the dollar appreciates relative to EM currencies when uncertainty rises, consistent with the evidence. We view this mechanism as relevant based on evidence suggesting that U.S. intermediaries play an outsized role in pricing EM assets (e.g. Bertaut et al. (2021)), and see our mechanism and those studied in the aforementioned literature as complementary.

Our contribution to this literature on uncertainty shocks' macroeconomic effects is to bring in the impact of such shocks on determining exchange rates, UIP premia, and capital flows. The key mechanism in our model that through which higher uncertainty transmits globally is changes in the net worth position of global financial intermediaries that are leverage constrained. In this respect, an important prediction of our model is that the spreads on international corporate bonds that are held by global banks facing tighter financing frictions (i.e., lower net worth) are more strongly associated with higher U.S. uncertainty. We test this prediction in the data and find strong evidence for our proposed mechanism.

We proceed as follows. Section 2 presents the empirical evidence. Section 3 lays out the model. Section 4 shows the dynamic effects of the uncertainty shocks. Section 5 is devoted to inspecting the key model mechanisms to understand the global transmission of uncertainty shocks and exchange rate determination in the model. Section 6 concludes.

2 Empirical Evidence

This section aims to provide an empirical evidence regarding the quantitative effects of uncertainty shocks on the expected excess returns for holding risky assets around the world, the value of U.S. dollar vis-à-vis foreign currencies, as well as on the U.S. risk-free real interest rates. We use two different measures for the expected excess returns for holding risky assets. First, we use the corporate bond credit spreads for the U.S. dollar denominated bonds to measure expected excess returns on domestic and cross-border equity holdings of global investors. Second, we construct time series to measure deviations from UIP condition that measure risk premia faced by global investors for their holdings of foreign currency government bonds relative to the U.S. treasuries denominated in the dollar. Both of these variables can be directly measured in the model we propose in the next section. We first discuss briefly the identification of U.S. uncertainty shocks and then present the results for the estimated effects of the identified U.S. based uncertainty shock on the evolution of U.S. and foreign financial variables just listed.[5]

2.1 Identification of U.S. Uncertainty Shocks

We identify uncertainty shocks in the data as an exogenous increase in the implied volatility of future stock returns, consistent with the theoretical model presented in Basu and Bundick (2017). We regress a monthly measure of uncertainty on a measure of U.S. real activity and the federal funds rate as shown in equation (1).

$$VIX_t = \alpha + \sum_{i=0}^{i=12} \beta_i X_{t-i} + \sum_{i=1}^{i=12} \gamma_i VIX_{t-i} + \epsilon_t \tag{1}$$

where X_t is a vector of controls and includes the 12-month percent change in the U.S. industrial production and the level of federal funds rate. The model is estimated with 12 lags. We then use the residuals, ϵ_t, as the identified uncertainty shock. We use monthly data from 1990 to 2022.

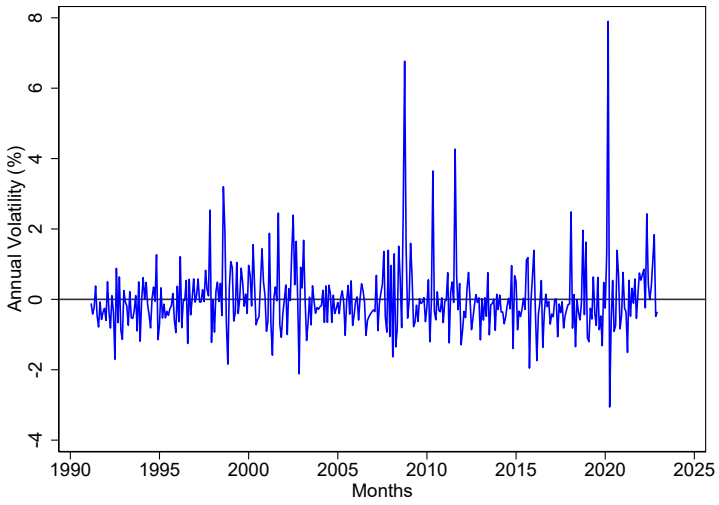
Figure 2 plots the identified uncertainty shocks, and the evolution of the raw VIX over the same period is shown in Figure B.13 in Appendix. The largest uncertainty shocks are during the global financial crisis and more recently during the covid pandemic. While the volatility has been higher on average in the post global financial crisis period, there were also times at which volatility was elevated in the pre-crisis period such as the LTCM crisis.

2.2 Global Effects of U.S. Uncertainty Shocks

We next turn to estimating the effects of uncertainty shocks on the U.S. and foreign corporate credit spreads, the UIP risk premia for holding foreign currencies relative to the U.S. dollar, the value of U.S. dollar vis-à-vis foreign currencies, and the U.S. risk-free real interest rates. These variables are not only commonly used in the literature documenting the global financial cycle facts but also

[5] In Appendix C we present an evidence on the role of global/U.S. banks' equity positions to transmit those shocks across the borders.

Figure 2: **Identified Uncertainty Shocks**



Note: The shocks are calculated as the residuals of a regression of the VIX on contemporaneous and lagged values of 12-month percent change in U.S. industrial production and the level federal funds rate, as well as lagged values of VIX itself. We used monthly data from 1990 to 2022, and included 12 lags in the estimation.

the ones that we can directly measure in the model we propose in the next section. Moreover, as we show, these are the variables critical for us to disentangle the effects of the first order shocks such as productivity shocks, from the second order shocks such as uncertainty shocks, that are at the center of our proposed model.[6]

With the identified uncertainty shocks are at hand, we compute the dynamic responses of U.S. and foreign credit spreads, UIP risk premia for holding foreign currencies, the value of U.S. dollar and the risk free U.S. real interest rates using the local projection method developed by Jordà (2005) at monthly frequency. This method allows us to compute the response of variables to shocks at different horizons without imposing many structural restrictions.

For computing the response of U.S. credit spread, the real broad dollar, and the U.S. risk-free real rate, we estimate the following equation:

$$y_{t+h} = \alpha_h + \beta_h \epsilon_t + \sum_{i=1}^{i=2} \eta_{h,i} \epsilon_{t-i} + \sum_{i=1}^{i=2} \gamma_{h,i} y_{t-i} + \upsilon_{t+h} \tag{2}$$

where y_{t+h} is either the U.S. credit spreads, the real broad dollar index, or the 5-year real U.S. government bond rate in month t+h, ϵ_t is the identified U.S. based uncertainty shocks.[7] In each

[6] As in Kalemli-Özcan and Varela (2021), the UIP premium is measured using deposit and money market interest rates, i_t, and expectations of exchange rates, s_t based on the formula: $UIP_{t+h} = (i_t - i_t^{US}) + (s_{t+h}^e - s_t)$, where h is 12 months. Data sources are listed in Table A.2 in Appendix.

[7] The real broad dollar index contains the currencies of 26 economies for which bilateral trade with the United States accounts for at least 0.5 percent of total U.S. bilateral trade.

regression we include two lags of the dependent variable and of the uncertainty shocks. A plot of β_h is the dynamic response of each of these U.S. variables to an innovation in ϵ_t. We also estimate equation (2) using the VIX index as y_{t+h} to compute its response to the identified shock.

When we compute the foreign credit spreads, and also the UIP risk premia for holding foreign currencies, we take advantage of the panel dimension of our data. More specifically, we estimate a version of equation (2) as follows:

$$y_{c,t+h} = \alpha_{c,h} + \beta_h \epsilon_t + \sum_{i=1}^{i=2} \eta^i_{h,c} \epsilon_{c,t-i} + \sum_{i=1}^{i=2} \gamma^i_{h,c} y_{c,t-i} + \upsilon_{c,t+h} \tag{3}$$

where $y_{c,t+h}$ refers to the credit spread or the UIP premia of country c in month t, and $\alpha_{c,h}$ is a country-specific fixed effect. In all the regressions, the shock is a 1 standard deviation increase in ϵ_t. As we regress all countries on the same shock ϵ_t, our estimates on β_h in this case measures the average response of credit spreads and UIP risk premia across countries to an innovation in ϵ_t.[8]

Figure 3 shows the responses of U.S. credit spreads, foreign credit spreads, the real broad dollar index, the UIP risk premia, and the 5 year U.S. risk free real interest rate to an identified uncertainty shocks.[9] The gray shaded areas denote 90 percent confidence intervals that control for Heteroskedasticity and Autocorrelation (HAC).

One standard deviation shock to U.S. based uncertainty increases the annual volatility index, VIX, by 15 percent on impact. The shock then induces 25 basis points increase in the U.S. credit spreads after a month. The U.S. spreads remains elevated for about eight months before the effect of the shock on the spread almost vanishes. The dynamic response of foreign credit spreads to the U.S. based volatility shocks follow a similar profile to the U.S. one but slightly more persistent. Foreign credit spreads increase by about 30 basis points a month after the shock, as large as the increase in U.S. credit spreads and it takes about ten months before the effect of the shock on the foreign spreads dies out. We also find that higher U.S. based uncertainty leads to an appreciation of the broad real dollar on impact but the effects is not estimated to be very persistent. UIP risk premia for holding foreign currencies increase by about 50 basis and remain elevated for a couple of years. Last but not least, we find that higher uncertainty is associated with lower U.S. real risk-free interest rates over the medium term while the effect of the shock on the risk free rate on impact is largely muted.[10] All told, these results are consistent with the global financial cycle facts documented in the earlier literature, and we documented that an identified uncertainty shock is potentially an important driver.[11]

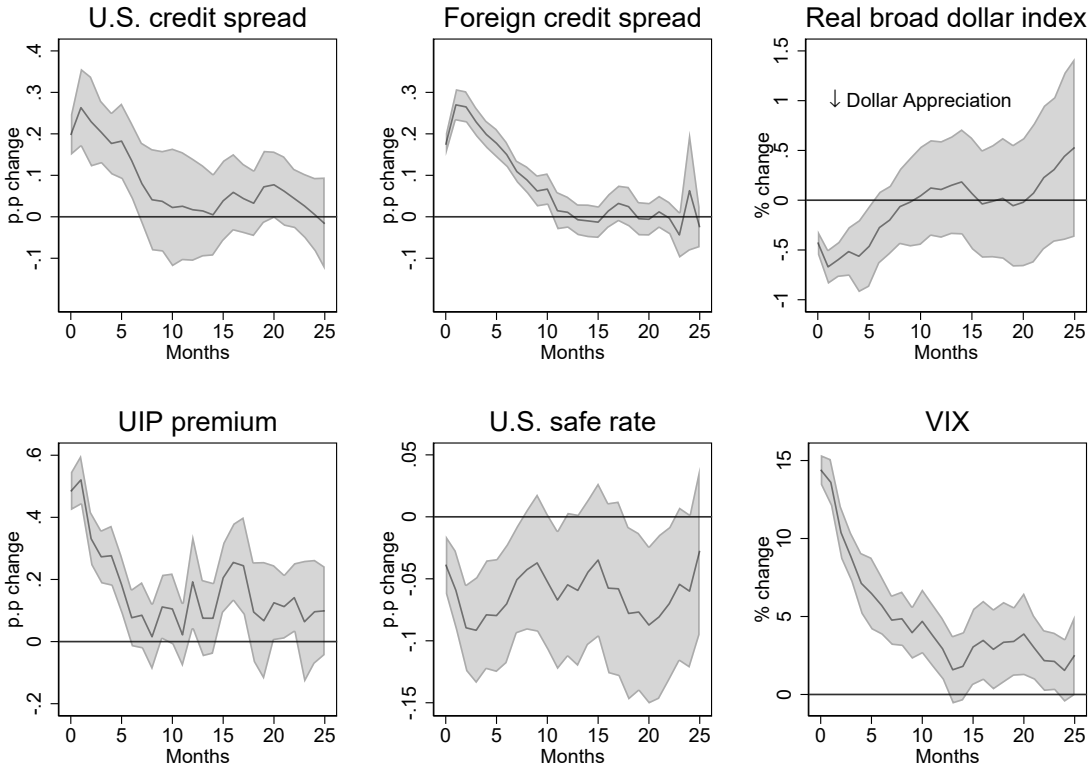
[8] Our panel data sample excludes countries and time periods during which countries in the sample had fixed exchange rate regimes, based on the exchange rate classification provided in Ilzetzki et al. (2017). The list of countries are presented in Table A.1 in Appendix.

[9] Figure B.14 in Appendix shows the response of the same set of variables to a raw VIX index.

[10] It is not shown in the figure, but splitting the foreign countries between the emerging and advanced economies, we find that the shock has larger effects on emerging market corporate credit spreads and also on UIP risk premia for holding emerging market currencies.

[11] In Appendix C we present an evidence on the role of global/U.S. banks' equity positions to transmit those shocks across the borders.

Figure 3: **Empirical Responses to Uncertainty Shock**



Note: Impulse response to a U.S. uncertainty shock. UIP refers to uncovered interest rate parity that is measured using deposit and money market interest rates and expectations of exchange rates from Consensus Forecast. Credit spreads, UIP premia and the real interest rates are in percentage points change. Real broad dollar index and VIX are in percent change. The shaded areas denote 90 percent confidence intervals that control for HAC.

3 Model: Open Lucas Tree Economy with Constrained Global Intermediaries

Our model is an open economy version of a standard single-good exchange economy (as in Lucas (1978)). There are two countries, the United States (home) and a foreign country which is denoted by *. While it is straightforward to extend the model to allow for endogenous production, focusing on an endowment economy helps make our analysis more transparent. Accordingly, we assume there is fixed aggregate supply of capital ("trees") in each country, that produce a random amount of output ("fruit") each period. The productivity of capital, Z_t, follows an exogenous random process that is uncorrelated across countries. In addition, and crucially, the volatility of Z_t in the home economy (which we take to represent the U.S.) is *time-varying*. Thus, uncertainty shocks are captured by the volatility of (next-period) home productivity, denoted $\sigma_{z,t}$.

The model economy features U.S. based financial intermediaries that are specialists in holding home and foreign capital, and foreign-currency government bonds. However, they may face limits in their ability to borrow from their depositors to finance the acquisition of home and EM physical capital. It is because claims on capital held by financial intermediaries are subject to financing frictions (as in, for example, He and Krishnamurthy (2013)) arising from limited enforcement assumption. Households (interpreted as "non-experts") can also hold risky capital but they are less efficient at doing so compared to intermediaries, captured by management costs they have to pay to hold these assets. The three types of agents in the economy are U.S. households, U.S. financial intermediaries, and EM households. We first describe the evolution of aggregate capital's productivity in each country, and then describe these agents in turn.

3.1 Endowment

Aggregate capital in each country is exogenous and its aggregate supply is normalized to unity. Capital's productivity is exogenous and given by random variable Z_t, subject to time-varying volatility:

$$Z_t = (1-\rho_z) + \rho_z Z_{t-1} + \sigma_{z,t-1}\varepsilon_{zt} \tag{4}$$

$$\sigma_{z,t} = (1-\rho_\sigma)\overline{\sigma}_z + \rho_\sigma \sigma_{z,t-1} + \varepsilon_{\sigma t} \tag{5}$$

A positive shock to $\varepsilon_{\sigma t}$ means that agents feel more uncertain about the future productivity of capital. The formulation of uncertainty fluctuations is similar to the one used by Basu and Bundick (2017). We assume that the foreign productivity process, Z_t^*, is given by

$$Z_t^* = (1-\rho_z) + \rho_z Z_{t-1}^* + \overline{\sigma}_z \varepsilon_{zt}^*, \tag{6}$$

where ε_{zt}^* follows an *iid* process (and is thus uncorrelated with ε_{zt}).

3.2 U.S. Households

U.S. households consume and save via deposits at financial intermediaries. Utility is

$$\mathcal{U}_t = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\varrho} - 1}{1-\varrho} - \frac{\alpha}{1+\eta} K_{h,t}^{1+\eta} \right) \tag{7}$$

where C_t is a Cobb-Douglas aggregate of a home-produced good, $C_{H,t}$, and a foreign-produced one, $C_{F,t}$, that is given by:

$$C_t = \left(\frac{C_{H,t}}{\omega} \right)^{\omega} \left(\frac{C_{F,t}}{1-\omega} \right)^{(1-\omega)}, \tag{8}$$

and $K_{h,t}$ denotes the amount of capital stock directly hold by domestic households. We assume that households are not fully efficient at managing their capital stock, which is reflected in terms

of disutility to households with a degree η from their direct holdings of physical capital. The parameter $\omega \in (0.5, 1]$ governs home bias in consumption preferences.

The budget constraint is:

$$\frac{P_{H,t}}{P_t}C_{H,t} + \frac{P_{F,t}}{P_t}C_{F,t} + Q_t K_{h,t} + D_t \leq (\frac{P_{H,t}}{P_t}Z_t + Q_t)K_{h,t-1} + R_{t-1}D_{t-1} + T_t \tag{9}$$

where $P_t = P_{H,t}^{\omega} P_{F,t}^{1-\omega}$ is the consumer price index, $P_{H,t}$ and $P_{F,t}$ are the prices of the domestically produced and imported basket, respectively. The variable Q_t is the price of claims on domestic capital. D_t is deposits, R_{t-1} is the safe interest rate between $t-1$ and t, and T_t is net transfers from bankers.

The first-order condition of the households' optimization problem for the choice between the home- and foreign-produced goods are static and can be expressed, respectively, as:

$$C_{H,t} = \omega \left(\frac{P_{H,t}}{P_t}\right)^{-1} C_t \tag{10}$$

$$C_{F,t} = (1-\omega) \left(\frac{P_{F,t}}{P_t}\right)^{-1} C_t \tag{11}$$

We use identity $P_t C_t \equiv P_{H,t}C_{H,t} + P_{F,t}C_{F,t}$ to write the budget constraint as:

$$C_t + Q_t K_{h,t} + D_t \leq (Z_t + Q_t)K_{h,t-1} + R_{t-1}D_{t-1} + T_t \tag{12}$$

The dynamic first-order condition of the households' optimization problem for physical capital holdings, $K_{h,t}$, and deposits, D_t, are then given, respectively, by:

$$\beta \mathbb{E}_t \left[\left(\frac{C_{t+1}}{C_t}\right)^{-\varrho} \right] R_t = 1 \tag{13}$$

$$\beta \mathbb{E}_t \left[\left(\frac{C_{t+1}}{C_t}\right)^{-\varrho} (\frac{P_{H,t+1}}{P_{t+1}}Z_{t+1} + Q_{t+1}) \right] = \alpha \frac{K_{h,t}^{\eta}}{C_t^{-\varrho}} + Q_t \tag{14}$$

The representative household includes a set of *bankers* who run financial intermediaries. Because they are members of the household, they use the household's stochastic discount factor to value payoffs, and therefore they are risk averse to the extent that the household is. The presence of financial constraints, however, works to magnify the bankers' risk aversion, as we show. We next turn to describing the bankers' problem.

3.3 U.S. Financial Intermediaries

Financial intermediaries ("banks," for short) obtain funds from households and also through internally accumulated net worth. Each banker, denoted by i, uses these funds to finance claims on domestic capital, $K_{i,b,t}$, and on foreign capital, $K_{i,b,t}^*$. They also hold a (real) foreign government

bond, $B^*_{i,t}$, denominated in the foreign currency. We think of these institutions as "global banks," as they hold international private securities and government bonds in addition to domestic private securities.

The balance sheet identity of the bank (in real terms) dictates that the capital funded within a given period—domestic and foreign—and foreign government bond holdings must equal the sum of the banker's own net worth ($N_{i,t}$) and debt raised from domestic households ($D_{i,t}$):

$$Q_t K_{i,b,t} + Q^*_t K^*_{i,b,t} + \mathcal{S}_t B^*_{i,t} = D_{i,t} + N_{i,t} \tag{15}$$

where Q_t is the price of claims on domestic capital, $K_{i,b,t}$, and Q^*_t is the price of claims on foreign capital, $K^*_{i,b,t}$. The variable $\mathcal{S}_t$ is the real exchange rate, defined as the price of the foreign consumption basket in terms of the home basket, and banker's foreign government bond holdings, $B^*_{i,t}$, are expressed in (real) foreign currency terms.

Bankers exit with probability $1-\sigma$, at which point they pay out their earnings to the household. Exiting bankers are replaced by a set of entrant bankers who receive initial equity endowment equal to fraction ξ of the value of the aggregate capital stock.

For a continuing banker, the budget constraint states that the bank's expenditures (consisting of asset purchases, both at home and abroad, and repayment on debt obtained from domestic households, $R_{t-1}D_{i,t-1}$) cannot exceed its revenues (stemming from new financing raised from households, $D_{i,t}$, and payments of previous-period capital and bond holdings):

$$\begin{aligned} Q_t K_{i,b,t} + Q^*_t K^*_{i,b,t} + \mathcal{S}_t B^*_{i,t} + R_{t-1} D_{i,t-1} \leq \\ D_{i,t} + (\frac{P_{H,t}}{P_t} Z_t + Q_t) K_{i,b,t-1} + (\frac{P_{F,t}}{P_t} Z^*_t + Q^*_t) K^*_{i,b,t-1} + \mathcal{S}_t R^*_{t-1} B^*_{i,t-1} \end{aligned} \tag{16}$$

where Z_t and Z^*_t denote the productivity of domestic and foreign capital, respectively. The variable R^*_t denotes the foreign risk-free gross interest rate paid by the foreign country.

Combining equations (15) and (16) we obtain the net worth evolution equation:

$$N_{i,t} = (\frac{P_{H,t}}{P_t} Z_t + Q_t) K_{i,b,t-1} + (\frac{P_{F,t}}{P_t} Z^*_t + Q^*_t) K^*_{i,b,t-1} + \mathcal{S}_t R^*_{t-1} B^*_{i,t-1} - R_{t-1} D_{i,t-1} \tag{17}$$

We motivate a friction in the banks' ability to raise funds by a simple limited enforcement problem, following Gertler and Kiyotaki (2010): after borrowing funds, the banker can renege on the obligations to depositors and instead divert a fraction of the assets he or she owns. This puts an endogenous limit on how much creditors allow the banker to lever up in the first place. Thus, the banker's incentive constraint is:

$$V_t \geq \theta \left(Q_t K_{i,b,t} + Q^*_t K^*_{i,b,t} \right) \tag{18}$$

where the parameter θ denotes the fraction that can be diverted. The incentive compatibility constraint states that the value of "misbehaving" must be no larger than the value of operating

"honestly."

We solve the banker's problem by undetermined coefficients. As it is standard, we begin by guessing that the value function is linear.

$$V_{i,t} = \Psi_t N_{i,t},$$

where Ψ_t is non-bank-specific. We also define the following ratios:

$$\begin{aligned}
\phi_{i,t} &= \frac{Q_t K_{i,b,t}}{N_{i,t}} \\
\phi^*_{i,t} &= \frac{Q^*_t K^*_{i,b,t}}{N_{i,t}} \\
\phi^*_{i,b,t} &= \frac{\mathcal{S}_t B^*_{i,t}}{N_{i,t}}
\end{aligned}$$

The variable $\phi_{i,t}$ is the ratio of domestic risky assets to net worth, the banker's leverage. The variables $\phi^*_{i,t}$ and $\phi^*_{i,b,t}$ are the ratio of foreign risky assets to net worth and foreign government bonds to net worth, respectively. All three ratios also turn out to be independent of banker-specific variables. In anticipation of that result we write $\phi_{i,t} = \phi_t$, $\phi^*_{i,t} = \phi^*_t$, and $\phi^*_{i,b,t} = \phi^*_{b,t}$.

The banker's problem can then be re-written as:

$$\Psi_t = \max_{\phi_t, \phi^*_t, \phi^*_{b,t}} \quad \phi_t \mu_t + \phi^*_t \mu^*_t + \phi^*_{b,t} \mu^*_{b,t} + \nu_t \tag{19}$$

subject to

$$\phi_t \mu_t + \phi^*_t \mu^*_t + \phi^*_{b,t} \mu^*_{b,t} + \nu_t \geq \theta \left(\phi_t + \phi^*_t\right) \tag{20}$$

where expected discounted excess returns for holding a unit of net worth, ν_t, or a unit of domestic capital, foreign capital, and foreign bonds, μ_t, μ^*_t, $\mu^*_{b,t}$, are given, respectively, by:

$$\begin{aligned}
\nu_t &= \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}]R_t \\
\mu_t &= \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}(R_{k,t+1} - R_t)] \\
\mu^*_t &= \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}(R^*_{k,t+1} - R_t)] \\
\mu^*_{b,t} &= \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}(\frac{\mathcal{S}_{t+1}}{\mathcal{S}_t}R^*_t - R_t)]
\end{aligned}$$

where

$$R_{k,t+1} = \frac{\frac{P_{H,t+1}}{P_{t+1}} Z_{t+1} + Q_{t+1}}{Q_t}$$
$$R^*_{k,t+1} = \frac{\frac{P_{F,t+1}}{P_{t+1}} Z^*_{t+1} + Q^*_{t+1}}{Q^*_t}$$

with

$$\Lambda_{t,t+1} \equiv \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\varrho}$$
$$\Omega_{t,t+1} \equiv 1 - \sigma + \sigma \Psi_{t+1}$$

Note that the banker uses the discount factor $\Lambda_{t+1}\Omega_{t+1}$ to evaluate payoffs, which weighs the household's stochastic discount factor with the prospective value of a unit of net worth to the banker.

The solution of the banker's problem states that the expected discounted excess returns on banks holding of claims for domestic and foreign risky assets have to equalize, $\mu_t = \mu^*_t$. Furthermore, expected discounted excess returns for holding a unit of foreign government bonds have to be zero, $\mu^*_{b,t} = 0$. As long as the total excess return μ_t satisfies $0 < \mu_t < \theta$, the incentive constraint (20) binds, which then gives us the following definition of the banker's total leverage $\bar{\phi}_t = \phi_t + \phi^*_t$:

$$\bar{\phi}_t = \frac{\nu_t}{\theta - \mu_t}. \tag{21}$$

Observe that ϕ_t is the same for all banks. The undetermined coefficient Ψ_t can then be solved from equation (19).

In each period, any banker exits with probability $1-\sigma$. The exiting bankers are replaced by new entrants who receive a transfer from the household equal to fraction ξ of the value of the capital stock in the previous period. Accordingly, the evolution of aggregate net worth, N_t, is:

$$N_t = \sigma \Big[(R_{k,t} - R_{t-1}) Q_{t-1} K_{b,t-1} + (R^*_{k,t} - R_{t-1}) Q^*_{t-1} K^*_{b,t-1} + (\frac{\mathcal{S}_t}{\mathcal{S}_{t-1}} R^*_{t-1} - R_{t-1}) S_{t-1} B^*_{t-1} + R_{t-1} N_{t-1} \Big] + (1-\sigma)\xi \left[Q_{t-1} K_{b,t-1} + Q^*_{t-1} K^*_{b,t-1} + \mathcal{S}_{t-1} B^*_{t-1} \right] \tag{22}$$

3.4 Foreign Households

The foreign households consume and save via home capital holdings, $K^*_{h,t}$, as well as holdings of home risk-free government bonds, $B^*_{h,t}$.

Utility is

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{(C^*_t)^{1-\varrho} - 1}{1-\varrho} - \frac{\alpha^*}{1+\eta^*} (K^*_{h,t})^{1+\eta^*} - \frac{\alpha^*_b}{1+\eta^*_b} (B^*_{h,t})^{1+\eta^*_b} \right) \tag{23}$$

where C_t^* is a Cobb-Douglas aggregate of a foreign-produced good, $C_{F,t}^*$, and a home-produced one, $C_{H,t}^*$:

$$C_t^* = \left(\frac{C_{F,t}^*}{\omega}\right)^{\omega} \left(\frac{C_{H,t}^*}{1-\omega}\right)^{(1-\omega)} \tag{24}$$

where the parameter $\omega \in (0.5, 1]$ governs home bias in consumption preferences. Similar to home households we assume that households are not fully efficient at managing their holdings of capital stock and holdings of home government bonds, which is reflected as they having disutility from their direct holdings of these assets.

The budget constraint is:

$$\begin{aligned} &P_{F,t}^* C_{F,t}^* + P_{H,t}^* C_{H,t}^* + P_t^* \mathcal{S}_t^{-1} Q_t^* K_{h,t} + P_t^* B_{h,t}^* \leq \\ &P_t^* (Z_t^* + \mathcal{S}_t^{-1} Q_t^*) K_{h,t-1}^* + P_t^* R_{t-1}^* B_{h,t-1}^* + P_t^* T_t^* \end{aligned} \tag{25}$$

where P_t^* is the Consumer Price Index, $P_{F,t}^*$ and $P_{H,t}^*$ are the prices of the domestically produced and imported basket, respectively. The variable Q_t^* is the *dollar* price of claims on home capital. The variable R_{t-1}^* is the safe interest rate between $t-1$ and t, and T_t^* is net transfers to foreign households.

The first-order conditions of the households' optimization problem for the choice between the home- and foreign-produced goods are:

$$C_{H,t}^* = (1-\omega) \left(\frac{P_{H,t}^*}{P_t^*}\right)^{-1} C_t^* \tag{26}$$

$$C_{F,t}^* = \omega \left(\frac{P_{F,t}^*}{P_t^*}\right)^{-1} C_t^* \tag{27}$$

where

$$P_t^* = (P_{F,t}^*)^{\omega} (P_{H,t}^*)^{1-\omega} \tag{28}$$

As before, we use identity $P_t^* C_t^* = P_{F,t}^* C_{F,t}^* + P_{H,t}^* C_{H,t}^*$ to rewrite the budget constraint in real terms:

$$C_t^* + \mathcal{S}_t^{-1} Q_t^* K_{h,t} + B_{h,t}^* \leq \left(\frac{P_{F,t}^*}{P_t^*} Z_t^* + S_t^{-1} Q_t^*\right) K_{h,t-1}^* + R_{t-1}^* B_{h,t-1}^* + T_t^* \tag{29}$$

The first-order conditions of the foreign households' optimization problem are:

$$\beta \mathbb{E}_t \left[\left(\frac{C^*_{t+1}}{C^*_t} \right)^{-\varrho} \right] R^*_t = \alpha^*_b \frac{(B^*_{h,t})^{\eta^*_b}}{(C^*_t)^{-\varrho}} + 1 \tag{30}$$

$$\beta \mathbb{E}_t \left[\left(\frac{C^*_{t+1}}{C^*_t} \right)^{-\varrho} \left(\frac{P^*_{F,t+1}}{P^*_{t+1}} Z^*_{t+1} + \mathcal{S}^{-1}_{t+1} Q^*_{t+1} \right) \right] = \alpha \frac{(K^*_{h,t})^{\eta}}{(C^*_t)^{-\varrho}} + \mathcal{S}^{-1}_t Q^*_t \tag{31}$$

3.5 Terms of Trade, Real Exchange Rate and Market Clearing

We assume that both countries practice producer currency pricing and the law of one price holds: $P_{H,t} = P^*_{H,t}$ and $P_{F,t} = P^*_{F,t}$. We denote the terms of trade (defined as the price of the foreign good in terms of the home good, $\frac{P_{F,t}}{P_t}$) by $\mathcal{T}_t$, and the real exchange rate (defined as the price of the foreign consumption basket in terms of the home basket) by $\mathcal{S}_t$:

$$S_t \equiv \frac{P^*_t}{P_t}$$

Using $P_t = P^{\omega}_{H,t} P^{1-\omega}_{F,t}$, $P^*_t = (P^*_{F,t})^{\omega} (P^*_{H,t})^{1-\omega}$, it is then straightforward to show that $\mathcal{T}_t$ and $\mathcal{S}_t$ must satisfy the following condition:

$$\mathcal{S}_t = \mathcal{T}^{2\omega-1}_t \tag{32}$$

There are five markets: for home and foreign goods, for claims on home and foreign capital, and for foreign government bonds. These are given, respectively, by:

$$C_{H,t} + C^*_{H,t} = Z_t \tag{33}$$

$$C_{F,t} + C^*_{F,t} = Z^*_t \tag{34}$$

$$K_{h,t} + K_{b,t} = 1 \tag{35}$$

$$K^*_{h,t} + K^*_{b,t} = 1 \tag{36}$$

$$B^*_{h,t} + B^*_{b,t} = 0 \tag{37}$$

where $K^*_{b,t}$ is total claims by home bankers on foreign capital, and $K^*_{h,t}$ is total claims by foreign households on home capital. Foreign government bonds are in zero net supply, so that the amount held by global banks, $B^*_{b,t}$, must be offset by holdings of households.

Given the above, combining U.S. households' and global banks' budget constraints we get the following balance of payments identity:

$$C_t + Q^*_t (K^*_{b,t} - K^*_{b,t-1}) + \mathcal{S}_t (B^*_{b,t} - R^*_{t-1} B^*_{b,t-1}) = \frac{P_{H,t}}{P_t} Z_t + \frac{P_{F,t}}{P_t} Z^*_t K^*_{b,t-1} \tag{38}$$

We present the complete set of equilibrium conditions in Appendix D.

3.6 Solution Method and Calibration

Our primary focus is examining the effect of an increase in the second moment of capital's productivity process in the U.S., $\sigma_{z,t}$. As in Basu and Bundick (2017), in order to examine the impulse response to a second-moment shock, we solve the model using a third-order approximation of the policy functions of the model using the Dynare software package. Dynare computes the rational expectations solution to the model using third-order Taylor series approximation around the deterministic steady state of the model.

Table 1 lists the calibrated and estimated parameters of our model. The household risk aversion, ϱ, and discount factor, β, are set to reasonably conventional values. We calibrate the home bias parameter, ω, to 0.95, consistent with the empirical value of the share of final goods imports in U.S. GDP of about 5 percent.

The parameters specific to the intermediary friction include the banking survival rate, σ, the transfer rate to new bankers, ξ, and the fractions of different assets that can be diverted, θ. We set the survival rate to 0.95, implying a 5 percent dividend payout ratio, similar to Gertler and Karadi (2011). We set θ and ξ to hit two targets: a steady-state U.S. credit spread (or risk premium) of around two hundred basis points and a total financial sector leverage of global banks of around four. These targets reflect the average values of corporate bond spreads for the U.S. and an estimate of intermediary leverage from MORELLI, respectively. The parameter values resulting from these targets, $\theta = 0.25$ and $\xi = 0.01$, are well within the range of values used within the related literature. We calibrate the parameters of households' financial technology to match the share of U.S. capital held by global banks, the share of total foreign assets held by global banks, and the volatility of credit spreads.

The bottom of Table 1 shows the parameters pertaining to the stochastic processes (including for the uncertainty shock). We calibrate the processes for the home and foreign endowment to roughly replicate the properties of U.S. and foreign GDP, and we calibrate the uncertainty shock process to match the standard deviation and autocorrelation of the VIX. The resulting parameters are close to those in Basu and Bundick (2017).

4 Quantitative Analysis

We now turn to a quantitative analysis of the model. We focus on the effect of U.S. based uncertainty shock, $\sigma_{z,t}$. Figure 4 shows the model-implied counterparts of responses to a higher U.S. uncertainty of the variables shown in Figure 3. In particular, the figure displays the effects on credit spread (or risk premium) $\mathbb{E}_t[R_{k,t+1} - R_t]$, on exchange rate $\mathcal{S}_t$, as well as on its cross-border effects including the effects on foreign credit spreads $\mathbb{E}_t[R^*_{k,t+1} - R_t]$ and expected excess foreign currency returns $\mathbb{E}_t[\frac{\mathcal{S}_{t+1}}{\mathcal{S}_t} R^*_t - R_t]$ (or UIP premium for holding foreign currency). We calibrate the size of the uncertainty shock such that the impulse response for the model-implied measure of aggregate uncertainty, VIX, rises just above 15 percent on impact as shown in the last panel of the figure,

Table 1: Parameter Values

Parameter	Description	Value	Target
HH Preferences			
β	Discount factor	0.99	Standard value
ϱ	Risk aversion	5	Average VIX
ω	Home bias	0.95	U.S. import share
Global banks			
σ	Survival probability	0.95	Standard value
ξ	New banker endowment	0.01	Global bank leverage
θ	Divertable share	0.25	Average credit spread
HH financial technology			
α	Mgt. cost, home	1	Bank's U.S. capital share
α^*	Mgt. cost, foreign	11	Bank's foreign capital share
η	Mgt. cost, curvature	5	Spreads volatility
Shock processes			
ρ_z	Autocorr. productivity shock	0.90	Data
ρ_σ	Autocorr. uncertainty shock	0.70	Data
$\overline{\sigma}_z$	Avg. SD of productivity	0.01	Data
σ_{ϵ_σ}	SD of Uncertainty shock	0.001	Data

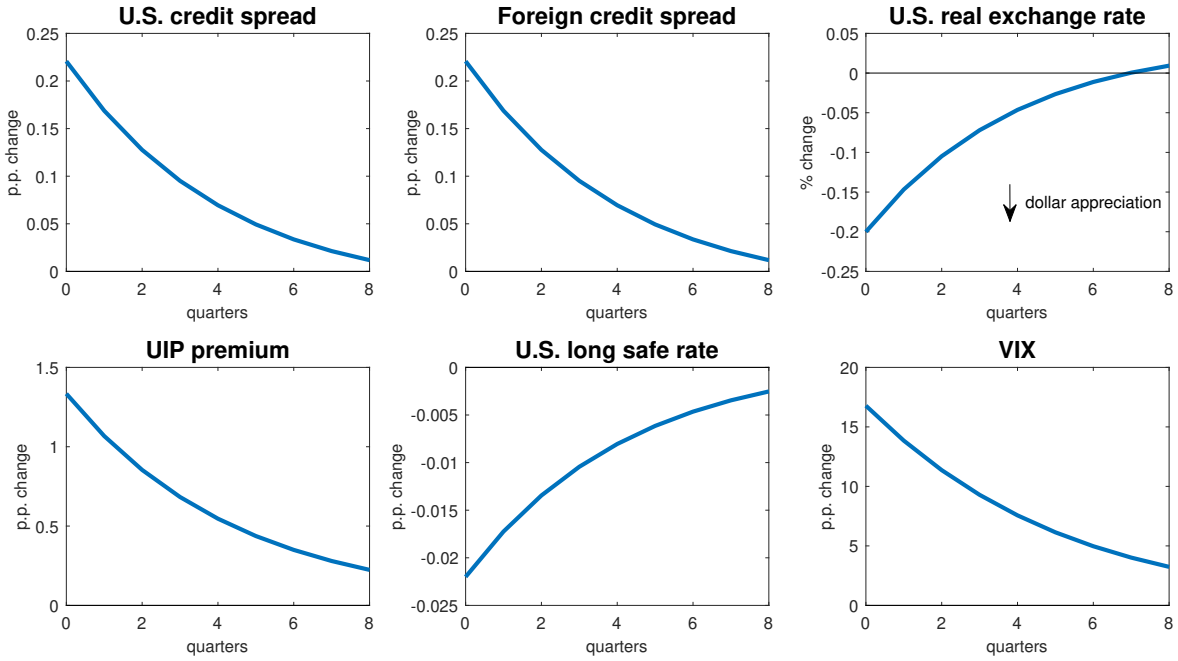
which is closely matching the one from our identified VAR.[12]

The model does pretty well in matching both the magnitudes and the dynamics of global financial variables to an increase in U.S. based uncertainty. The shock leads to an increase in corporate bond spreads in the U.S. and in foreign economies of just above 20 basis points. The model-implied effects are generally very close to the empirical ones, especially for credit spreads. Credit spreads, both in the U.S. and abroad, remain elevated for about two years. Higher U.S. based uncertainty leads to an appreciation of the broad real dollar on impact, and the effect of the shock on the real broad dollar dies out after one-and-a-half year. Similar to its empirical counterpart, UIP risk premium for holding foreign currencies increase on impact and remains high for more than two years. The model-implied impact response, about 130 basis points, is a bit higher than what is shown in Figure 3, but we note that the effects are broadly consistent with the estimates from a panel results obtained using data only coming from emerging market countries. Last but not least, we find that higher uncertainty is associated with lower U.S. long safe rate, consistent with the empirical results documented here or elsewhere in the literature.

We next turn to discuss the transmission mechanism of uncertainty shocks through their effects on the price of capital both at home and abroad Q_t and Q_t^*, on intermediary net worth N_t. Figure 5 presents the results. The prospect of a more-risky total capital productivity (i.e., higher VIX) has the effect of lowering the expected excess returns from holding risky assets. This occurs through

[12] We compute the model counterpart of an aggregate annual uncertainty as $VIX_t = 100 * \sqrt{4 * \text{VAR}_t(R_{k,t+1})}$, where $\text{VAR}_t(R_{k,t+1})$ is the quarterly conditional variance of the expected return on risky capital.

Figure 4: **Model-Implied Responses to Uncertainty Shock**

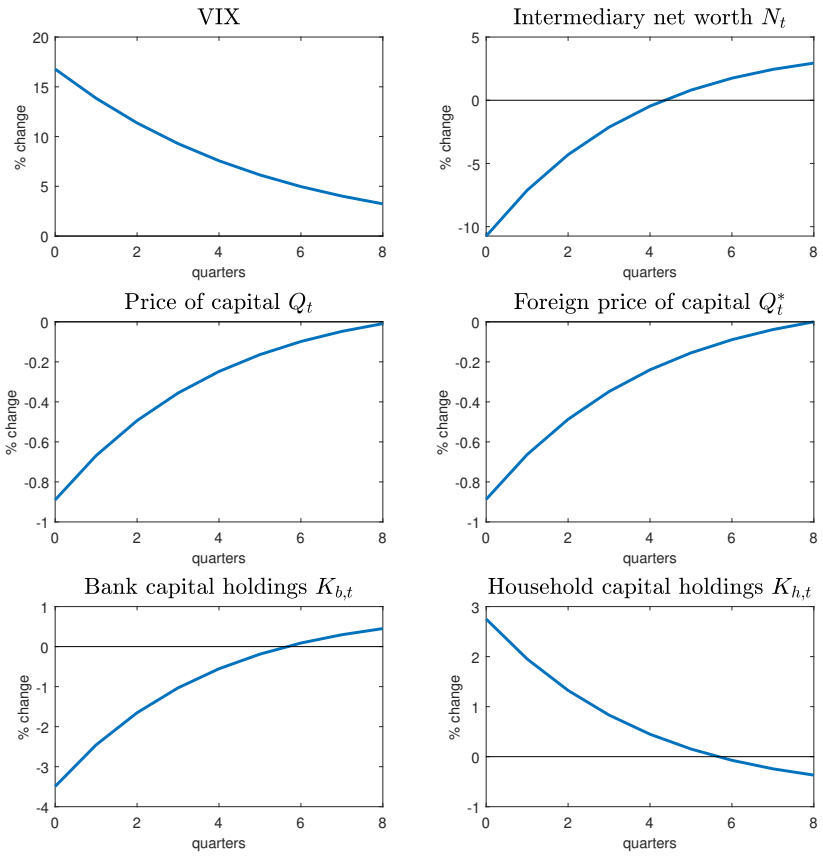


a downward movement in $cov_t(\mathbf{\Omega}_{t+1}, R_{k,t+1} - R_t)$, which is negative on average, and turns more negative when aggregate uncertainty rises. A lower expected excess returns puts downward pressure on asset prices at home Q_t (for a given net worth of global banks, N_t). In addition, the decline in the asset price Q_t works to depress intermediary net worth N_t, via a lower realized return $R_{k,t}$—this is the standard "financial accelerator" feedback effect between asset prices and net worth. This explains the observed responses in N_t and Q_t in the figure. At the same time, intermediation becomes riskier in response to higher uncertainty, which endogenously tightens intermediaries' leverage constraints. Thus with higher home uncertainty, *both* home and foreign assets effectively become riskier, and thus intermediaries face deleveraging pressure for both types of risky assets whether it is home or foreign assets, giving rise to a decline in bankers' holding of risky capital $K_{b,t}$ and the foreign asset prices Q_t^*. As shown in the last panel of the figure, households tend to absorb the risky capital that bankers sell, explaining the positive response of $K_{h,t}$ on impact to higher U.S. based uncertainty. These mechanisms will be discussed further in Section 5.

5 Understanding the Key Features of the Model

In this section, we start with the autarky to clarify what are the key determinants of global spillovers of uncertainty shocks discussed in the previous section. We think an economy in autarky provides useful insight into how uncertainty shocks propagate in this economy. We then consider the effects of higher uncertainty in the financially integrated economy in a hypothetical one-good setup where

Figure 5: Model-Implied Responses to Uncertainty Shock–Additional Model Variables



exchange rate would be fixed. We will then move to the open economy version of the model with two goods that features deviations from UIP conditions and fluctuations in exchange rates.

5.1 Uncertainty shocks in autarky

Financial autarky in the model is characterized by the case in which home bankers do not have access to either foreign risk-free government bonds or foreign capital. The model then reduces to the following system of four equations:

$$1 = \beta \mathbb{E}_t \left[\left(\frac{Z_{t+1}}{Z_t} \right)^{-\varrho} \right] R_t, \tag{39}$$

$$\mu_t = \mathbb{E}_t[\mathbf{\Omega_{t+1}}(R_{k,t+1} - R_t)], \tag{40}$$

$$Q_t = \frac{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]R_t}{\theta - \mu_t} N_t, \tag{41}$$

$$N_t = \sigma[(R_{k,t} - R_{t-1})Q_{t-1} + R_{t-1}N_{t-1}] + (1-\sigma)\xi Q_{t-1}, \tag{42}$$

determining the four endogenous variables $\{R_t, \mu_t, Q_t, N_t\}$, where $R_{k,t+1} \equiv (Z_{t+1} + Q_{t+1})/Q_t$ and

$$\mathbf{\Omega}_{t+1} \equiv \beta \left(\frac{Z_{t+1}}{Z_t} \right)^{-\varrho} \left(1 - \sigma + \sigma\theta \frac{Q_{t+1}}{N_{t+1}} \right), \tag{43}$$

for a given exogenous process of capital's productivity, Z_t, and its volatility, $\sigma_{z,t}$.

Equation (39) is the household's Euler equation determining the risk-free rate R_t. The variable μ_t in equation (40) is financial intermediaries *expected discounted excess return*—the prospective return on assets net of the risk-free rate, evaluated using the *intermediaries'* stochastic discount factor: $\mathbf{\Omega}_{t+1}$. This discount factor augments the household's marginal utility of consumption in $t+1$ relative to t (given by $(Z_{t+1}/Z_t)^{-\varrho}$) with a term equal to the probability weighted average of the marginal value of net worth to exiting and continuing bankers in $t+1$. For bankers that exit (which occurs with probability $1-\sigma$), the marginal value of net worth is simply unity. For bankers that continue, the marginal value of net worth is $\Psi_{t+1} = \phi_{t+1}\mu_{t+1} + \nu_{t+1} = \theta \frac{Q_{t+1}}{N_{t+1}}$, where the latter equality follows from the fact that the constraint binds. In bad times, N is low relative to Q (net worth is scarce). This makes the banker's SDF much more countercyclical than the households'.

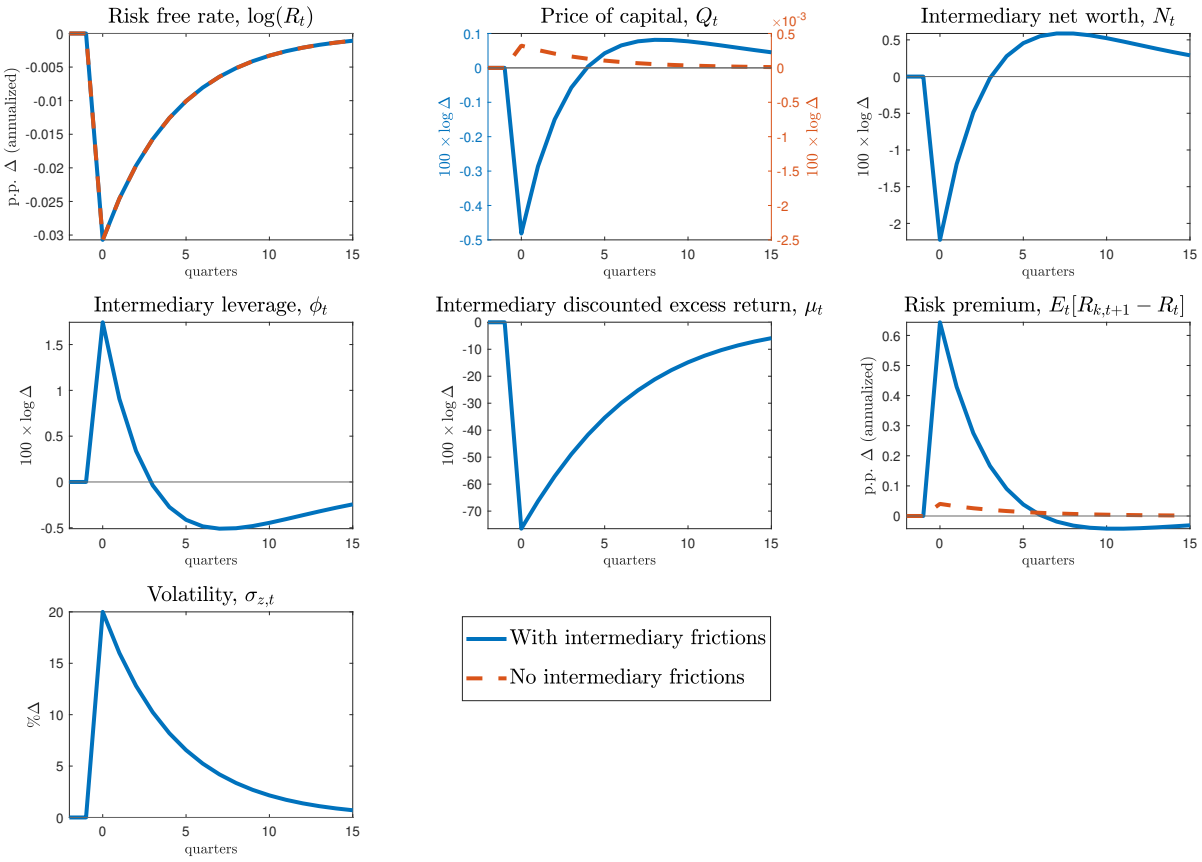
Equation (41) is the intermediaries' incentive constraint at equality. It can be viewed as an endogenous *leverage* constraint, where $\frac{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]R_t}{\theta - \mu_t}$ determines the maximum leverage that banks' balance sheets can assume. Given a binding constraint, the aggregate value of assets (which equals Q_t, since the aggregate supply of capital is fixed at unity) must be equal to the leverage times intermediaries' aggregate net worth. Importantly, leverage is *increasing* in μ_t: everything else equal, lower expected excess returns imply a lower continuation value for the bank. With a binding incentive constraint, this must be met by a lower value of banks' leverage.

Equation (42) describes the evolution of aggregate net worth. The latter is given by the sum of surviving bankers' net worth and the endowment of entering bankers, with the net worth of survivors determined by the realized excess return on capital plus the earnings on previous-period net worth.

We now turn to the effects of an increase in aggregate uncertainty in this economy, depicted in Figure 6. The dividend's volatility $\sigma_{z,t}$ increases by twenty percent relative to its steady-state level, as shown in the last panel of the figure. The prospect of a more-risky Z_{t+1} has the effect of lowering the excess return μ_t. This occurs through a downward movement in $cov_t(\mathbf{\Omega}_{t+1}, R_{k,t+1} - R_t)$, which is negative on average, and turns more negative when aggregate uncertainty rises. A lower μ_t puts downward pressure on leverage. Through (41), this leads to lower Q_t (for a given N_t). In addition, the decline in the asset price Q_t works to depress N_t, via a lower realized return $R_{k,t}$—this is the standard "financial accelerator" feedback effect between asset prices and net worth.

As seen in Figure 6, the *risk premium*, defined as $\mathbb{E}_t[R_{k,t+1} - R_t]$, also rises sharply following an increase in uncertainty. This is driven by the effect of higher risk on the covariance between

Figure 6: Dynamic effects of uncertainty shock, autarky



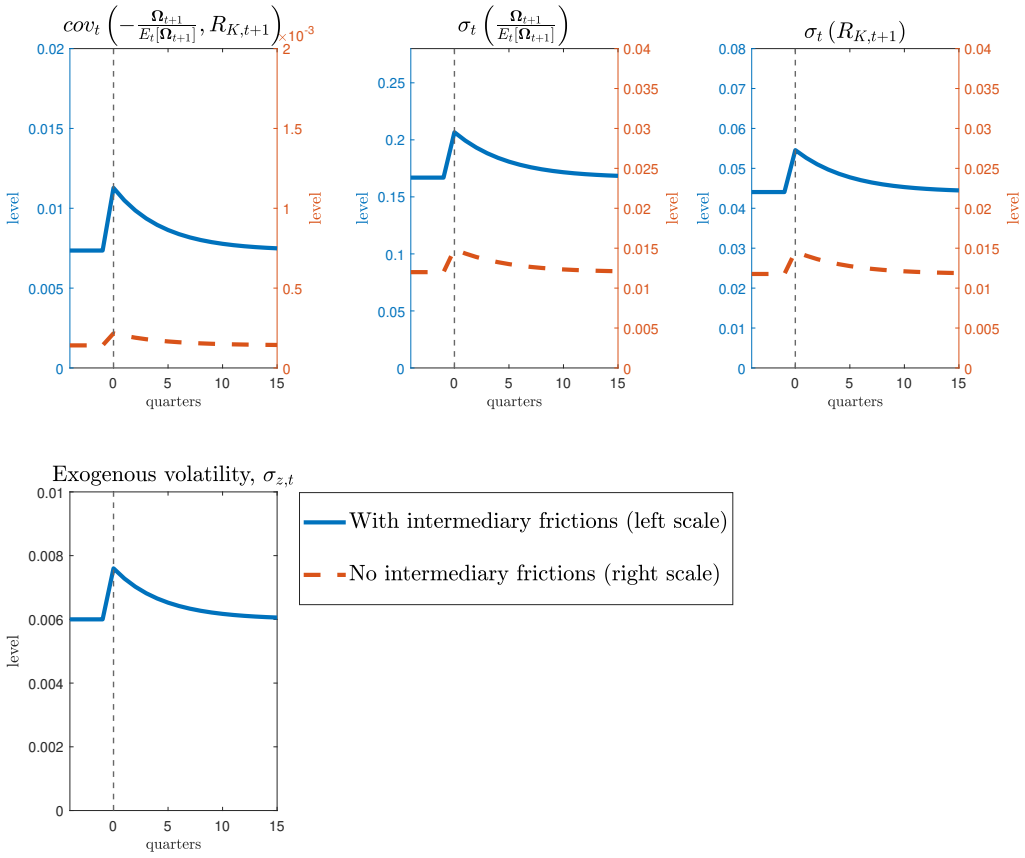
bankers' SDF and the return on capital. Rearranging (40), the risk premium can be written

$$\begin{aligned}\mathbb{E}_t[R_{k,t+1} - R_t] &= \frac{\mu_t}{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]} + cov_t\left(-\frac{\mathbf{\Omega}_{t+1}}{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]}, R_{k,t+1}\right) \\ &\approx \frac{\mu_t}{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]} + \sigma_t\left(\frac{\mathbf{\Omega}_{t+1}}{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]}\right) \times \sigma_t\left(R_{k,t+1}\right). \end{aligned} \tag{44}$$

Thus, the risk premium is positively linked with the excess return μ_t (normalized by the expected SDF), as well as with the conditional covariance between the (negative of the) normalized SDF and the asset's return. As shown in the first panel of Figure 7, in the wake of the uncertainty shock, this conditional covariance rises sharply—accounting for the sharp increase in the risk premium, despite the fact that μ_t falls.

The conditional covariance in (44) can, in turn, be approximately expressed as the product of the standard deviation of the normalized SDF, $\sigma_t\left(\frac{\mathbf{\Omega}_{t+1}}{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]}\right)$, and that of the return, $\sigma_t\left(R_{k,t+1}\right)$. In the consumption-based asset pricing literature, these two standard deviations are sometimes referred to as the "price" and "quantity" of risk, respectively. The price of risk is a function of the volatility of the SDF, and is therefore the same for any asset priced by the intermediary; the

Figure 7: Uncertainty shock: price and quantity of risk



quantity of risk (of a given asset) is a function of the volatility of the asset's returns.

In Figure 7 we plot the price (middle panel) and quantity (right panel) of risk. Two insights stand out from the figure. First, in the "risk-adjusted" (or "stochastic") steady state (that is, before the uncertainty shock hits in period 0), the price of risk has a dominant role in accounting for the covariance between SDF and return: it is about four times as large as the quantity of risk. Thus, on average, the covariance term in the risk premium largely reflects the price of risk. Second, conditional on an increase in aggregate uncertainty, both price and quantity of risk play a significant role: they both increase by similar amounts in percentage terms. Thus, the rise in the risk premium seen in Figure 6 reflects increases in both the price and quantity of risk.

It is useful to contrast the effects described until now with those that would occur absent constraints on intermediaries. In that case, it is straightforward to show that the following two

equations hold:

$$\beta \mathbb{E}_t \left[\left(\frac{Z_{t+1}}{Z_t} \right)^{-\varrho} \right] R_t^U = 1, \tag{45}$$

$$\beta \mathbb{E}_t \left[\left(\frac{Z_{t+1}}{Z_t} \right)^{-\varrho} \left(Z_{t+1} + Q_{t+1}^U \right) \right] = Q_t^U, \tag{46}$$

which determine the endogenous variables $\left\{ R_t^U, Q_t^U \right\}$, where the superscript "U" stands for "unconstrained." These equations constitute a standard Lucas (1978) asset pricing model, and can be used to compute the impact of higher uncertainty $\sigma_{z,t}$ on the asset price Q_t^U, the risk-free rate R_t^U, and the risk premium. As is well known (Mehra and Prescott (1985)), such a frictionless setting predicts very small effects of risk for conventional values of ϱ. Figure 6 confirms these earlier findings in the literature: the movements in both Q_t^U and the risk premium are orders of magnitude smaller than their counterparts with intermediary frictions.[13] (The behavior of the risk-free rate is identical in both cases, as it is determined by the same equation.) Importantly, the effects of higher risk on the price of capital have the "wrong" sign: Q_t^U *rises* with higher risk. To understand this point, note that Q_t^U satisfies

$$Q_t^U = \frac{\mathbb{E}_t[Z_{t+1} + Q_{t+1}^U]}{R_t^U + cov_t \left(-\frac{\Lambda_{t+1}}{\mathbb{E}_t[\Lambda_{t+1}]}, R_{k,t+1} \right)} \tag{47}$$

With higher risk, the covariance term in the denominator rises as agents require a larger premium to hold risky assets, depressing Q_t^U. At the same time, the risk-free rate, R_t^U, falls in response to the higher precautionary savings induced by the increase in consumption risk. The latter effect puts upward pressure on asset prices, and turns out to dominate the former effect, leading the asset price to rise.

To summarize, the presence of asset pricing by constrained intermediaries leads to (i) large amplification relative to a frictionless model, and (ii) a behavior of asset prices following uncertainty shocks that qualitatively has the right sign—unlike in the frictionless model.

We conclude this section by addressing the following question: can first-moment shocks that directly affects bankers' net worth deliver results similar to the ones we obtain from risk shocks, in a way that also accounts for the VAR evidence on the relationship between the VIX and asset prices? In Figure E.4, we plot the effects of an uncertainty shock, alongside the effects of a shock to bankers' dividend Z_t sized to deliver the same decline in net worth upon impact. Two results are worth mentioning: First, as shown by the dashed-dotted yellow line in the last panel, the first-moment shock implies a movement in the implied stock market volatility in the model (calculated

[13] Interestingly, the degree of amplification due to constrained intermediaries appears to be much larger for uncertainty shocks than for the typical first-moment shocks that have been analyzed in related literature, such as monetary shocks or capital quality shocks. For example, in Gertler and Karadi (2011) the presence of financial constraints amplifies the responses of investment and asset prices to these shocks by around threefold, relative to a model without financial frictions. Our results show that the degree of amplification is much larger for uncertainty shocks.

the same way as the VIX is in the data) that is minuscule, compared with the movement following an uncertainty shock. This finding provides model-based support for our empirical strategy of identifying uncertainty shocks by ordering the VIX first in a VAR. As in Basu and Bundick (2017), this ordering assumes that non-uncertainty shocks do not contemporaneously affect stock market volatility. Second, in response to the first-moment shock, the risk-free rate rises, while it falls in response to uncertainty shocks, consistent with the empirical evidence (e.g., Basu and Bundick (2017)). These two findings together provide support for the relevance of studying an exogenous rise in uncertainty to account for the (cross-border) movements in asset prices, risk-free interest rates, risk premia, and exchange rates, which we turn to next.

5.2 Uncertainty shocks with financial integration

We next analyze the case in which the two countries are financially integrated. As shown in Figure 5, the asset prices across countries, Q and Q^*, become highly positively correlated across the two countries with integration, although the dividends (Z and Z^*) are assumed to be uncorrelated. Moreover, home bankers' SDF comoves negatively with the foreign country's payoff, and the conditional covariances within each country become significantly smaller. This reflects a risk-sharing arrangement between countries that emerges due to financial integration (see, for example, Coeurdacier et al. (2020)).

In this section, we analyze the dynamic effects of higher home uncertainty in a world in which countries are financially integrated, shown in Figure 8. Recall from the analysis of the autarky case that the key channel trough which higher uncertainly feeds into the economy is by making the conditional covariance between intermediaries payoffs and their SDF more negative. In effect, intermediation becomes riskier, which endogenously tightens intermediaries' leverage constraints. Now consider higher uncertainty under financial integration. In the second column, second row of Figure 8, we plot the covariances between home bankers' SDF and the excess return on home securities (blue solid line) and between foreign bankers' SDF and foreign securities (orange dash-dotted line). As shown, higher uncertainty leads both of these covariances to move down in tandem: in each case, the covariance increases (in absolute magnitude) relative to its pre-shock value—where the magnitutes are similar to the time path of the shock $\sigma_{z,t}$ itself. Thus, with higher home uncertainty, *both* home and foreign assets effectively become riskier, and thus *both* sets of intermediaries face deleveraging pressure.[14]

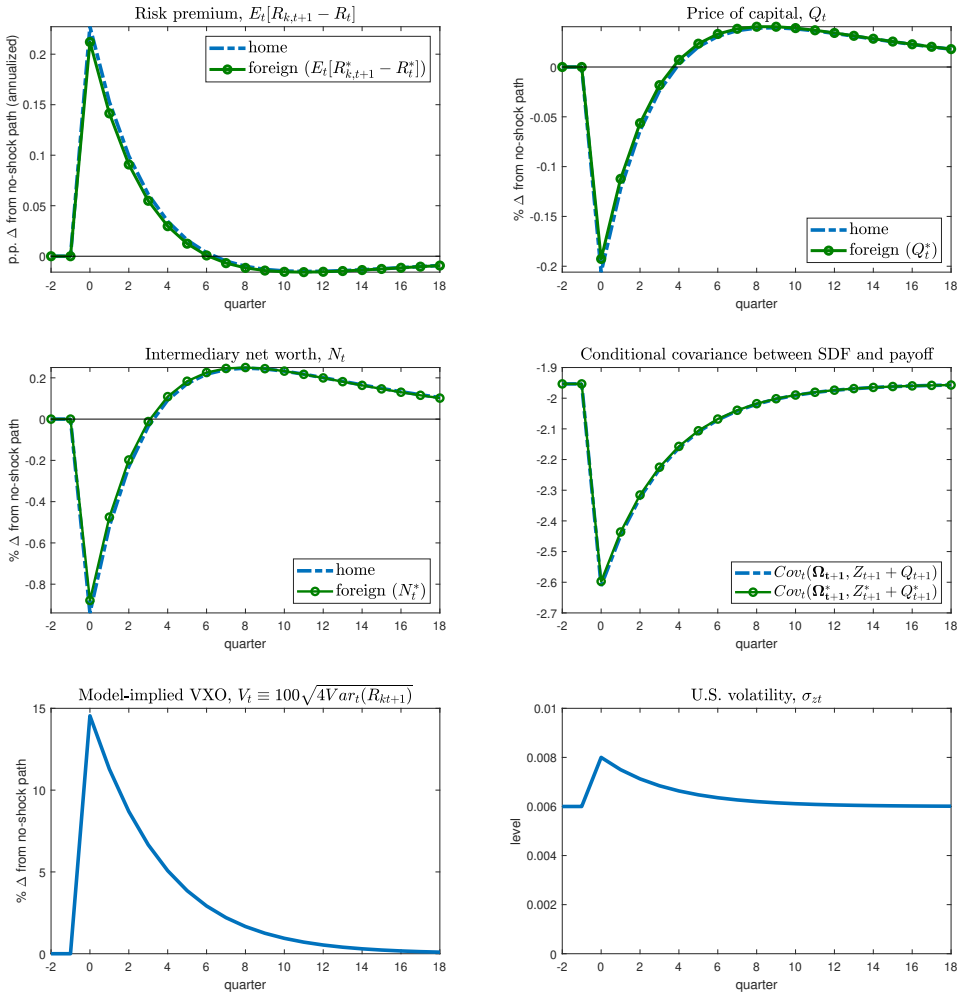
To understand why the covariances move synchronously, it is helpful to recall the optimal portfolio for U.S. (or global) banks:

$$\mathbb{E}_t[\mathbf{\Omega}_{t+1} R^*_{k,t+1}] = \mathbb{E}_t[\mathbf{\Omega}_{t+1} R_{k,t+1}] \tag{48}$$

Suppose that a standard adverse productivity shock (a negative disturbance to Z_t) hurts home

[14] Figure E.2 in the Appendix shows the effects with financial integration but without intermediary frictions. As in the case with autarky, the (cross-border) effects of higher uncertainty are very small. But more importantly, the asset values in the model, Q and Q^*, move in opposite directions, contrary to what is implied by the empirical estimates.

Figure 8: Dynamic effects of U.S. uncertainty shock with financial integration



banks' net worth. This limits home banks' ability to arbitrage, and triggers a rise in the domestic expected return on capital (the right-hand side of (48)) and a decline in Q_t. Note that a first-order approximation is sufficient for the present argument: observe that $E_t(\mathbf{\Omega}_{t+1})$ vanishes from (48) to a first order. Without any change in foreign variables, equation (48) would be violated: the left-hand side would exceed the right-hand side, indicating that global intermediaries have incentives to pull investments out of the foreign economy and into the domestic one. To restore portfolio optimality, the foreign expected excess return must rise as well, which occurs through a fall in Q^*_t.

In turn, the tight link between Q_t and Q^*_t induced by the presence of global banks helps explain why *all* conditional covariances increase with higher uncertainty. Suppose that the riskiness of home productivity goes up. This makes home securities more risky not just because their dividend process has turned more volatile, but also (and mainly) because their price has turned more volatile as well. But through arbitrage by global banks, the foreign price Q^*_t turns more volatile at the same time, and thus the risk facing foreign bankers also rises—as reflected in the more-negative

covariance shown in Figure 8.

Observe also that the effects of the shock are considerably muted under financial integration relative to the autarky economy: comparing Figure 6 with Figure 8, the risk premium increases much more in autarky, and Q_t and N_t fall more, given the same increase in uncertainty. Key to this finding is that movements in domestic productivity Z_t have considerably smaller effects under financial integration. In autarky, lower home productivity, and the consequent drop in net worth, must be accommodated by lower Q_t. The usual financial accelerator dynamics operate powerfully: lower N_t leads to lower Q_t, which feeds back into net worth. Financial integration introduces a second margin of adjustment: now Q_t^* also falls (through global banks' portfolio condition). In turn, this mitigates the required adjustment of Q_t and N_t. The covariances between discount factors and asset payoffs are thus much smaller (in absolute value) under financial integration. This also means that they increase by less (in absolute value) with integration. In this way, the size of the impulse that triggers deleveraging pressure (which ultimately rests on the magnitude of the rise in the conditional covariances between SDF and asset payoffs) is smaller under financial integration.

5.3 Uncertainty shocks and exchange rate determination

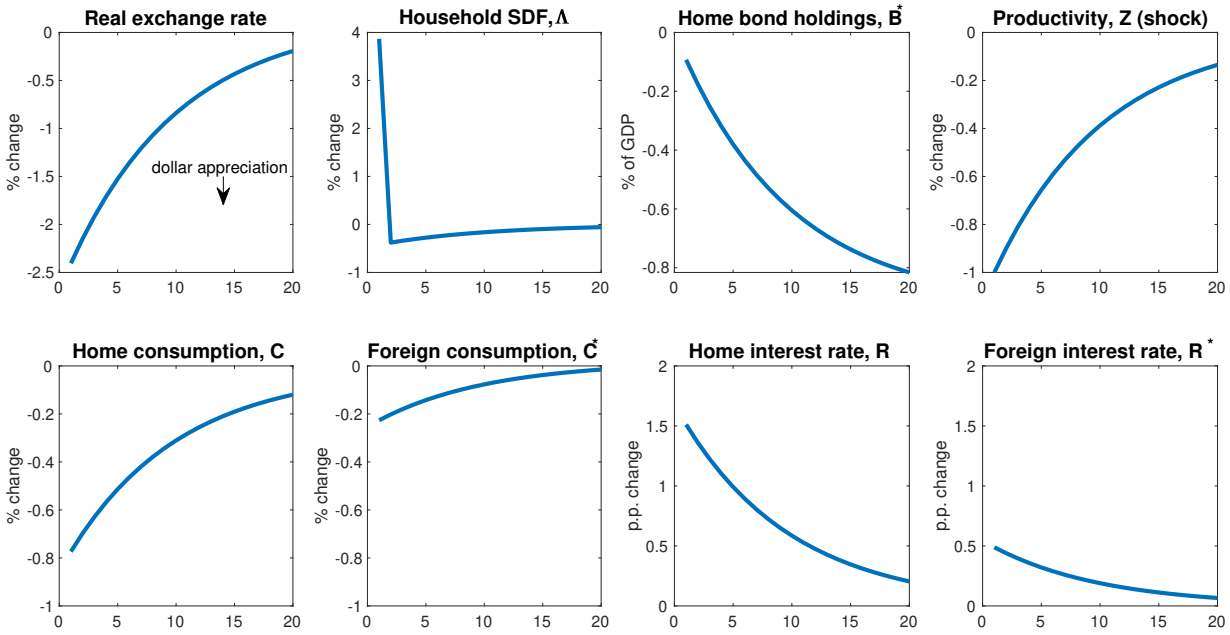
We now turn to the full model presented in Section 3 to clarify the key determinants of exchange rates and UIP deviations. The intuition developed in the previous subsections highlights the potential role played by constrained intermediaries in pricing the risky assets in the exchange rate determination. It is useful to recall from the analysis of the autarky case that the key channel trough which higher uncertainly feeds into the economy is by making the conditional covariance between intermediaries payoffs and their SDF more negative. In effect, intermediation becomes riskier, which endogenously tightens intermediaries' leverage constraints.

We begin by reviewing exchange rate determination–including the role of time-varying risk–in a canonical two-country setting without any banking frictions. Thus, we develop a version of the model presented above without global banks, without capital holdings, and in which households can hold the international bond (the only asset in this economy) without facing any portfolio costs. What results is a standard endowment economy with two goods, two countries, and home bias in preferences, with the exchange rate determined by a standard UIP condition (with the household's stochastic discount factor).[15]

Figure 9 shows the effects of a negative home productivity shock in this frictionless economy. The lower supply of the home (U.S.) good triggers an increase in the relative price of the home good, which is associated with an appreciation of the dollar real exchange rate. Home consumers, who disproportionately enjoy the home good, cut back consumption substantially more than foreign consumers. Accordingly, the home interest rate increases more than the foreign one. These responses are helpful in understanding the effects of an uncertainty shock in this economy, shown in figure 10. The higher volatility of the home endowment is associated with an increase in $Cov_t(-\Lambda_{t+1}, S_{t+1})$,

[15] See the Appendix for the full set of equations in this case.

Figure 9: Frictionless model, effects of productivity shock



which represents an *increase* in the risk premium associated with the foreign currency.[16] To understand this increase, consider the impulse responses in figure 9, showing an elevated home stochastic discount factor (SDF) when foreign currencies are weak against the dollar.

This higher risk premium would tend to push the dollar up, everything else equal. But as seen in the figure, the home interest rate falls considerably more than the foreign interest rate—a drop in home's interest rate differential which more than offsets the higher foreign currency risk premium, and which results in the dollar depreciating. Note, however, that the effects are very small quantitatively, and very far from the empirical impulse responses documented earlier.

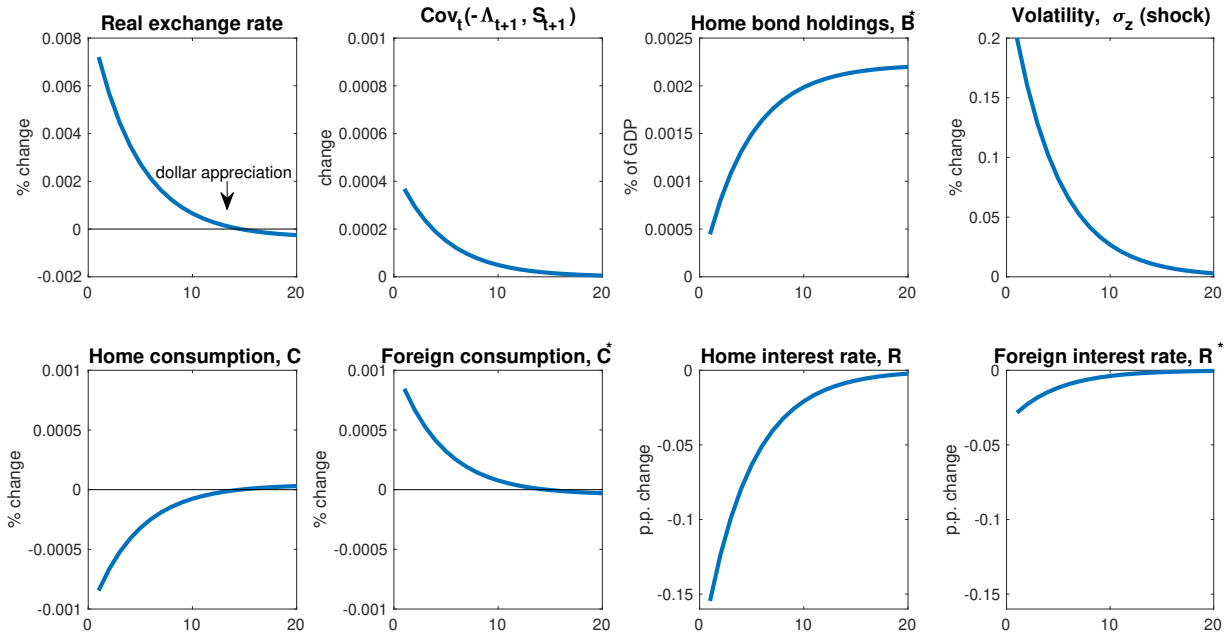
Now go back to our full model with global banking frictions. A decline in home productivity in that model, shown in figure 11 has similar effects on the exchange rate as the frictionless case. The crucial difference, however, is that now the relevant stochastic discount factor—the global banker's—increases sharply in response to the lower productivity—by an order of magnitude more than the increase in the household's SDF in the previous case. This occurs because when U.S. productivity is low, bankers' returns on U.S. assets are low, triggering financial accelerator effects and thus making bankers' constraints tight, and the value of a unit of equity high. In this way the presence of constrained global intermediaries makes the UIP premium highly elastic to uncertainty.

[16] Note that we can write the UIP premium as

$$\mathbb{E}_t\left[\frac{\frac{\mathcal{S}_{t+1}}{\mathcal{S}_t}R_t^*}{R_t}\right]-1=cov_t\left(-\frac{\mathbf{\Omega}_{t+1}}{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]},\frac{\frac{\mathcal{S}_{t+1}}{\mathcal{S}_t}R_t^*}{R_t}\right)$$

given the relevant stochastic discount factor $\mathbf{\Omega}_{t+1}$.

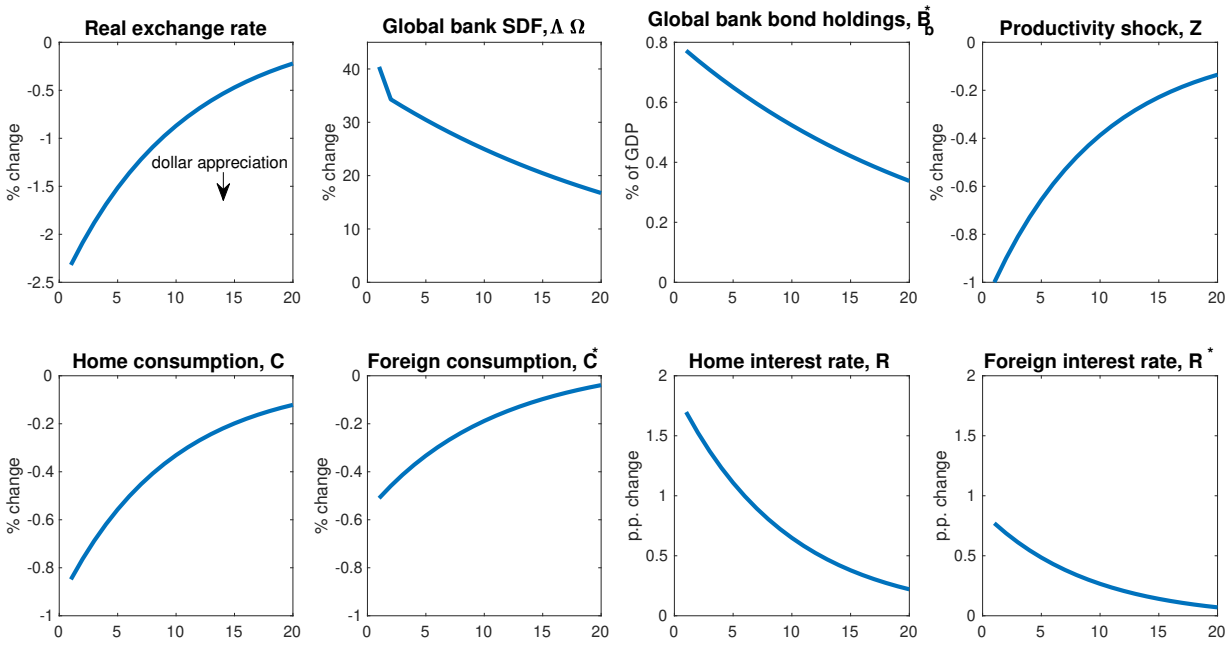
Figure 10: Frictionless model, effects of uncertainty shock



As a consequence, this risk effect dominates the interest differential channel, and home real exchange rate now *appreciates vis-á-vis* the foreign currency following the increase in uncertainty. Further, the magnitude of the appreciation is substantial–an order of magnitude larger than without frictions. Accompanying the stronger dollar is a persistent outflow from foreign bonds ($\Delta B^*_{b,t} < 0$).

These findings are consistent with the often-discussed notion of the dollar as a "safe haven" currency which appreciates in times of higher uncertainty. More specifically, they help rationalize the observed positive correlation between the VIX and the dollar exchange rate.

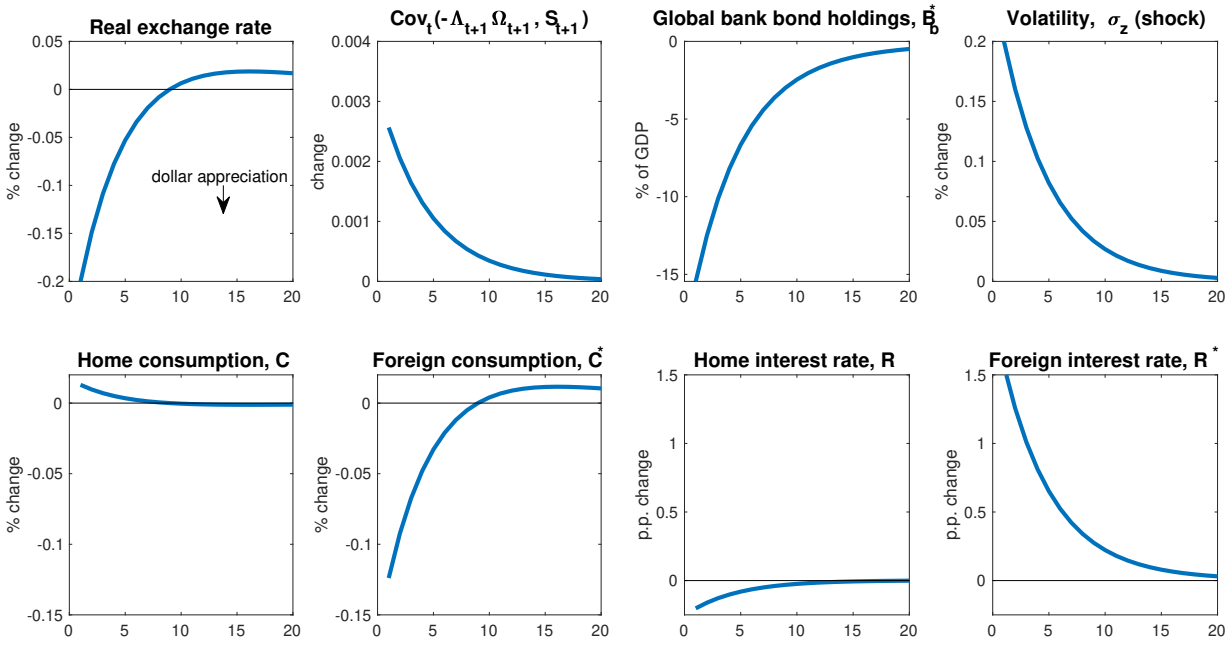
Figure 11: Baseline model with global banking friction, effects of productivity shock



6 Conclusion

We present a unifying open economy framework with financial intermediaries that are balance-sheet-constrained and subject to time-varying uncertainty in the prospective returns on their capital holdings. The constraint is about risky leverage and not about a limit to arbitrage in risk free asset returns. We show that in a financially integrated world, an increase in U.S. uncertainty leads to global deleveraging pressure, a decrease in global asset prices, and a rise in global risk premia, with magnitudes consistent with those obtained in the data. The model also implies an appreciation of the dollar, a depreciation of the foreign currency, and a rise in uncovered interest parity premia on foreign currencies in the wake of higher U.S. uncertainty, also consistent with the data.

Figure 12: Baseline model with global banking friction, effects of uncertainty shock



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A Sample Description and Data Sources

Country sample for panel regressions: We use countries listed in Table A.1, and drop country-quarters with peg ER regimes (IRR classifications 1 and 6).

Table A.1: Country Sample

Albania	Armenia	Azerbaijan	Belarus	Bolivia
Brazil	Canada	Chile	China	Colombia
Czech Republic	Denmark	Egypt	Georgia	Germany
Hong Kong	Hungary	India	Indonesia	Israel
Italy	Japan	Kazakhstan	Korea	Malaysia
Mexico	Moldova	Nigeria	Norway	Pakistan
Peru	Philippines	Poland	Romania	Russia
Serbia	Singapore	South Africa	Sri Lanka	Sweden
Switzerland	Taiwan	Thailand Turkey	Ukraine	
United Kingdom	Uruguay	Venezuela		

Note: We follow the IMF 2000 World Economic Outlook country groups classification. Because we measure U.S. uncertainty spillovers, we drop the U.S. Red text indicates a country is an emerging market.

Table A.2: Data sources and description

Variable	Description	Source
UIP	12-month UIP deviations	IFS, Bloomberg, Consensus Economics
Real Exchange Rate	Broad dollar index	Federal Reserve Board
Corporate Spreads	Dollar denominated corp. bond spreads	ICE indices and J.P. Morgan
U.S. Gov. Bond rate	Yields on 5-year Gov. Bonds	Federal Reserve Board

B Empirical Evidence: Additional Results

Figure B.13: **VIX**

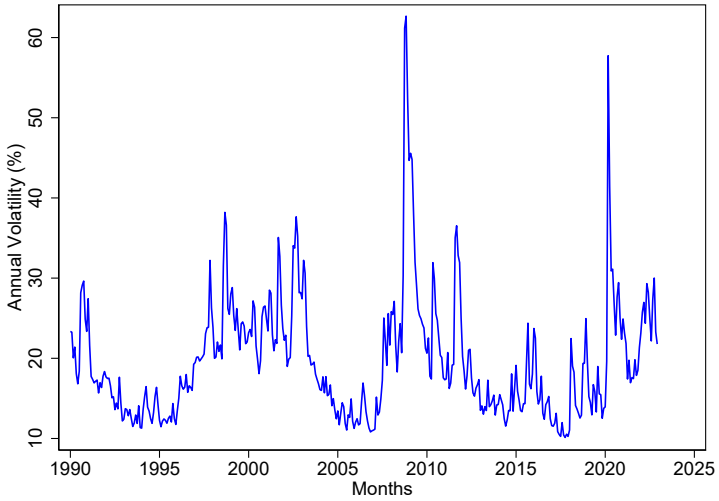
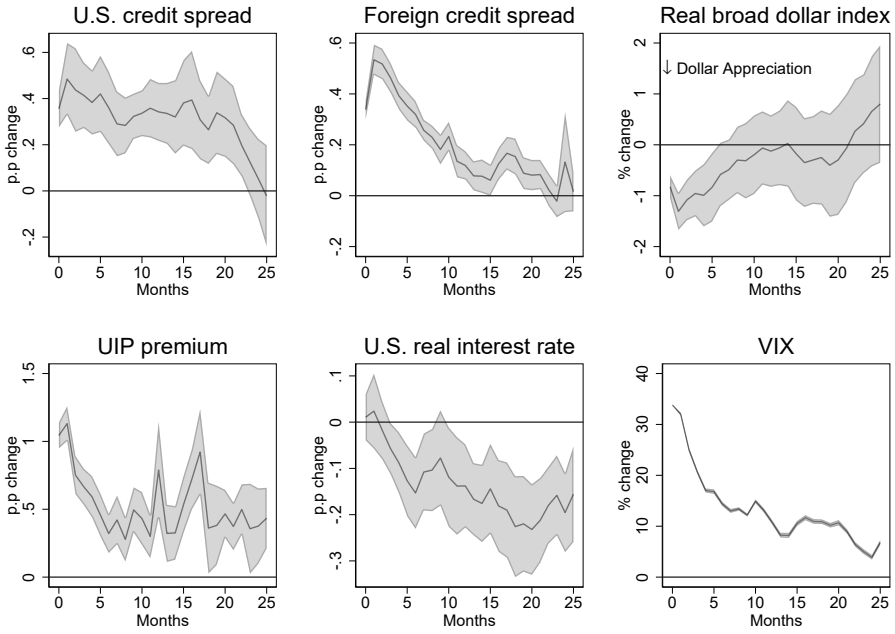


Figure B.14: **Response to Uncertainty Shocks**



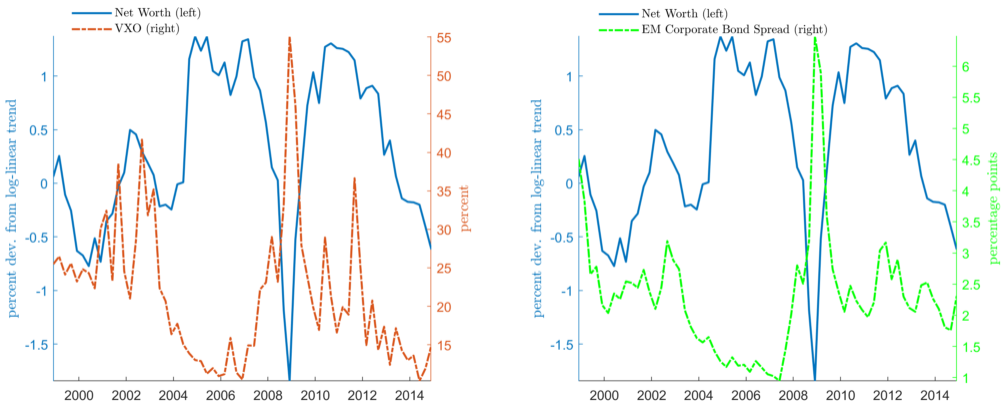
Note: Impulse responses to an unfiltered VIX shock. UIP refers to uncovered interest rate parity. Credit spreads, UIP premia and the real interest rates are in percentage points change. Real broad dollar index and VIX are in percent change. The shaded areas denote 90 percent confidence intervals that control for HAC.

C Uncertainty Shocks, Global Banks' Net Worth, and EM Corporate Spreads

The price of EM corporate bonds held by global investors is highly correlated with uncertainty (proxied by the VXO). Moreover, fluctuations in uncertainty appear to be related to global financial intermediaries' equity positions. These observations are illustrated in Figure C.1, which shows the evolution of the VXO, along with U.S. banks' net worth position and EM corporate bond spreads, over the 1998-2014 period.

These observations suggest that uncertainty shocks might potentially transmit to EM risky asset prices through their impact on global banks' equity position. In this section we attempt to provide some motivational evidence using macro-level regressions for the presence of such channel. More specifically, we begin with the following regression:

Figure C.1: EM Corporate Spread, VXO, and U.S. Banks' Net Worth.



Note: Spreads (expressed in percentage points) is the JP Morgan Corporate Bond Index for the EM aggregate. The U.S. banks' net worth is defined as the difference between the real value of assets and liabilities reported by U.S. chartered depository institutions obtained from the Federal Reserve Board, Flow of Funds, and displayed as a percent change from a loglinear trend (computed as in Morelli et al. (2022)). VXO is the Chicago Board Options Exchange's CBOE Volatility Index, also expressed in percent.

$$\Delta Spread_{c,t} = \eta_c + \alpha NW_{t-1}\Delta VXO_t + \beta \Delta VXO_t + \delta NW_{t-1} + \epsilon_t \tag{49}$$

where the quarterly changes in EM corporate bond spreads ($\Delta Spread_{c,t}$) are regressed on the interaction term between the change in a measure of global uncertainty and the lagged value of U.S. banks' net worth ($NW_{t-1}\Delta VXO_t$). In the regressions we control for the change in VXO (ΔVXO_t) and the (lagged) values of the net worth positions of the U.S. banks (NW_{t-1}), as well as the Global Financial Crisis (where the dummy for the latter takes a value of 1 for the 2008Q3-2009Q4 period and zero otherwise). Note that we use data from 20 EMs on the risk premia that the corporates in these countries have pay in the international markets to borrow from global banks, and run regressions using the country fixed effects (η_c).

Table C.1: EM Corporate Spreads, Uncertainty and U.S. Banks' Net Worth

	(1) $\Delta Spread_{c,t}$	(2) $\Delta Spread_{c,t}$	(3) $\Delta Spread_{c,t}$	(4) $\Delta Spread_{c,t}$
$NW_{t-1}\Delta VXO_t$	0.0239***	-0.0488***	-0.0500***	-0.0503***
	(4.43)	(-5.99)	(-6.16)	(-6.19)
ΔVXO_t		0.0899***	0.0913***	0.0917***
		(11.20)	(11.43)	(11.45)
NW_{t-1}			-0.166**	-0.195**
			(-2.89)	(-2.92)
GFC Dummy				-0.129
				(-0.86)
Country Fixed Effects	yes	yes	yes	yes
Observations	651	651	651	651

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; t statistics in parentheses.

Note: Spread represents the JP Morgan Corporate EM Bond Index for 20 EMs (denoted by c) over the Q4 1998 to Q4 2014 period (denoted by t). EMs include Argentina, Brazil, Chile, China, Colombia, Hong Kong, India, Indonesia, Israel, Korea, Mexico, Malaysia, Philippines, Russia, Saudi Arabia, Singapore, South Africa, Taiwan, Thailand, Turkey. The U.S. banks' net worth (NW) is defined as the difference between the real value of assets and liabilities reported by U.S. chartered depository institutions obtained from the Federal Reserve Board, Flow of Funds (computed as in Morelli et al. (2022)). VXO is the Chicago Board Options Exchange's CBOE Volatility Index. The global financial crisis (GFC) is defined between Q3 2008 and Q4 2009. The results are robust to including EM local currency bonds.

Table C.1 presents the results for regression (49). The estimated coefficient for the effect of VXO on the spread is positive and significant, implying that higher uncertainty is associated with higher corporate bond spreads in EMs. More importantly, once we control for changes in VXO, we find that the interaction term that we are interested in becomes negative and significant: if the net worth positions of global banks are low in the previous period (implying that the banks are more likely to be constrained), EM corporate spreads increase by more for an increase in the VXO of a given size. Or conversely, if global banks are well-capitalized (NW is high in the previous period, and thus financial constraints are more relaxed), EM corporate bond spreads move less for a given change in VXO in the current period. So, we take this finding as a suggestive evidence that global banks' net worth plays an important role in transmitting uncertainty shocks to the price of EM corporate bonds.

D Complete Set of Equilibrium Conditions

Global banks

$$\phi_t\mu_t + \phi_t^*\mu_t^* + \phi_{b,t}\mu_{b,t} + \phi_{b,t}^*\mu_{b,t}^* + \nu_t = \theta\phi_t + \theta^*\phi_t^* + \theta_b\phi_{b,t} + \theta_b^*\phi_{b,t}^* \tag{1}$$

$$\Omega_t = 1 - \sigma + \sigma\left(\phi_t\mu_t + \phi_t^*\mu_t^* + \phi_{b,t}\mu_{b,t} + \phi_{b,t}^*\mu_{b,t}^* + \nu_t\right) \tag{2}$$

$$\mu_t^* = \frac{\theta^*}{\theta}\mu_t \tag{3}$$

$$\mu_{b,t} = \frac{\theta_b}{\theta}\mu_t \tag{4}$$

$$\mu_{b,t}^* = \frac{\theta_b^*}{\theta}\mu_t \tag{5}$$

$$\begin{aligned} N_t = \sigma\Big[&(R_{k,t} - R_{t-1})Q_{t-1}K_{b,t-1} \\ &+ (R_{b,t} - R_{t-1})Q_{b,t-1}\overline{B} + (R_{k,t}^* - R_{t-1})Q_{t-1}^*K_{b,t-1}^* + (\frac{S_t}{S_{t-1}}R_{t-1}^* - R_{t-1})S_{t-1}B_{b,t-1}^* \\ &+ R_{t-1}N_{t-1}\Big] + (1-\sigma)\xi\left[Q_{t-1}K_{b,t-1} + Q_{t-1}^*K_{b,t-1}^* + Q_{b,t-1}\overline{B} + S_{t-1}B_{b,t-1}^*\right] \end{aligned} \tag{6}$$

$$\nu_t = \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}]R_t \tag{7}$$

$$\mu_t = \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}(R_{k,t+1} - R_t)] \tag{8}$$

$$\mu_t^* = \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}(R_{k,t+1}^* - R_t)] \tag{9}$$

$$\mu_{b,t} = \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}(R_{b,t+1} - R_t)] \tag{10}$$

$$\mu_{b,t}^* = \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}(\frac{S_{t+1}}{S_t}R_t^* - R_t)] \tag{11}$$

$$\phi_t = \frac{Q_tK_{b,t}}{N_t} \tag{12}$$

$$\phi_t^* = \frac{Q_t^*K_{b,t}^*}{N_t} \tag{13}$$

$$\phi_{b,t} = \frac{Q_{b,t}\overline{B}}{N_t} \tag{14}$$

$$\phi_{b,t}^* = \frac{S_tB_{b,t}^*}{N_t} \tag{15}$$

$$R_{k,t+1} = \frac{(S_{t+1}^{\frac{-(1-\omega)}{2\omega-1}})Z_{t+1} + Q_{t+1}}{Q_t} \tag{16}$$

$$R_{k,t+1}^* = \frac{(S_{t+1}^{\frac{\omega}{2\omega-1}})Z_{t+1}^* + Q_{t+1}^*}{Q_t^*} \tag{17}$$

$$R_{b,t+1} = \frac{1}{Q_{b,t}} \tag{18}$$

Home households

$$C_{F,t} = (1-\omega)(S_t^{\frac{\omega}{2\omega-1}})^{-1} C_t \tag{19}$$

$$C_{H,t} = \omega(S_t^{\frac{-(1-\omega)}{2\omega-1}})^{-1} C_t \tag{20}$$

$$\alpha K_{h,t}^{\eta} + C_t^{-\varrho} Q_t = \beta \mathbb{E}_t[C_{t+1}^{-\varrho}(S_{t+1}^{\frac{-(1-\omega)}{2\omega-1}} Z_{t+1} + Q_{t+1})] \tag{21}$$

$$C_t^{-\varrho} = \beta R_t \mathbb{E}_t[C_{t+1}^{-\varrho}] \tag{22}$$

$$\Lambda_{t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\varrho} \tag{23}$$

Foreign households

$$C_{H,t}^* = (1-\omega)(S_t^{\frac{-\omega}{2\omega-1}})^{-1} C_t^* \tag{24}$$

$$C_{F,t}^* = \omega(S_t^{\frac{1-\omega}{2\omega-1}})^{-1} C_t^* \tag{25}$$

$$\alpha^*(K_{h,t}^*)^{\eta^*} + (C_t^*)^{-\varrho} S_t^{-1} Q_t^* = \beta \mathbb{E}_t[(C_{t+1}^*)^{-\varrho}(S_{t+1}^{\frac{(1-\omega)}{2\omega-1}} Z_{t+1}^* + S_{t+1}^{-1} Q_{t+1}^*)] \tag{26}$$

$$\alpha_b^*(B_{h,t}^*)^{\eta_b^*} + (C_t^*)^{-\varrho} = \beta R_t^* \mathbb{E}_t[(C_{t+1}^*)^{-\varrho}] \tag{27}$$

Market clearing & BOP

$$C_{H,t} + C_{H,t}^* = Z_t \tag{28}$$

$$C_{F,t} + C_{F,t}^* = Z_t^* \tag{29}$$

$$K_{h,t} + K_{b,t} = 1 \tag{30}$$

$$K_{h,t}^* + K_{b,t}^* = 1 \tag{31}$$

$$B_{h,t}^* + B_{b,t}^* = \overline{B}^* \tag{32}$$

$$C_t + Q_t^*(K_{b,t}^* - K_{b,t-1}^*) + S_t(B_{b,t}^* - R_{t-1}^* B_{b,t-1}^*) = S_t^{\frac{-(1-\omega)}{2\omega-1}} Z_t + S_t^{\frac{\omega}{2\omega-1}} Z_t^* K_{b,t-1}^* \tag{33}$$

Variables.

Global banks: $N_t, \Omega_t, \nu_t, \mu_t, \mu_t^*, \mu_{b,t}, \mu_{b,t}^*, \phi_t, \phi_t^*, \phi_{b,t}, \phi_{b,t}^*, R_{k,t}, R_{k,t}^*, R_{b,t}, K_{b,t}, K_{b,t}^*, B_{b,t}^*, Q_{b,t}$.

Home: $C_{F,t}, C_{H,t}, C_t, K_{h,t}, R_t, Q_t, \Lambda_t$

Foreign: $C_{F,t}^*, C_{H,t}^*, C_t^*, K_{h,t}^*, R_t^*, B_{h,t}^*, Q_t^*$. RER: S_t.

E Additional model results

Figure E.2: Effects of U.S. uncertainty shock with financial integration and no intermediary frictions

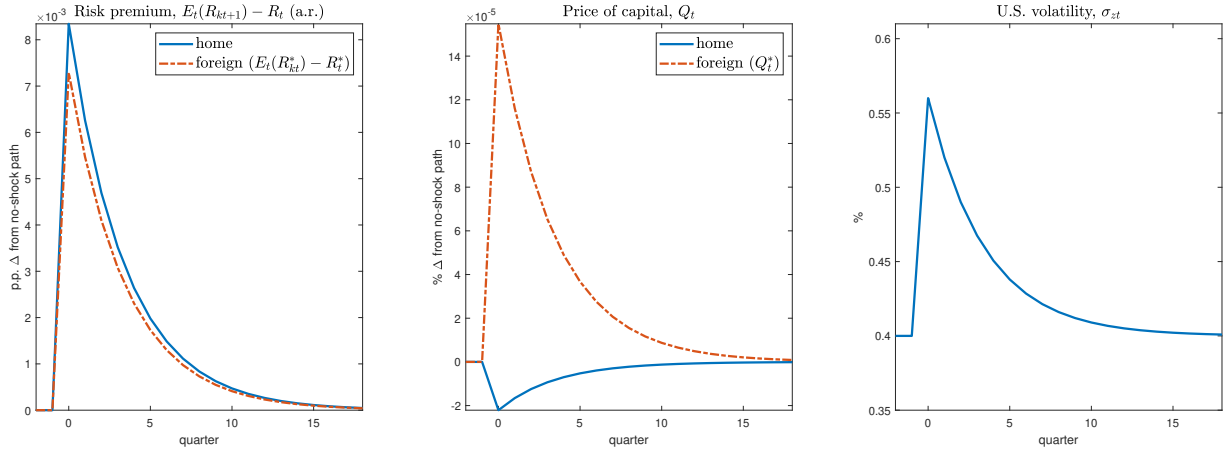


Figure E.3: Exchange rate model, effects of U.S. uncertainty shock without intermediary frictions

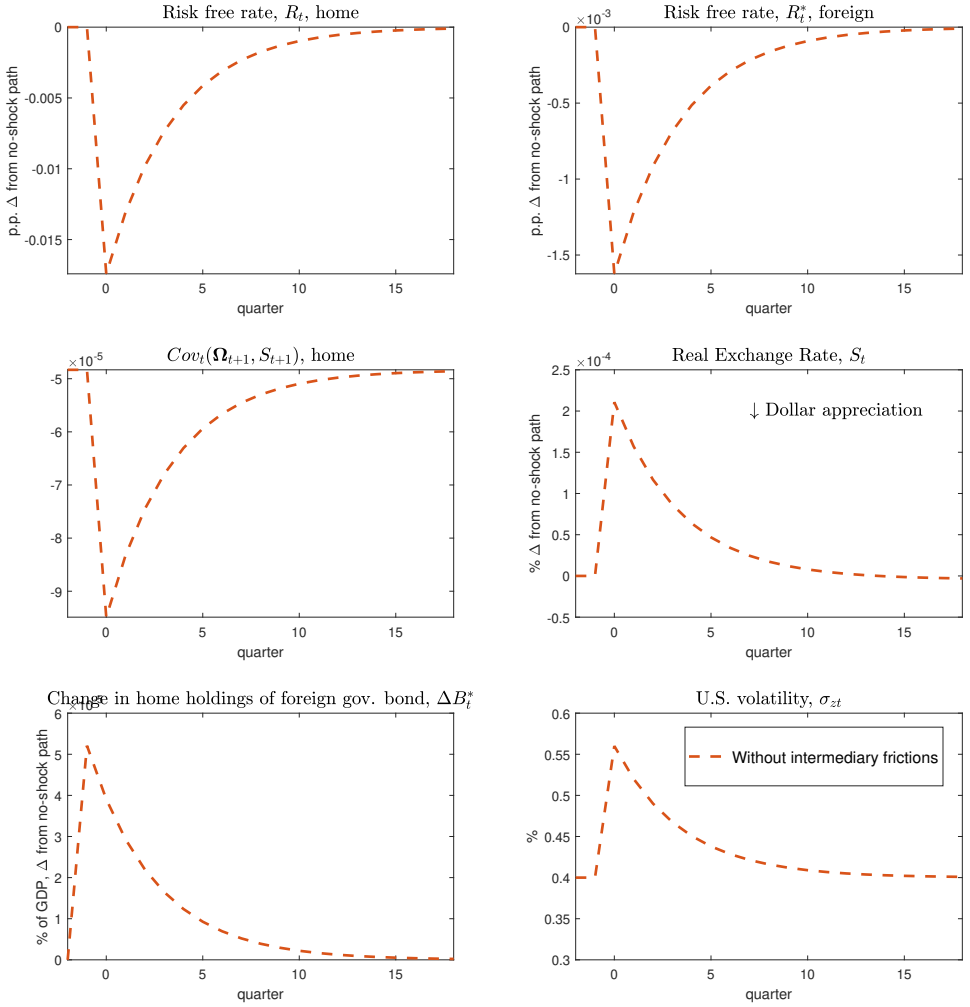


Figure E.4: Effects of first- v. second-moment shocks

