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Abstract

Foreign investors' changing appetite for risk-taking has been shown to be a key determinant of the global financial cycle. Such fluctuations in risk sentiment also correlate with the dynamics of uncovered interest parity (UIP) premia, capital flows, and exchange rates. To understand how these risk sentiment changes transmit across borders, we propose a two-country macroeconomic framework. Our model features cross-border holdings of risky assets by U.S. financial intermediaries that operate under financial frictions and act as global intermediaries in that they take on foreign asset risk. In this setup, an exogenous increase in U.S.-specific uncertainty, modeled as higher volatility in U.S. assets, leads to higher risk premia in both countries. This occurs because higher uncertainty leads to deleveraging pressure on U.S. intermediaries, triggering higher global risk premia and lower global asset values. Moreover, when U.S. uncertainty rises, the exchange rate in the foreign country vis-a-vis the dollar depreciates, capital flows out of the foreign country, and the UIP premium increases in the foreign country and decreases in the U.S., as in the data.

Key words: financial frictions, risk premia, time-varying uncertainty, intermediary asset pricing, financial spillovers, global financial cycle

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1 Introduction

A large empirical literature shows the importance of global risk aversion, uncertainty, and related measures of global investors' "risk sentiment" in driving international risky asset prices and capital flows (e.g. Rey (2013), Miranda-Agrippino and Rey (2020), Miranda-Agrippino and Rey (2021)). Dubbed the "global financial cycle" (GFC), this process can imply large fluctuations in domestic credit, volatile capital flows, and boom-bust cycles, especially in emerging markets (EMs) (as shown, for example, by di Giovanni et al. (2021) for Turkey, and by Morais et al. (2019) for Mexico). To date, we still lack a theoretical framework to understand these empirically-shown sources and effects of uncertainty or "risk-on/risk-off" shocks in an open economy context. Our paper provides such a model and tests the predictions of the model in the data.[1]

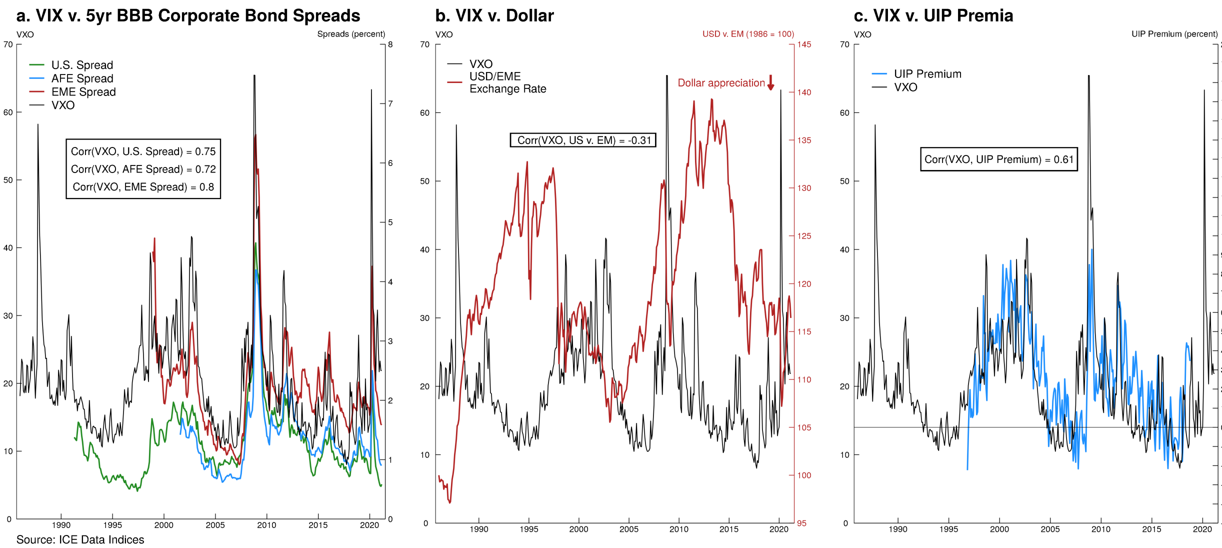
Figure 1 summarizes some of the key facts emphasized in the literature on the GFC. Panel (a) shows the time series of a measure of risk sentiment, proxied here by the VIX (an index of expected U.S. stock market volatility), along with series for 5-year BBB bond spreads issued by corporations in the U.S. (in green), in a set of advanced foreign economies (blue), and in EMs (red). All three spread series are highly correlated with the VIX. Panel (b) shows that risk sentiment also 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 risk sentiment and UIP premia on foreign currencies (as in Kalemli-Özcan and Varela (2021)).

Accordingly, our objective is to understand the linkage between fluctuations in uncertainty in the "financial center" (the U.S.) and movements in risk premia, asset prices, exchange rates, UIP premia, and capital flows globally.[2] To this end, we propose a two-country dynamic macro model, consisting of the U.S. and a foreign economy, an EM. A key feature of our model is the presence of balance-sheet constrained financial intermediaries. These intermediaries play a key role in determining global asset prices, exchange rates, and capital flows. The main exogenous driving force in our model is a shock to the standard deviation of the future productivity (or dividend) of U.S. physical capital. This shock generates time variation in uncertainty about intermediaries' prospective returns. 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 intermediaries' returns is outside the control of intermediaries due to unexpected exogenous disturbances. Crucially, while uncertainty fluctuations are exogenous in our model, risk premia are

[1] Recent work with a related objective is a paper by Davis and van Wincoop (2021) that provides a theoretical framework for the GFC. Unlike our GFC framework, which focuses on the role of uncertainty (or volatility) shocks, the main driver of the GFC in their paper is a shock to the risk aversion parameter. Moreover, their model is completely silent about the sources and effects of global risk aversion on exchange rates and UIP premia, important features of the GFC as documented in Kalemli-Özcan (2019).

[2] U.S. monetary policy has been shown to be a key driver of the GFC through its effect on risk sentiment (e.g., Bekaert et al. (2013), Rey (2013), Bruno and Shin (2015)). As EM capital flows are more risk-sensitive, U.S. monetary policy-driven GFC affects EMs more than advanced economies (AEs), as documented by Kalemli-Özcan (2019). See Degasperi et al. (2021) for a similar risk spillover mechanism of U.S. monetary policy transmission through long-term interest rates and the yield curve.

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



fully endogenous, as we emphasize throughout.[3]

We begin by studying a *single-good* endowment economy, in which the exchange rate is fixed at unity by assumption. In each country there is a fixed supply of capital ("trees") which produce a random dividend ("fruit") each period. Dividends are completely uncorrelated across countries. We assume the two countries are asymmetric in the following sense: The financial center (the U.S.) can hold claims to productive capital both at home and abroad, but agents in the foreign country (the EM) can only purchase claims to their own capital. Our work 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 household sector does not have direct access to financial instruments in either country, and instead owns financial intermediaries who make investments decisions in these risky assets on its behalf.

We first consider an economy in (financial and trade) autarky: U.S. banks cannot hold foreign assets, and there is no trade in goods and services. This case provides a useful benchmark to illustrate how uncertainty shocks transmit in our economy with constrained intermediaries. We find that an increase in uncertainty leads to large declines in asset values and in intermediaries' net worth, and to sharp increases in risk premia.

The presence of constrained intermediaries is crucial to obtain these 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

[3]We also provide a model-based comparison of the effects driven by our proposed *exogenous* uncertainty shocks with those implied by more-standard first-moment shocks that directly affects banks' equity values. As we show, only uncertainty shocks can generate quantitatively realistic movements in implied stock market volatility in the model. Moreover, in response to first-moment shocks, the risk-free rate rises, while it falls in response to uncertainty shocks, consistent with the empirical evidence (e.g., Basu and Bundick (2017)).

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 it 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 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 highly risk averse, despite a very modest value of risk aversion 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.

We then examine what happens when we open up the economies to trade in financial assets. Financial openness introduces powerful motives for U.S. banks to hold foreign risky assets in addition to standard government bonds: given uncorrelated returns, this offers important risk sharing benefits. For this reason, our economy features capital flowing from the U.S. to the EM as the economy transits from autarky to financial openness. In effect, U.S. banks act as *global intermediaries*, and play a powerful role in driving capital flows and global asset prices, consistent with the empirical GFC literature.[4]

In fact, 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.[5]

[4] In addition to aforementioned empirical papers, see also Avdjiev and Hale (2019), and Bräuning and Ivashina (2020) on capital flows to EM by U.S. banks due to search-for yield motives.

[5] A similar form of propagation across markets has also been emphasized by Dedola and Lombardo (2012) and

Next, we consider the global effects of a rise in *U.S.-specific* uncertainty. This means that the riskiness of U.S. capital's productivity rises (with no change in the riskiness in the productivity of EM capital). Through the effects described earlier when discussing the autarky case, this shock causes deleveraging pressure on the U.S. (now global) intermediaries. Because of the arbitrage channel described in the previous paragraph (tying together the movements in asset prices in both countries), the shock also implies that the effective riskiness of foreign assets endogenously rises.

In this way the shock transmits to foreign intermediaries, which also face deleveraging pressure—ultimately resulting in a fall in the foreign risky asset price. 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 United States, 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.

We next extend the model to a two-good economy in order to open our countries to trade in goods and incorporate fluctuations in the real exchange rate. In this economy, U.S. intermediaries can hold both U.S. government bonds (in U.S. dollars) and EM government bonds (denominated in the local currency of the EM).[6] We shut down trade in risky assets in this case to focus on the implications for real exchange rate and the UIP premium and show how deviations from UIP condition can arise even without trade in risky assets and limit to arbitrage. We can now study the interaction between uncertainty shocks, risk premia, and the real exchange rate. As mentioned earlier, measures of uncertainty move together with the USD exchange rate (see also Sarno et al. (2012), Lilley et al. (2020) and Shin et al. (2010)), and with UIP premia (see di Giovanni et al. (2021) and Kalemli-Özcan and Varela (2021)). There are significant failures of UIP in the two-good economy model, due to movements in the "risk term" (i.e. the conditional covariance between intermediaries' SDF and the exchange rate) stemming from fluctuations in uncertainty. We show that the model-implied effects of uncertainty shocks on UIP premia and on exchange rates align quite well with their empirical counterparts (calculated via an identified VAR).

Our UIP deviations do not depend on limits to arbitrage between U.S. government bonds and EM government bonds stemming from financing frictions, as in Gabaix and Maggiori (2015) or Itskhoki and Mukhin (2021): we assume that global intermediaries do not face limits to arbitrage in pricing foreign-currency bonds. Yet, our model generates a sizable dollar appreciation in the wake of increased U.S. uncertainty. The reason is that these intermediaries are highly exposed

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.

[6] See Du and Schreger (2016) who show an increase in local currency-denominated borrowing of EM sovereigns.

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 the EM 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 following higher uncertainty, fully consistent with the implications of our model.

Literature. Our model builds on a substantial theoretical literature studying the effects of uncertainty shocks. Well-known examples include Bloom (2009) and Basu and Bundick (2017). Much of this literature focuses on closed economy settings. Our goal, instead, is to study the global effects of fluctuations in uncertainty. Another difference with the literature is that our work studies the role of financial constraints in shaping the effects of uncertainty. By contrast, the literature on time-varying uncertainty has mostly focused on settings without financing frictions (exceptions include Arellano et al. (2019) and Fernández-Villaverde and Guerrón-Quintana (2020), but the workings of the financing friction differs considerably between these models and ours).

There is a large literature emphasizing some form of intermediation friction in driving exchange rate dynamics. Well-known examples include Gabaix and Maggiori (2015), Itskhoki and Mukhin (2021), and Basu et al. (2020). We also emphasize intermediation frictions, but 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.

More generally, in our model uncertainty shocks that hit global intermediaries transmit internationally to foreign economies' risky asset prices, capital flows and exchange rates through financial intermediaries' net worth. In recent work Morelli et al. (2022) show global financial intermediaries play a relevant role in driving borrowing costs in emerging markets.[7] Differently from their work, we focus in our modeling framework on the distinct role of uncertainty shocks in determining exchange rates and UIP premia (in addition to the prices of risky asset worldwide), and we argue that an important mechanism through which higher uncertainty transmits globally is changes in the net worth position of global financial intermediaries that are balance-sheet 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.

Our work relates in some ways to a prominent literature that aims to explain the role of the U.S. in the world financial architecture (Gourinchas et al. (2010), Maggiori (2017)). Like in some

[7] 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.

of this literature, U.S. financial intermediaries in our framework have a key role because they price global assets. Unlike this literature, our focus is on the implications of this setting for how U.S. uncertainty shocks transmit globally. Recent work by Kekre and Lenel (2021)) builds on that literature by embedding a 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. 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.

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 extend the model to two goods to incorporate the exchange rate. Section 6 concludes.

2 Empirical Evidence

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 2, 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.

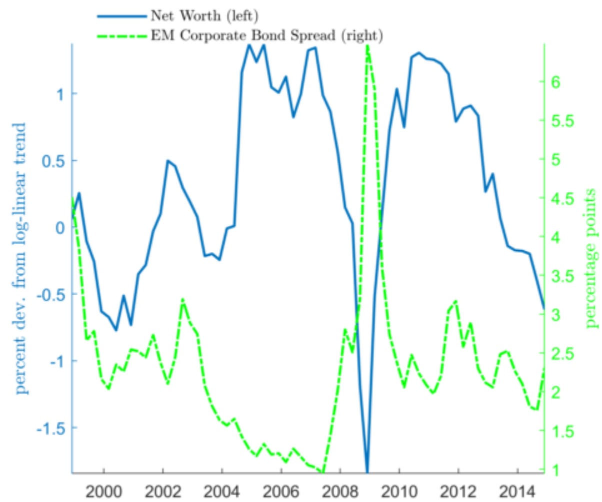
These observations suggest that uncertainty shocks might potentially transmit to EM risky asset prices through their impact on global banks' equity position. In this section we attempt to provide some motivational evidence using macro-level regressions for the presence of such channel. More specifically,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

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

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 1 presents the results for regression (1). The estimated coefficient for the effect of VXO on the spread is positive and significant, implying that higher uncertainty is associated with higher

Figure 2: 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.

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.

We next run a dynamic panel vector autoregressive model (VAR) to try to disentangle the role played by global banks' net worth position in determination of the dynamics of EM corporate bond spreads in times of elevated uncertainty. More specifically, we estimate a panel VAR model with quarterly data from several emerging economies which includes the VXO, U.S. banks' net worth, and the EM corporate bond spreads (in this exact order). Uncertainty shocks are identified by assuming that they are the only ones that move the VXO on impact, as in Basu and Bundick (2017). We assume that EM corporate spreads react to both VXO and the U.S. bank's net worth (contemporaneously and with lags), but developments in individual EMs do not affect global financing conditions.

Figure 3 shows the estimated effects an increase in U.S. uncertainty. A one-standard-deviation uncertainty shock increases the VXO by around 15 percent, leading U.S. banks' net worth to de-

Table 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

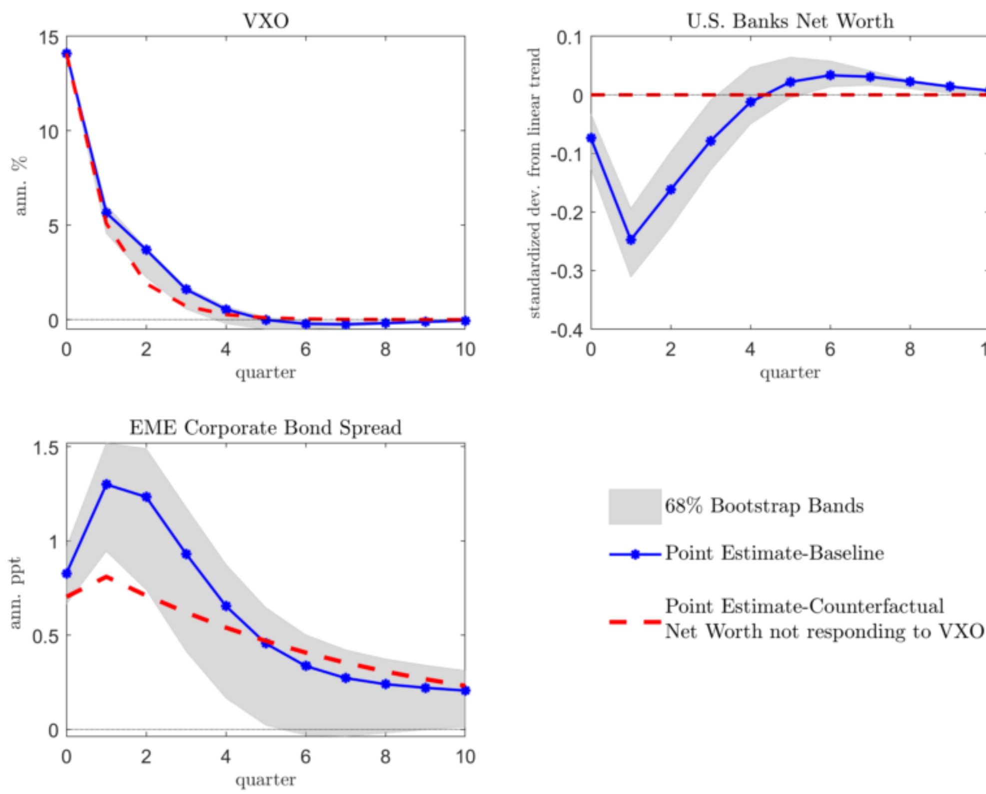
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; t statistics in parentheses.

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.

crease by 0.25 percent one quarter after the shock hits before rising back up to its long run value. EM corporate bond spreads rise 0.80 percentage points on impact, increase further another 0.50 percentage points, and remain elevated for about a year. It is unclear whether EM corporate bond spreads are reacting to higher uncertainty or its effects on global banks' net worth. A natural question is to what extent the *endogeneity* of net worth to VIX contributes to exacerbating fluctuations in risk premia faced by EM corporates.

We address this question by means of a counterfactual exercise, where the purpose is at gauging the degree to which global banks' net worth position amplify the effects of a shock to VXO. To this end, we calculate the "direct" effect of an exogenous rise in VIX on EM corporate spreads in a (counterfactual) world where the EM corporate spread does not directly depend on the US banks' net worth. Specifically, the net worth equation in the VAR is modified by setting to zero the coefficients on the VXO. We then compute the impulse response functions based on the modified VAR system. The results are shown by dashed red lines in Figure 3. Once U.S. banks' net worth is not allowed to react to uncertainty, the effect of a VXO shock on EM corporate bond spreads is dampened considerably: the effect of the same VXO shock on EM corporate bond spread is reduced from 1.30 to 0.80 percent one quarter after the shock hits, and the red line remains below the blue line for over a year.

Figure 3: Impulse response to a one standard deviation shock to VIX.



Note: Solid blue lines with stars show point estimates of impulse responses; and 68% confidence bands are depicted with light-gray shaded areas. Red dashed lines show point estimates of impulse responses obtained under the counterfactual that changes in VXO do not affect U.S. Bank's net worth. Spread represents the pooled panel of JP Morgan Corporate EM Bond Index for Brazil, Chile, China, Colombia, Hong Kong, India, Indonesia, Israel, Korea, Mexico, Malaysia, Philippines Singapore, South Africa, Taiwan, Thailand, Turkey.

Overall, we take these results as a suggestive evidence 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. Motivated by this evidence, we next describe our proposed model.

3 Model

We begin by studying a single-good exchange economy (as in Lucas (1978)) with two countries. 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 $\sigma_{z,t}$.

We assume that claims on capital held by financial intermediaries are subject to financing frictions (as in, for example, He and Krishnamurthy (2013)). In our analysis, we primarily focus on the effect of $\sigma_{z,t}$ on the price of capital Q_t, on the credit spread (or risk premium) $\mathbb{E}_t[R_{k,t+1} - R_t]$, on intermediary net worth N_t, as well as on its cross-border effects.

3.1 Home Economy

We assume home represents the United States, and foreign is an EM. We use * to denote the foreign economy.

3.1.1 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:

$$Z_t = (1 - \rho_z) + \rho_z Z_{t-1} + \sigma_{z,t-1}\varepsilon_{zt} \tag{2}$$

$$\sigma_{z,t} = (1 - \rho_\sigma)\overline{\sigma}_z + \rho_\sigma \sigma_{z,t-1} + \varepsilon_{\sigma t} \tag{3}$$

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).

3.1.2 Households

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

$$\mathbb{E}_t \left(\sum_{i=0}^{\infty} \beta^i \frac{C_{t+i}^{1-\varrho} - 1}{1 - \varrho} \right), \tag{4}$$

where C_t is consumption. The budget constraint is:

$$C_t + D_t \leq R_{t-1} D_{t-1} + T_t, \tag{5}$$

where 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 is

$$\beta \mathbb{E}_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\varrho} \right] R_t = 1 \tag{6}$$

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 (SDF) 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.

3.1.3 Financial intermediaries

Financial intermediaries ("banks," for short) obtain funds from households and also through internally accumulated net worth. They use these funds to finance claims on both domestic capital, $K_{i,t}$, and on foreign capital, $K_{F,i,t}$ (which denotes claims on foreign capital held by home banker i). Home bankers may also hold a risk-free government bond issued by the foreign country, which pays gross interest R_t^* (the foreign risk-free rate). This bond is a perfect substitute with domestic deposits. As a result, the home and foreign risk-free rates are equalized: $R_t = R_t^*$.

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 i, 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, $R_{t-1}D_{t-1}$) cannot exceed its revenues (stemming from new financing raised from households, D_t, and payments of previous-period capital and bond holdings):

$$Q_tK_{i,t} + Q_t^*K_{F,i,t} + B_t^* + R_{t-1}D_{i,t-1} \le D_{i,t} + (Z_t + Q_t)K_{i,t-1} + (Z_t^* + Q_t^*)K_{F,i,t-1} + R_{t-1}^*B_{t-1}^* \tag{7}$$

where Z_t, Z_t^* denote the productivity of domestic and foreign capital, respectively. The variable Q_t is the price of claims on domestic capital and Q_t^* is the price of claims on foreign capital.

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

$$Q_tK_{i,t} + Q_t^*K_{F,i,t} + B_t^* = D_{i,t} + N_{i,t} \tag{8}$$

Combining equations (7) and (8) and imposing $R_t = R_t^*$ we obtain the net worth evolution equation:

$$N_{i,t} = (R_{k,t} - R_{t-1})Q_{t-1}K_{i,t-1} + (R_{k,t}^* - R_{t-1})Q_{t-1}^*K_{F,i,t-1} + R_{t-1}N_{i,t-1} \tag{9}$$

where $R_{kt} \equiv \frac{Z_t+Q_t}{Q_{t-1}}$ and $R_{kt}^* \equiv \frac{Z_t^*+Q_t^*}{Q_{t-1}^*}$. Define the "leverage," denoted by $\phi_{i,t}$, and the ratio of the value of foreign to total assets in intermediary i's balance sheet, denoted by $x_{i,t}$, as the following, respectively:

$$\phi_{i,t} \equiv \frac{Q_t K_{i,t} + Q_t^* K_{F,i,t}}{N_{i,t}}, \tag{10}$$

$$x_{i,t} \equiv \frac{Q_t^* K_{F,t}}{Q_t K_{i,t} + Q_t^* K_{F,i,t}}. \tag{11}$$

Equation (9) then can be written as

$$N_{i,t} = [(R_{k,t} - R_{t-1})(1 - x_{i,t}) + (R_{k,t}^* - R_{t-1})x_{i,t}]\phi_{i,t} + R_{t-1}N_{i,t-1}, \tag{12}$$

which will help in formulating the banker's constrained optimization problem.

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 objective is:

$$V_{i,t} = \max_{K_{i,t}, K_{F,i,t}, D_{i,t}} \mathbb{E}_t \left[\Lambda_{t,t+1} \left((1-\sigma)N_{it+1} + \sigma V_{it+1}\right)\right] \tag{13}$$

subject to the evolution of net worth, equation (9), and the incentive compatibility constraint

$$V_{i,t} \geq \theta(Q_t K_{i,t} + Q_t^* K_{F,t}) \tag{14}$$

where $\Lambda_{t,t+1} \equiv \beta \frac{C_{t+1}^{-\varrho}}{C_t^{-\varrho}}$ denotes the household's stochastic discount factor, and 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. Define expected discounted returns

$$\mu_t \equiv \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}(R_{k,t+1} - R_t)] \tag{15}$$

$$\mu_{x,t} \equiv \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}(R_{k,t+1}^* - R_t)] \tag{16}$$

$$\nu_t \equiv \mathbb{E}_t(\Lambda_{t+1}\Omega_{t+1})R_t \tag{17}$$

$$\Omega_{t+1} \equiv (1-\sigma) + \sigma\Psi_{t+1} \tag{18}$$

Then the banker's problem can be re-written as

$$\Psi_t = \max_{\phi_{i,t}, x_{i,t}} \; [\mu_t(1 - x_{i,t}) + \mu_{x,t} x_{i,t}]\phi_{i,t} + \nu_t \tag{19}$$

subject to

$$\phi_{i,t} \leq \frac{\Psi_t}{\theta}. \tag{20}$$

Then the first-order condition with respect to x_{it} for the banker's problem is

$$\mu_{x,t} = \mu_t. \tag{21}$$

This optimal portfolio condition states that the expected discounted excess returns on domestic and foreign assets held by U.S. intermediaries have to equalize. As long as $\mu_t > 0$, the constraint (20) always binds. In our calibration below, the constraint always binds in a neighborhood of the steady state, so that (20) holds with equality. Observe that ϕ_{it} is the same for all i. The undetermined coefficient Ψ_t can be solved from (19): $\Psi_t = \mu_t \phi_t + \nu_t$.

In each period, any banker i 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, $N_t \equiv \int N_{it} di$, is

$$N_t = \sigma \left\{ [(R_{k,t} - R_{t-1})(1 - x_{t-1}) + (R^*_{k,t} - R_{t-1})x_{t-1}]\phi_{t-1} + R_{t-1} \right\} N_{t-1} + (1 - \sigma)\xi Q_{t-1} \tag{22}$$

3.2 Foreign Economy

The foreign economy is analogous to home, with one difference: foreign intermediaries cannot hold home capital, only capital of their own economy.[8] We assume that the foreign productivity process, Z^*_t, is given by

$$Z^*_t = (1 - \rho_z) + \rho_z Z^*_{t-1} + \overline{\sigma}_z \varepsilon^*_{zt}, \tag{23}$$

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

3.3 Market Clearing

There are five markets: for home deposits, for foreign deposits, for claims on home capital, for claims on foreign capital, and for foreign government bonds. Deposit market clearing requires that the amount supplied by households in each country equals amount demanded by intermediaries: $D_t = \int D_{i,t} di$, $D^*_t = \int D^*_{i,t} di$. Home capital can only be held by home bankers. Thus, $\int K_{i,t} di = 1$.

[8] This assumption is justified by the observation that net foreign liabilities and gross foreign liabilities for emerging markets moves closely. See, for example, Duttagupta et al. (2013) and Avdjiev et al. (2017).

Foreign capital can be held either by domestic or by foreign bankers, so we have

$$K_{F,t} + K^*_{F,t} = 1 \tag{24}$$

where $K_{F,t}$ is total claims by home bankers on foreign capital, and $K^*_{F,t}$ is total claims by foreign bankers on foreign capital. Finally, foreign government bonds are in zero net supply, so that the amount held by U.S. banks, B^*_t, must be offset by holdings by foreign households.

Given the above, combining home bankers' and households' budget constraints gives the aggregate resource constraint for the U.S.:

$$C_t + Q^*_t \Delta K_{F,t} + B^*_t - R^*_{t-1} B^*_{t-1} = Z_t + Z^*_t K_{F,t-1} \tag{25}$$

Similarly, one can derive the resource constraint for the foreign economy:

$$C^*_t + Q^*_t \Delta K^*_{F,t} = Z^*_t K^*_{Ft-1} + B^*_t - R^*_{t-1} B^*_{t-1} \tag{26}$$

Note that combining (25) and (26) give the world resource constraint:

$$C_t + C^*_t = Z_t + Z^*_t. \tag{27}$$

Equations (6), (15)-(18), (20) with equality, and (22) characterize the behavior of the home economy. An analogous set of equations holds for the foreign country, with $x^*_t = 0$ (foreign does not hold claims on home assets). Along with the market clearing conditions (24)-(26), these equations characterize the behavior of the world economy. We present the complete set of equilibrium conditions in Appendix A.

3.4 Calibration

Table 2 shows the parameter values we use in the model experiments shown below. The household risk aversion, ϱ, and discount factor, β, are set to reasonably conventional values. The parameters specific to the intermediary friction include the banking survival rate, σ, the transfer rate to new bankers, ξ, and the fraction of assets that can be diverted, θ. We set the survival rate to 0.97, similar to Gertler and Karadi (2011), implying a long horizon for bankers of nearly ten years. We set θ and ξ to hit two targets: a steady-state credit spread (or risk premium) of one hundred basis points, and a leverage ratio of five. The first target reflects the average values of corporate bond spreads. The second target is a conservative estimate of intermediary leverage. The parameter values resulting from these targets, $\theta = 0.33$ and $\xi = 0.08$, are well within the range of values used within the related literature.

The bottom of Table 2 shows the parameters pertaining to the stochastic processes (including for the uncertainty shock). We take these parameters from Basu and Bundick (2017).

Table 2: Parameter Values

Parameter	Description	Value	Source/Target
ϱ	Risk aversion	3	
β	Discount factor	0.995	Basu and Bundick (2017)
σ	Survival rate of bankers	0.97	Gertler and Karadi (2011)
ξ	Transfer to entering bankers	0.09	Leverage = 5 (assets/equity)
θ	Fraction of capital that can be diverted	0.34	Spread = 1 p.p. per year
ω	Home bias (two-good model)	0.95	
ρ_σ	Persistence of uncertainty shock	0.75	Basu and Bundick (2017)
$\overline{\sigma}_z$	Average SD of productivity shock	0.004	Basu and Bundick (2017)
ρ_z	Persistence of productivity shock	0.90	

4 Model Analysis

In this section, we consider the effects of higher uncertainty on the dynamics of risk premia, (global) risky asset prices, and financial intermediaries' net worth. We start our analysis with an economy in autarky, which we think provides useful insight into how uncertainty shocks propagate in this economy. We then consider the effects of higher uncertainty in the financially integrated economy.

4.1 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 (i.e., setting $x_t = B_t^* = K_{F,t} = 0$ in the previous equations). The model then reduces to the following system of four equations:

$$1 = \beta \mathbb{E}_t \left[\left(\frac{Z_{t+1}}{Z_t} \right)^{-\varrho} \right] R_t, \tag{28}$$

$$\mu_t = \mathbb{E}_t[\mathbf{\Omega_{t+1}}(R_{k,t+1} - R_t)], \tag{29}$$

$$Q_t = \frac{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]R_t}{\theta - \mu_t} N_t, \tag{30}$$

$$N_t = \sigma[(R_{k,t} - R_{t-1})Q_{t-1} + R_{t-1}N_{t-1}] + (1-\sigma)\xi Q_{t-1}, \tag{31}$$

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

$$\mathbf{\Omega}_{t+1} \equiv \beta \left(\frac{Z_{t+1}}{Z_t} \right)^{-\varrho} \left(1 - \sigma + \sigma\theta \frac{Q_{t+1}}{N_{t+1}} \right), \tag{32}$$

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

Equation (28) is the household's Euler equation determining the risk-free rate R_t. The variable

μ_t in equation (29) 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 (30) 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 (31) 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.

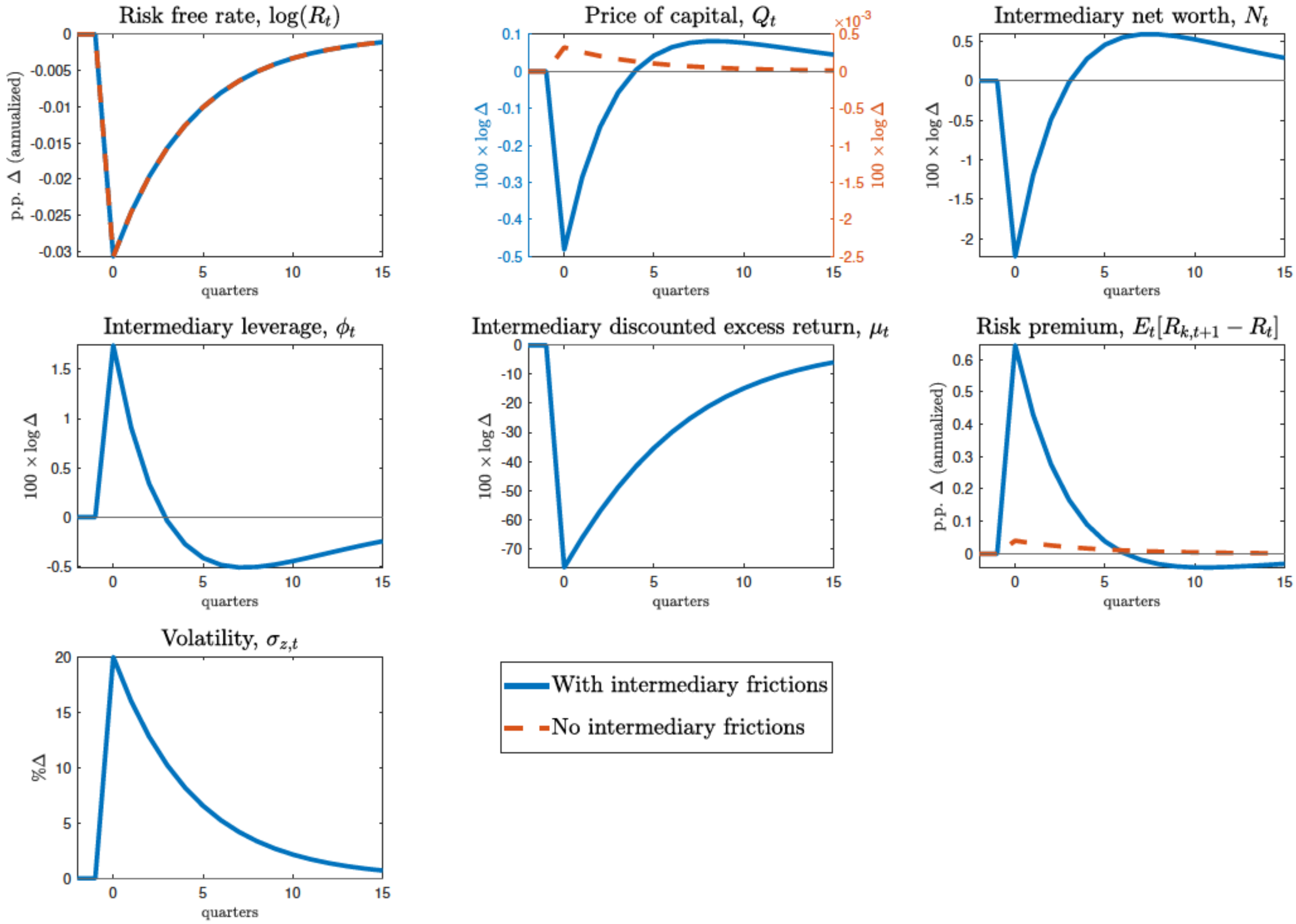
We now turn to the effects of an increase in aggregate uncertainty in this economy, depicted in Figure 4. The dividend's volatility $\sigma_{z,t}$ increases by twenty percent relative to its steady-state level, as shown in the last panel of the figure. The prospect of a more-risky Z_{t+1} has the effect 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 (30), 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 4, 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 bankers' SDF and the return on capital. Rearranging (29), the risk premium can be written

$$\begin{aligned}\mathbb{E}_t[R_{k,t+1} - R_t] &= \frac{\mu_t}{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]} + cov_t\left(-\frac{\mathbf{\Omega}_{t+1}}{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]}, R_{k,t+1}\right) \\ &\approx \frac{\mu_t}{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]} + \sigma_t\left(\frac{\mathbf{\Omega}_{t+1}}{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]}\right) \times \sigma_t\left(R_{k,t+1}\right). \end{aligned} \tag{33}$$

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 5, in the wake of the uncertainty shock,

Figure 4: Dynamic effects of uncertainty shock, autarky

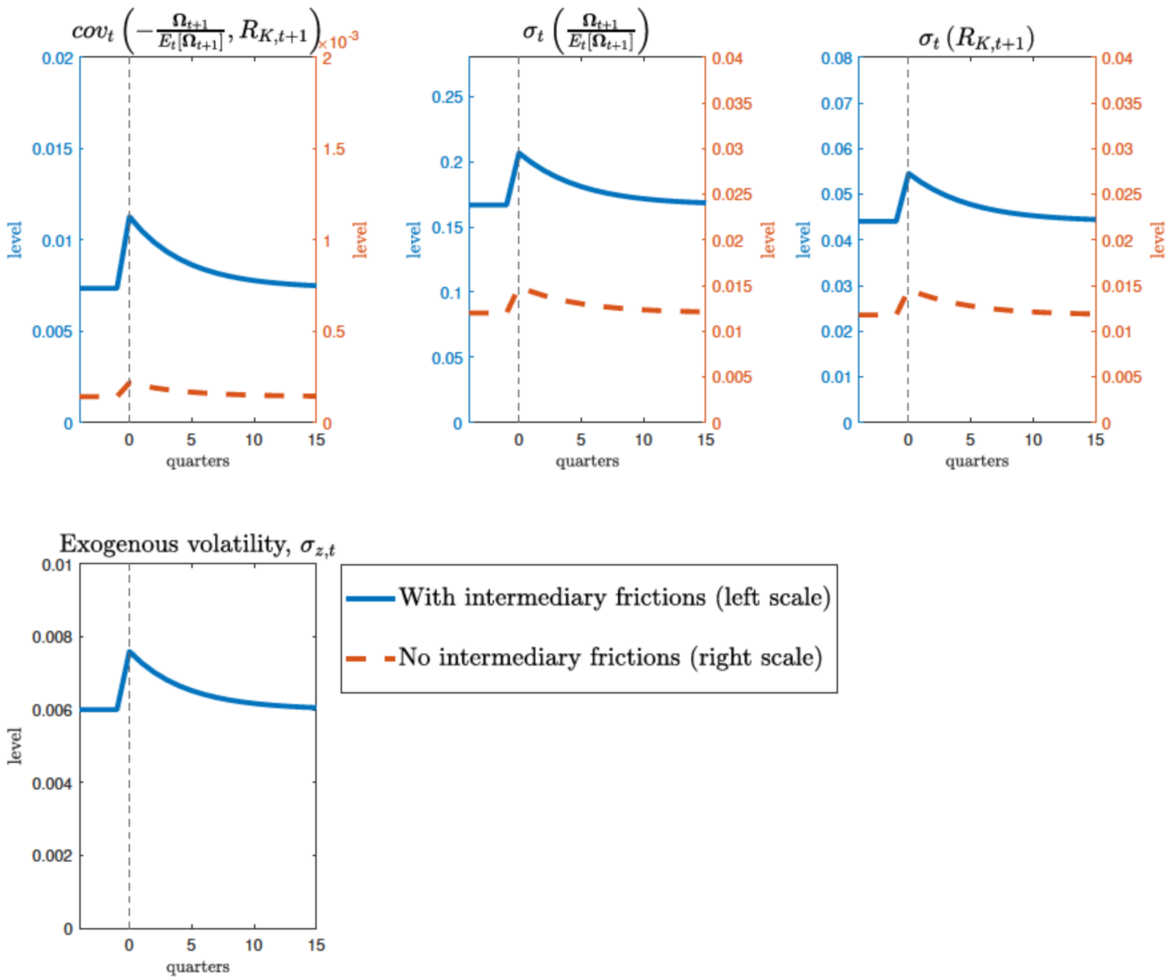


this conditional covariance rises sharply—accounting for the sharp increase in the risk premium, despite the fact that μ_t falls.

The conditional covariance in (33) can, in turn, be approximately expressed as the product of the standard deviation of the normalized SDF, $\sigma_t\left(\frac{\Omega_{t+1}}{\mathbb{E}_t[\Omega_{t+1}]}\right)$, 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 quantity of risk (of a given asset) is a function of the volatility of the asset's returns.

In Figure 5 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

Figure 5: Uncertainty shock: price and quantity of risk



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 4 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:

$$\beta \mathbb{E}_t \left[\left(\frac{Z_{t+1}}{Z_t} \right)^{-\varrho} \right] R_t^U = 1, \tag{34}$$

$$\beta \mathbb{E}_t \left[\left(\frac{Z_{t+1}}{Z_t} \right)^{-\varrho} \left(Z_{t+1} + Q_{t+1}^U \right) \right] = Q_t^U, \tag{35}$$

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 4 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.[9] (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

$$Q_t^U = \frac{\mathbb{E}_t[Z_{t+1} + Q_{t+1}^U]}{R_t^U + cov_t\left(-\frac{\Lambda_{t+1}}{\mathbb{E}_t[\Lambda_{t+1}]}, R_{k,t+1}\right)} \tag{36}$$

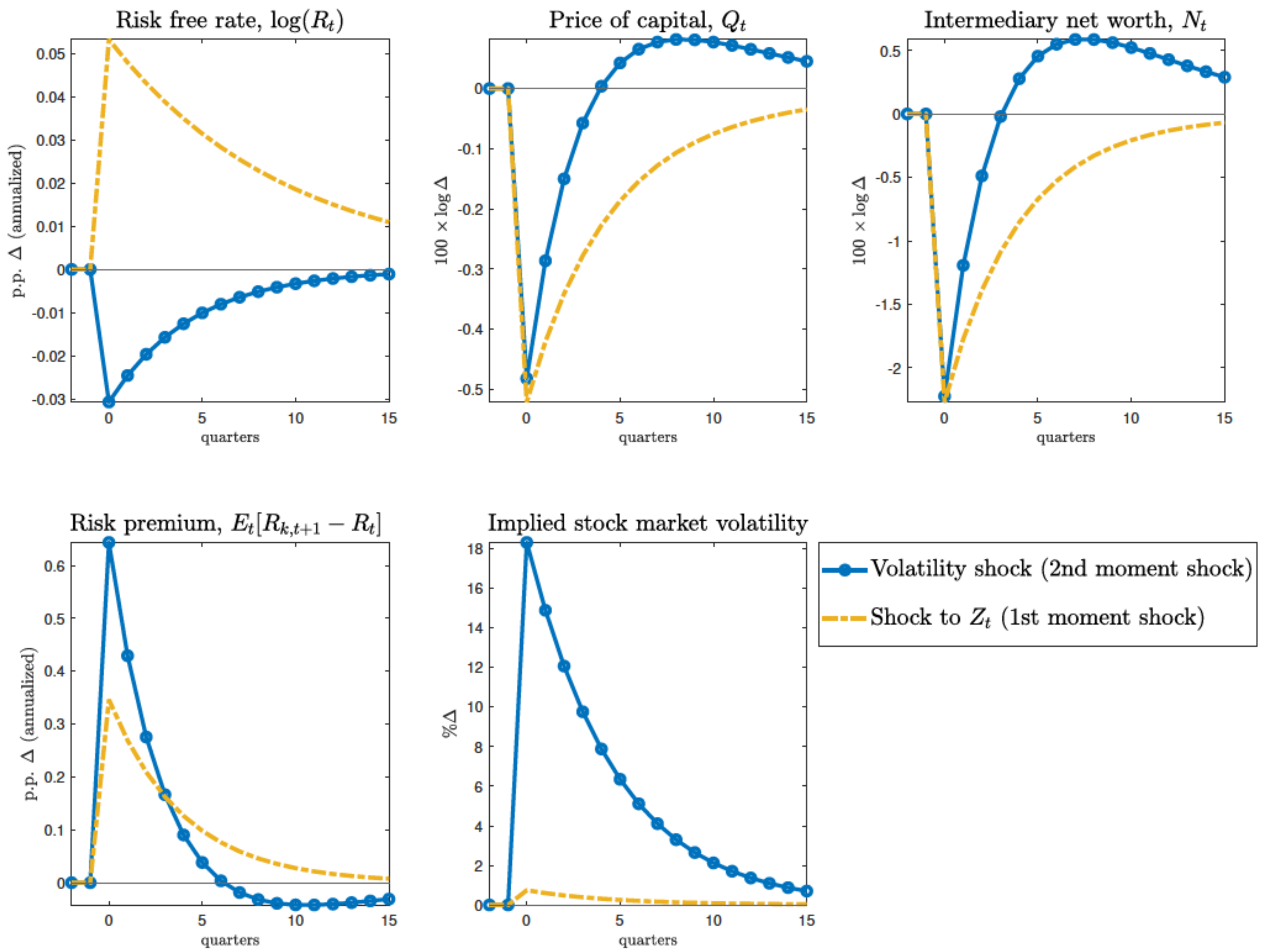
With higher risk, the covariance term in the denominator rises as agents require a larger premium to hold risky assets, depressing Q_t^U. At the same time, the risk-free rate, R_t^U, falls in response to the higher precautionary savings induced by the increase in consumption risk. The latter effect puts 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 6, 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 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

[9] 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.

Figure 6: Effects of first- v. second-moment shocks



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.

4.2 Uncertainty shocks with financial integration

We next analyze the case in which the two countries are financially integrated. Table 3 shows the conditional covariances with financial integration (the first row with numbers), and compares the results with the economy in financial autarky (the second row with numbers). As shown in the table, 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

Table 3: Conditional covariances (in the risk-adjusted steady state)

Variable	Financial Integration	Autarky
$Cov_t(Z_{t+1}, Z^*_{t+1})$	0	0
$Cov_t(Q_{t+1}, Q^*_{t+1})$	38.6	0
$Cov_t(\mathbf{\Omega}_{t+1}, Q_{t+1} + Z_{t+1})$	-1.95	-3.90
$Cov_t(\mathbf{\Omega}_{t+1}, Q^*_{t+1} + Z^*_{t+1})$	-1.95	0
$Cov_t(\mathbf{\Omega}^*_{t+1}, Q^*_{t+1} + Z^*_{t+1})$	-1.95	-3.90

risk-sharing arrangement between countries that emerges due to financial integration.

We now turn to the dynamic effects of higher home uncertainty in a world in which countries are financially integrated, shown in Figure 7. The key observation is that a rise in home uncertainty affects the foreign economy variables by almost as much as it does the home economy variables: the increases in the risk premium abroad, and the declines in the foreign asset values and intermediary net worth, are nearly of the same magnitude as their counterparts at home. Thus, the model features powerful spillovers on foreign economies of increases in home uncertainty.

What drives these larges cross-border effects? 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 7, 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.[10]

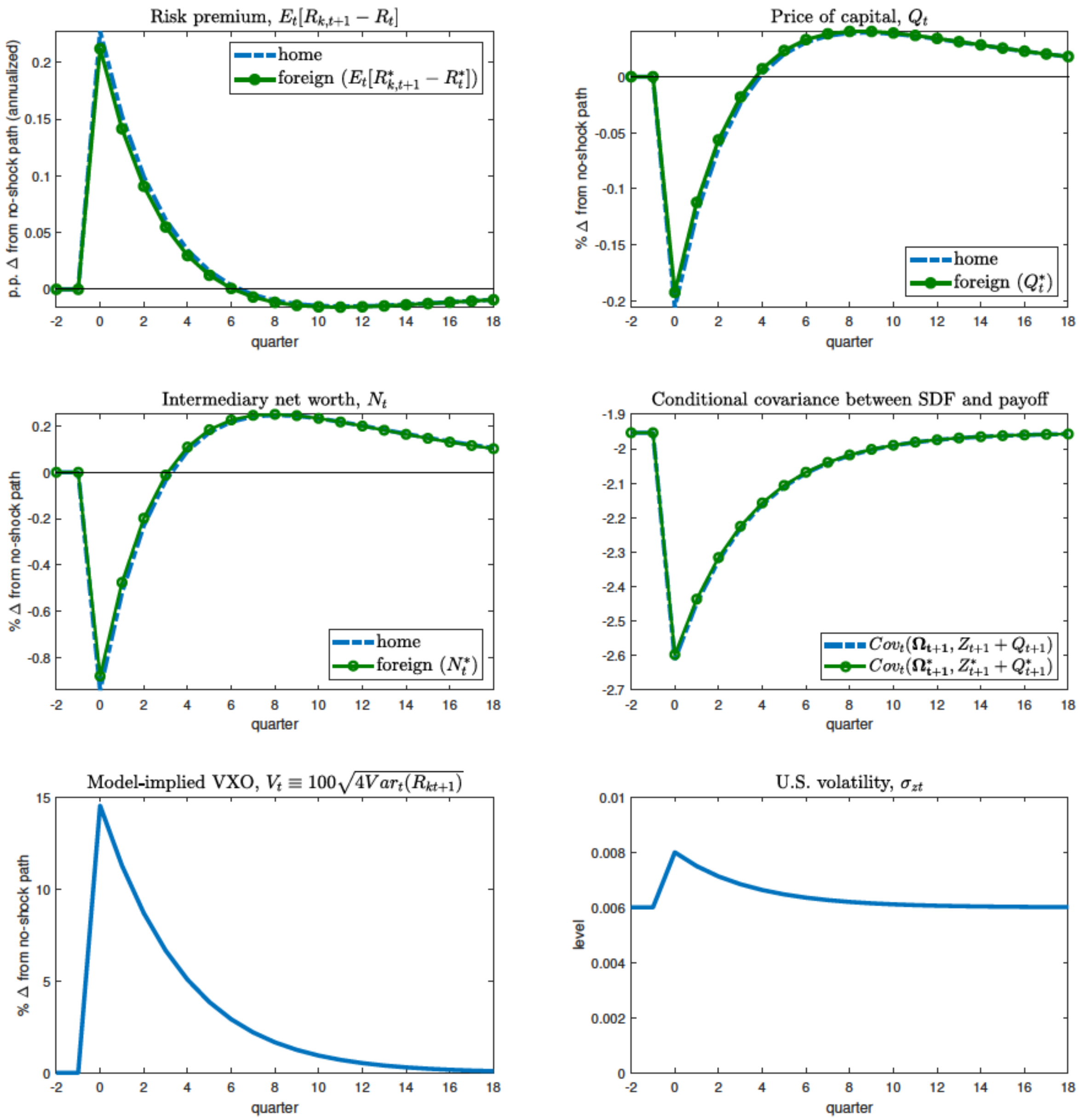
To understand why the covariances move synchronously, it is helpful to recall the optimal portfolio for U.S. (or global) banks, equation (21):

$$\mathbb{E}_t[\mathbf{\Omega}_{t+1} R^*_{k,t+1}] = \mathbb{E}_t[\mathbf{\Omega}_{t+1} R_{k,t+1}] \tag{37}$$

Suppose that a standard adverse productivity shock (a negative disturbance to Z_t) hurts home 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 (37)) and a decline in Q_t. Note that a first-order

[10] Figure 13 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.

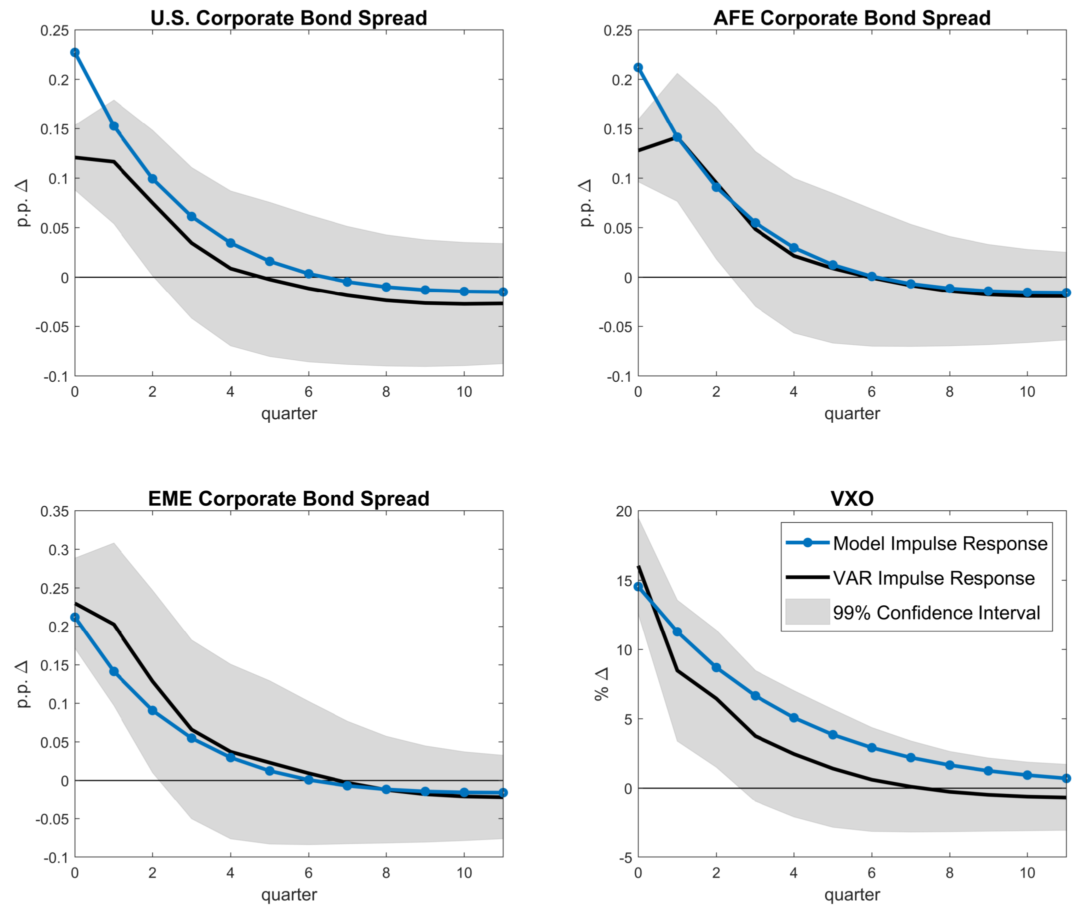
Figure 7: Dynamic effects of U.S. uncertainty shock with financial integration



approximation is sufficient for the present argument: observe that $E_t(\mathbf{\Omega}_{t+1})$ vanishes from (37) to a first order. Without any change in foreign variables, equation (37) 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

Figure 8: Effects of uncertainty shock on credit spreads, VAR v. model



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 7.

Observe also that the effects of the shock are considerably muted under financial integration relative to the autarky economy: comparing Figure 4 with Figure 7, 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, as made clear by Table 3. 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.

Overall, our findings offer a very natural explanation for the high degree of comovement between measures of U.S. uncertainty, such as the VIX, and corporate bond spreads for different countries. More formally, Figure 8 shows the empirical counterpart of the effects of an increase in U.S. uncertainty. These empirical estimates are obtained from a standard Vector Autoregressive (VAR) model including measures of credit spreads (proxying for the risk premium) in the United States, advanced foreign economies (AFEs) and emerging market economies (EMEs) as well as the VXO. Uncertainty shocks are identified by assuming that they are the only ones that move the VXO on impact, as in Basu and Bundick (2017). The figure also reproduces the results predicted by the model. In the data, a one-standard-deviation uncertainty shock increases the VXO by around 15 percent, and leads to an increase in corporate bond spreads in the U.S. and in AFEs of just under 0.2 percentage points, and around 0.25 percentage points in EME corporate bond spreads. The model-implied effects are generally very close to the empirical ones. Overall, we argue that the model does pretty well in matching the observed responses in credit spreads globally to an increase in uncertainty.

5 Uncertainty Shocks, UIP Premia, and the Exchange Rate

We have so far studied a single-good economy real in which the real exchange rate is accordingly fixed at unity by assumption, and trade results entirely from consumption-smoothing motivations. We next study an extension with two goods in which the exchange rate can fluctuate. Our goal is to study the effect of uncertainty on the exchange rate. We make a number of simplifications to the previous setting to make the analysis transparent. In particular, we abstract from cross-border holdings of risky securities, and from financial frictions in the foreign economy. We next describe the economy and derive the key equilibrium relationships.

5.1 Home Households

Domestic households continue to maximize (4), but now C_t is a Cobb-Douglas aggregate of a home-produced good, $C_{H,t}$, and a foreign-produced one, $C_{F,t}$:

$$C_t = \left(\frac{C_{H,t}}{\omega}\right)^{\omega} \left(\frac{C_{F,t}}{1-\omega}\right)^{(1-\omega)}, \tag{38}$$

where the parameter $\omega \in (0.5, 1]$ governs home bias in consumption preferences. We denote the terms of trade (defined as the price of the foreign good in terms of the home good) 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 $\mathcal{S}_t$. We assume that both countries practice producer currency pricing. Under this assumption, it is straightforward to show that $\mathcal{T}_t$ and S_t must satisfy the following condition:

$$\mathcal{S}_t = \mathcal{T}_t^{2\omega-1}. \tag{39}$$

Given consumer optimality, demands for home and foreign goods satisfy

$$C_{H,t} = \omega \mathcal{T}_t^{1-\omega} C_t, \tag{40}$$

$$C_{F,t} = (1-\omega) \mathcal{T}_t^{-\omega} C_t. \tag{41}$$

The home consumer's intertemporal optimality condition is

$$1 = \mathbb{E}_t[\Lambda_{t+1}] R_t, \tag{42}$$

where R_t is the home real interest rate and Λ_t is the household's SDF between $t-1$ and t, given by

$$\Lambda_t = \beta \frac{C_t^{-\varrho}}{C_{t-1}^{-\varrho}} \tag{43}$$

5.2 Home Financial Intermediaries and Government Bonds

As before, home financial intermediaries hold domestic risky securities. In addition, they can also hold a (real) foreign government bond as well, denominated in the foreign currency. We continue to think of these institutions as "global banks," as they hold international government bonds in addition to domestic private securities.

A continuing banker i's budget constraint is

$$Q_t K_{i,t} + R_{t-1} D_{i,t-1} + \mathcal{S}_t B^*_{i,t} \leq D_{i,t} + (Z_t + Q_t) K_{i,t-1} + \mathcal{S}_t R^*_{t-1} B^*_{i,t-1}, \tag{44}$$

where B^*_{it} is the intermediary's holdings of the foreign government bond, and R^*_t is the foreign-currency interest rate.

The intermediary's balance sheet identity is

$$Q_t K_{i,t} + \mathcal{S}_t B^*_{i,t} = D_{i,t} + N_{it}. \tag{45}$$

As a benchmark, we assume that the intermediary can divert holdings of private assets (capital), but *cannot* divert its portfolio of government bond holdings: the incentive constraint (the counterpart of equation (14)) reads

$$V_{i,t} \geq \theta Q_t K_{i,t}. \tag{46}$$

This assumption implies that the intermediary does not face limits to arbitrage in its financing of foreign government bonds. Given this assumption, it is straightforward to show that the following condition must hold:

$$\mathbb{E}_t\left[\Lambda_{t+1}\Omega_{t+1}\left(\frac{\mathcal{S}_{t+1}R_t^*}{\mathcal{S}_t}-R_t\right)\right]=0. \tag{47}$$

That is, there is perfect arbitrage between bonds denominated in different currencies. Note, however, that the relevant discount factor is the global banks', $\Lambda_{t+1}\Omega_{t+1} \equiv \boldsymbol{\Omega}_{t+1}$. Through this term, the model generates substantial deviations from uncovered interest parity (UIP) in response to uncertainty shocks, as we will show.

Proceeding in similar steps as before, whenever the constraint binds we must have

$$\phi_t(1-y_t)=\frac{\Psi_t}{\theta}, \tag{48}$$

where again Ψ_t is the marginal value of net worth,

$$\phi_t=\frac{Q_t+\mathcal{S}_tB_t^*}{N_t} \tag{49}$$

is total leverage, and

$$y_t=\frac{\mathcal{S}_tB_t^*}{Q_t+\mathcal{S}_tB_t^*} \tag{50}$$

is the share of foreign government bonds in domestic banks' portfolio. (These expressions hold for each individual bank i as well as for the aggregate, denoted here by letters without i subscripts.)

The value of banker wealth satisfies

$$\Psi_t=\mu_t(1-y_t)\phi_t+\nu_t, \tag{51}$$

where

$$\mu_t=\mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}(R_{k,t+1}-R_t)], \tag{52}$$

$$\nu_t=\mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}]R_t, \tag{53}$$

$$\Omega_{t+1}=(1-\sigma)+\sigma\Psi_{t+1}, \tag{54}$$

$$R_{k,t}=\frac{Z_t+Q_t}{Q_{t-1}}. \tag{55}$$

Combining (44) with (45) and aggregating across banks yields the law of motion for aggregate net worth:

$$N_t = \sigma \left\{ [(R_{k,t} - R_{t-1})(1 - y_{t-1}) + (\frac{\mathcal{S}_t}{\mathcal{S}_{t-1}} R^*_{t-1} - R_{t-1}) y_{t-1}] \phi_{t-1} + R_{t-1} \right\} N_{t-1} + (1 - \sigma) \xi Q_{t-1} \tag{56}$$

5.3 The Foreign Economy

Foreign households face a problem analogous to home households. They may also hold the foreign government bond (which we assume is in zero aggregate net supply). The corresponding optimality conditions are the following:

$$1 = \mathbb{E}_t[\Lambda^*_{t+1}] R^*_t, \tag{57}$$

$$\Lambda^*_t = \beta^* \frac{C_t^{-*\varrho}}{C_{t-1}^{*-\varrho}}, \tag{58}$$

$$C^*_{F,t} = \omega \mathcal{T}_t^{-(1-\omega)} C^*_t, \tag{59}$$

$$C^*_{H,t} = (1 - \omega) \mathcal{T}_t^{\omega} C^*_t. \tag{60}$$

5.4 Market Clearing

The total amount consumed of the home good must be equal to its total production:

$$Z_t = C_{H,t} + C^*_{H,t}. \tag{61}$$

(recall that we normalize the capital stock in each country to unity). A similar condition must hold for the foreign good:

$$Z^*_t = C^*_{F,t} + C_{F,t} \tag{62}$$

Finally, by combining home and foreign budget constraints it is possible to derive the following balance of payments condition:

$$C^*_{H,t} - \mathcal{T}_t C_{F,t} = \mathcal{T}_t^{\omega} \left(B^*_t - R^*_{t-1} B^*_{t-1} \right). \tag{63}$$

From equation (63), whenever home's imports exceed the value of exports, the home economy accumulates net foreign assets.

Equations (39), (40)-(43), (47)-(63) determine the endogenous variables $\Lambda_t, \Lambda^*_t, R_t, R^*_t, C_t, C^*_t, C_{H,t}, C^*_{H,t}, C_{F,t}, C^*_{F,t}, \mathcal{T}_t, \mathcal{S}_t, N_t, R_{k,t}, y_t, \phi_t, Q_t, \mu_t, \Omega_t, \nu_t, \Psi_t$, and B^*_t.

5.5 Dynamic Effects of Uncertainty Shocks on Exchange Rates

We now examine the model's implications for the effects of uncertainty on the exchange rate. We calibrate the home bias parameter, ω, to 0.95, to reflect the relatively small trade share of the United States with emerging market economies. All remaining parameters are calibrated as in Table 2.

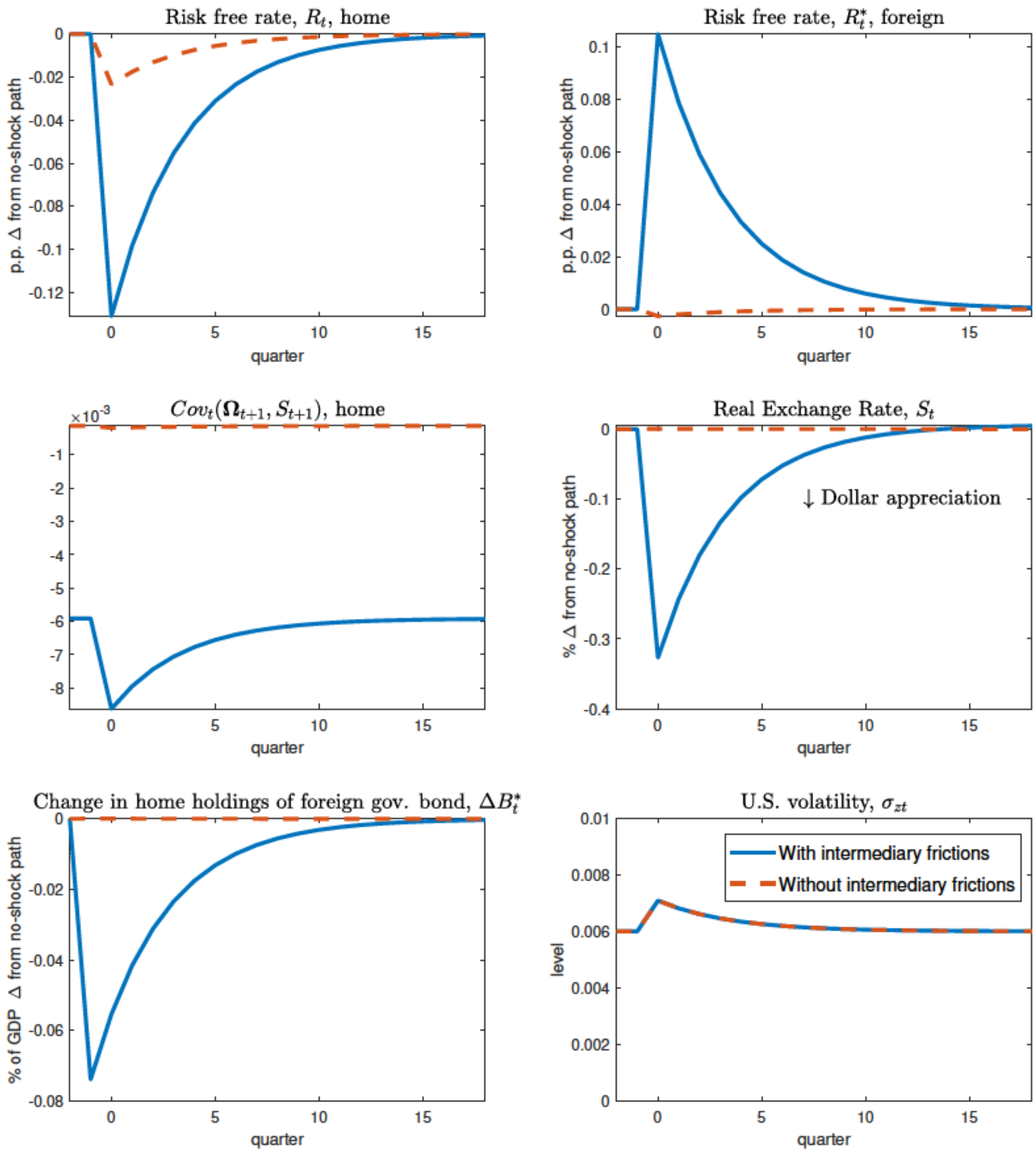
Figure 9 shows the effect of higher U.S. uncertainty, $\sigma_{z,t}$, in our baseline model with intermediary frictions. As a reference, the figure also shows the effects of the same shock in the setting without intermediary frictions (dashed red lines).[11] In the absence of intermediary frictions, there are two competing forces in determining the response of the exchange rate: on the one hand, the home risk-free rate declines by more than the foreign rate, which exerts upward pressure on $\mathcal{S}_t$. On the other hand, the "risk adjustment" (the conditional covariance between Λ_{t+1} and $\mathcal{S}_{t+1}$), which is always negative, turns more negative when σ_{zt} rises, thus exerting downward pressure on $\mathcal{S}_t$ (see equation (47)). (To understand why the covariance is negative, consider a decline in U.S. productivity Z_t: lower supply of the U.S. "fruit" makes it more expensive relative to the foreign fruit, lowering $\mathcal{S}_t$; at the same time, lower U.S. consumption increases the U.S. household's SDF). The interest differential channel turns out to dominate, and the dollar depreciates. The size of the effect, however, is very small.

With intermediary frictions, the risk adjustment term is much more powerful: observe that the downward move of $cov_t(\mathbf{\Omega}_{t+1}, \mathcal{S}_{t+1})$ is orders of magnitude larger than without frictions. The reason this risk-adjustment term is more powerful is that when U.S. fruit (Z_t) is low (which lowers $\mathcal{S}_t$), these bankers' returns are low, and therefore their constraints are tight. Thus, in a similar way as in the one-good model the presence of intermediaries' constraints made the covariance term in the risk premium much more elastic to movements in uncertainy, these constraints now also make the premium term in equation (47) more elastic to uncertainty. As a consequence, this risk effect dominates the interest differential channel, and the dollar now *appreciates* substantially *vis-á-vis* the foreign currency following the increase in uncertainty. Further, the magnitude of the appreciation is substantial. Accompanying the stronger dollar is a persistent outflow from foreign bonds ($\Delta B_t^* < 0$)—in contrast to the frictionless case, which featured a small inflow.

Figure 10 displays the effects of higher uncertainty on the UIP premium in our baseline model with intermediary frictions (solid blue line) and in a model without intermediary frictions (dashed red line). Note that the UIP premium is defined as the expected excess returns for holding emerging economy local bonds adjusted for the expected exchange rate depreciation of foreign currencies, $r_t^* + E_t(\Delta s_{t+1})$, over the (net) safe rate on U.S. bonds, r_t (lowercase denotes the log of uppercase letters). Consistent with the findings on the risk adjustment term $-Cov_t(\mathbf{\Omega}_{t+1}, \mathcal{S}_{t+1})$ we just described,[12]when uncertainty rises global investors require significantly larger excess returns for holding EM bonds in our baseline model, compared with the without intermediary frictions, consistent with the empirical evidence (see, for example, Kalemli-Özcan and Varela (2021)).

[11]See Figure 14 in the Appendix for a zoomed-in version of the figure without intermediate frictions.

[12]The UIP premium and the conditional covariance between SDF and future exchange rate can be shown to satisfy



These findings appear consistent with the often-discussed notion of the dollar as a "safe haven" currency which appreciates, especially against emerging market currencies, in times of higher uncertainty. More specifically, they may rationalize the observed positive correlation between the VIX and the dollar exchange rate against EMs.

the following equation:

$$\mathbb{E}_t\left[\frac{\frac{\mathcal{S}_{t+1}}{\mathcal{S}_t}R_t^*}{R_t}\right] - 1 = cov_t\left(-\frac{\mathbf{\Omega}_{t+1}}{\mathbb{E}_t[\mathbf{\Omega}_{t+1}]}, \frac{\frac{\mathcal{S}_{t+1}}{\mathcal{S}_t}R_t^*}{R_t}\right) \tag{64}$$

Thus, the UIP premium on foreign currencies (the left-hand side) is increasing in $cov_t(-\mathbf{\Omega}_{t+1}, \mathcal{S}_{t+1})$.

Figure 10: Exchange rate model, effects of U.S. uncertainty shock on UIP premium

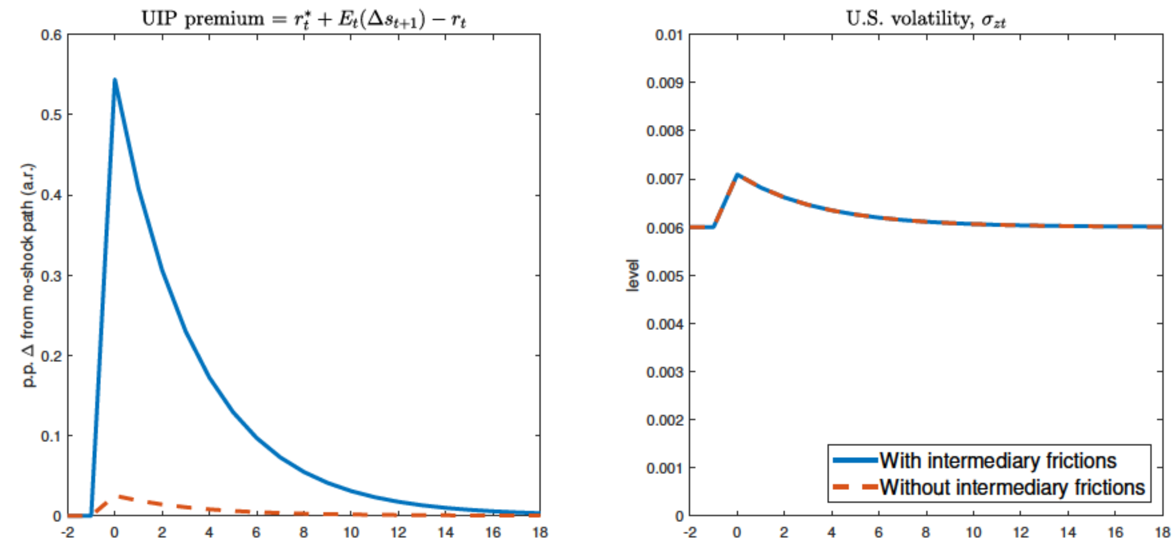


Figure 11: Effects of uncertainty shock on exchange rate, VAR v. model

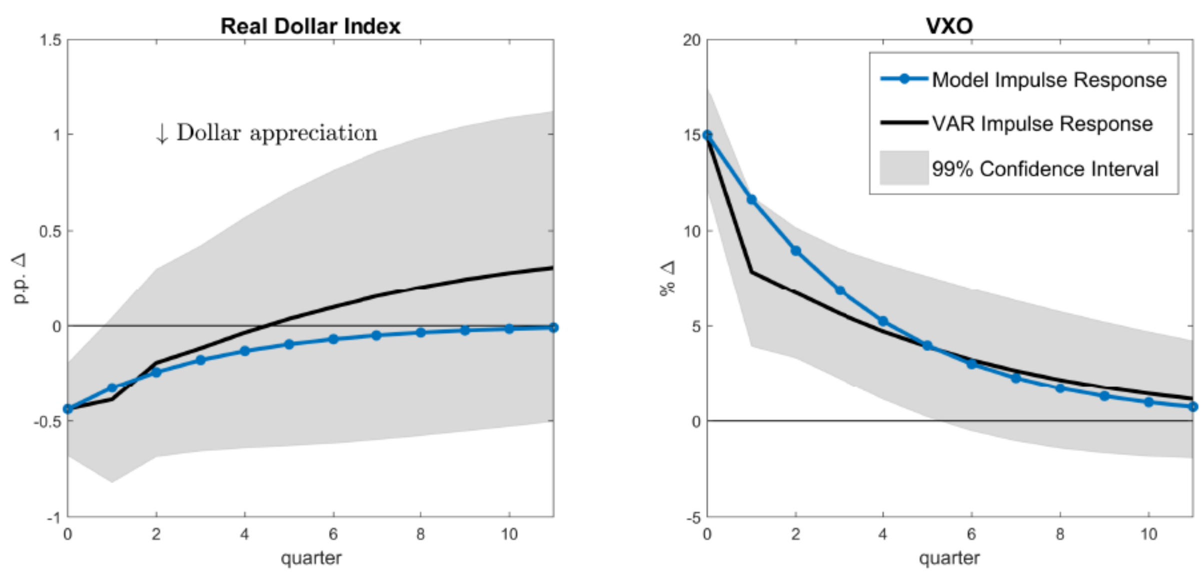
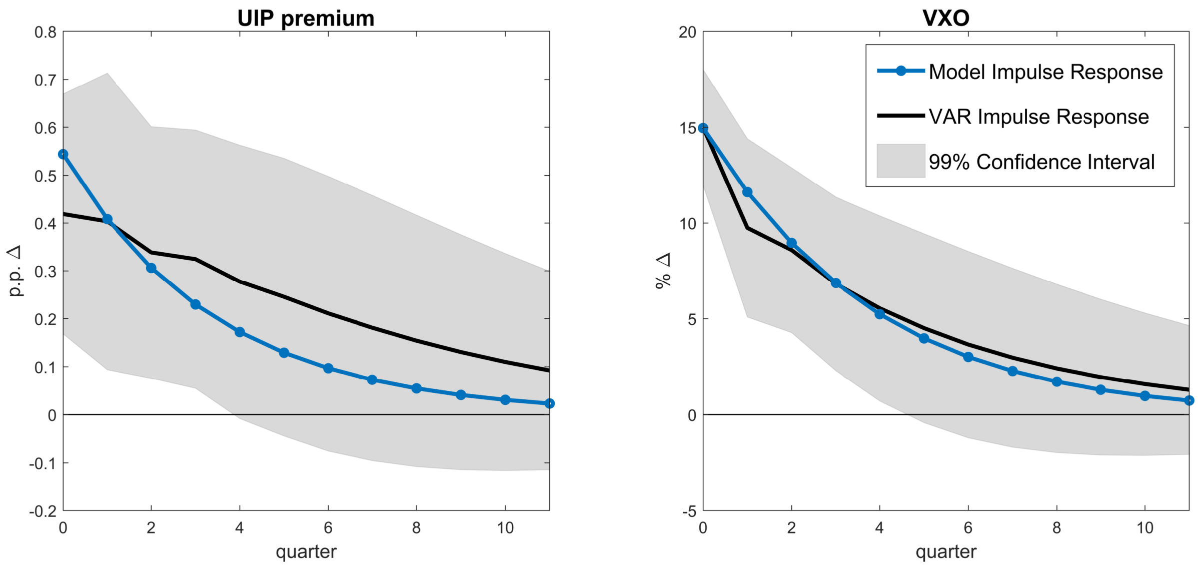


Figure 11 shows the effects of uncertainty shock on exchange rate, both implied by an empirical VAR model (solid black lines) and the model (blue lines). As before, the model does a reasonably good job in matching the observed responses of exchange rate to an increase in uncertainty: the dollar appreciates in both the model and the data in response to higher uncertainty. We also compare the model's implications for the UIP premium with those found in the data, using the empirical measures of the UIP premium constructed by Kalemli-Özcan and Varela (2021). We

Figure 12: Effects of uncertainty shock on UIP premium, VAR v. model



compute a single foreign UIP premium time series by taking the average of all countries in the sample, and then estimate a VAR with the UIP premium and the VXO. As shown in Figure 12 the UIP premium in the data rises significantly following an uncertainty shock. The model-implied response aligns quite well with the data for this case as well.

6 Conclusion

Three key facts of GFC is the global movements in risky asset prices, capital flows and leverage. The changes in the risk sentiment of global investors play a key role in these facts as documented extensively in the empirical literature. To date, we do not have a unifying open economy framework that can account for these facts.

We present such a framework. We model an open economy 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.

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A Complete Set of Equilibrium Conditions

Home:

$$1 = \mathbb{E}_t(\Lambda_{t+1})R_t \tag{65}$$

$$\Lambda_t = \beta \frac{C_t^{-\varrho}}{C_{t-1}^{-\varrho}} \tag{66}$$

$$\begin{aligned} N_t = {} & \sigma \left\{ [(R_{k,t} - R_{t-1})(1 - x_{t-1}) + (R^*_{k,t} - R_{t-1})x_{t-1}]\phi_{t-1} + R_{t-1} \right\} N_{t-1} \\ & + (1-\sigma)\xi Q_{t-1} \end{aligned} \tag{67}$$

$$R_{k,t} = \frac{Z_t + Q_t}{Q_{t-1}} \tag{68}$$

$$\mu_t = \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}(R_{k,t+1} - R_t)] \tag{69}$$

$$\mu_{x,t} = \mathbb{E}_t[\Lambda_{t+1}\Omega_{t+1}(R^*_{k,t+1} - R_t)] \tag{70}$$

$$\nu_t = \mathbb{E}_t(\Lambda_{t+1}\Omega_{t+1})R_t \tag{71}$$

$$\Omega_{t+1} = (1-\sigma) + \sigma\Psi_{t+1} \tag{72}$$

$$\mu_{x,t} = \mu_t \tag{73}$$

$$\phi_t = \frac{\Psi_t}{\theta} \tag{74}$$

$$\Psi_t = [\mu_t(1-x_t) + \mu_{x,t}x_t]\phi_t + \nu_t \tag{75}$$

$$\phi_t = \frac{Q_t + Q^*_t K_{F,t}}{N_t} \tag{76}$$

$$x_t = \frac{Q^*_t K_{F,t}}{Q_t + Q^*_t K_{F,t}} \tag{77}$$

$$C_t + Q^*_t \Delta K_{F,t} + B^*_t - R^*_{t-1}B^*_{t-1} = Z_t + Z^*_t K_{F,t-1} \tag{78}$$

Foreign:

$$1 = \mathbb{E}_t(\Lambda^*_{t+1})R^*_t \tag{79}$$

$$\Lambda^*_t = \beta^* \frac{C_t^{-*\varrho}}{C_{t-1}^{*-\varrho}} \tag{80}$$

$$N^*_t = \sigma[(R^*_{k,t} - R^*_{t-1})\phi^*_{t-1} + R^*_{t-1}]N^*_{t-1} + (1-\sigma)\xi^* Q^*_{t-1} \tag{81}$$

$$R^*_{k,t} = \frac{Z^*_t + Q^*_t}{Q^*_{t-1}} \tag{82}$$

$$\mu^*_t = \mathbb{E}_t[\Lambda^*_{t+1}\Omega^*_{t+1}(R^*_{k,t+1} - R^*_t)] \tag{83}$$

$$\nu^*_t = \mathbb{E}_t(\Lambda^*_{t+1}\Omega^*_{t+1})R^*_t \tag{84}$$

$$\Omega^*_{t+1} = (1-\sigma) + \sigma \Psi^*_{t+1} \tag{85}$$

$$\phi^*_t = \frac{\Psi^*_t}{\theta^*} \tag{86}$$

$$\Psi^*_t = \mu^*_t \phi^*_t + \nu^*_t \tag{87}$$

$$\phi^*_t = \frac{Q^*_t K^*_t}{N^*_t} \tag{88}$$

$$C^*_t + Q^*_t \Delta K^*_{F,t} = Z^*_t K^*_{F,t-1} + B^*_t - R^*_{t-1} B^*_{t-1} \tag{89}$$

Market clearing for claims on foreign capital and risk-free rate equalization:

$$K_{F,t} + K^*_{F,t} = 1 \tag{90}$$

$$R_t = R^*_t \tag{91}$$

The 27 equilibrium conditions above determine the evolution of the 27 endogenous variables $R_t, R^*_t, B^*_t, \Lambda_t, \Lambda^*_t, C_t, C^*_t, N_t, N^*_t, R_{k,t}, R^*_{k,t}, Q_t, Q^*_t, \mu_t, \mu^*_t, \mu_{xt}, \nu_t, \nu^*_t, \Omega_t, \Omega^*_t, \phi_t, \phi^*_t, \Psi_t, \Psi^*_t, x_t, K_{F,t}, K^*_{F,t}$, given the process for exogenous variables $Z_t, Z^*_t, \sigma_{z,t}$.

B Additional model results

Figure 13: Effects of U.S. uncertainty shock with financial integration and no intermediary frictions

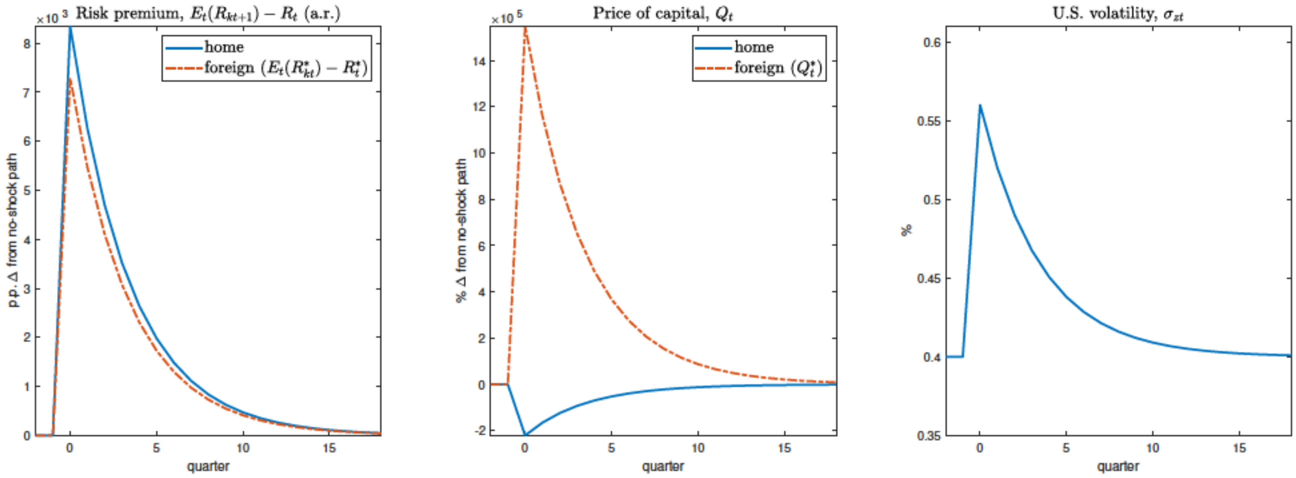
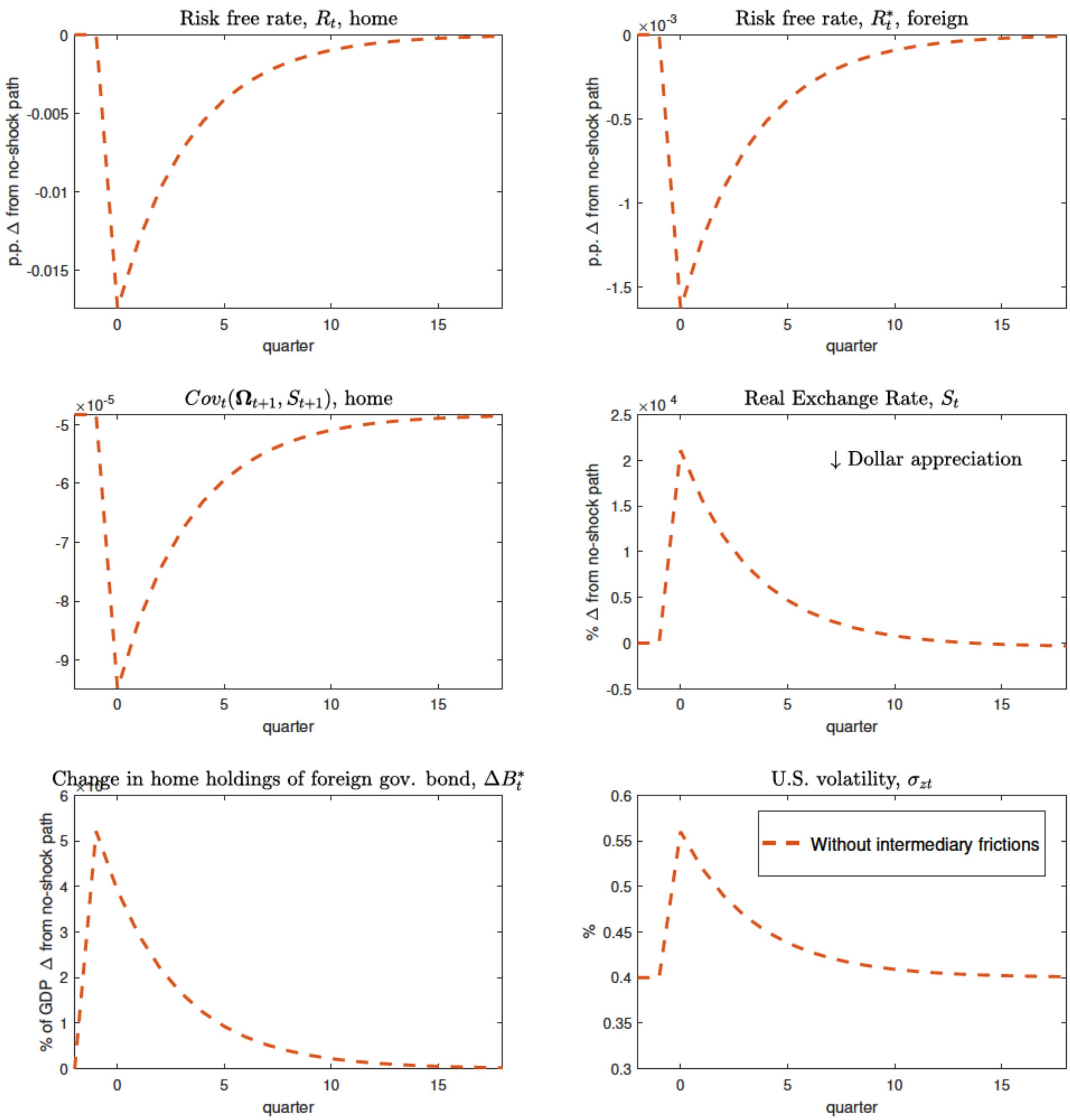


Figure 14: Exchange rate model, effects of U.S. uncertainty shock without intermediary frictions



C Data

Figure 15: VAR-predicted effects of uncertainty shock on credit spreads

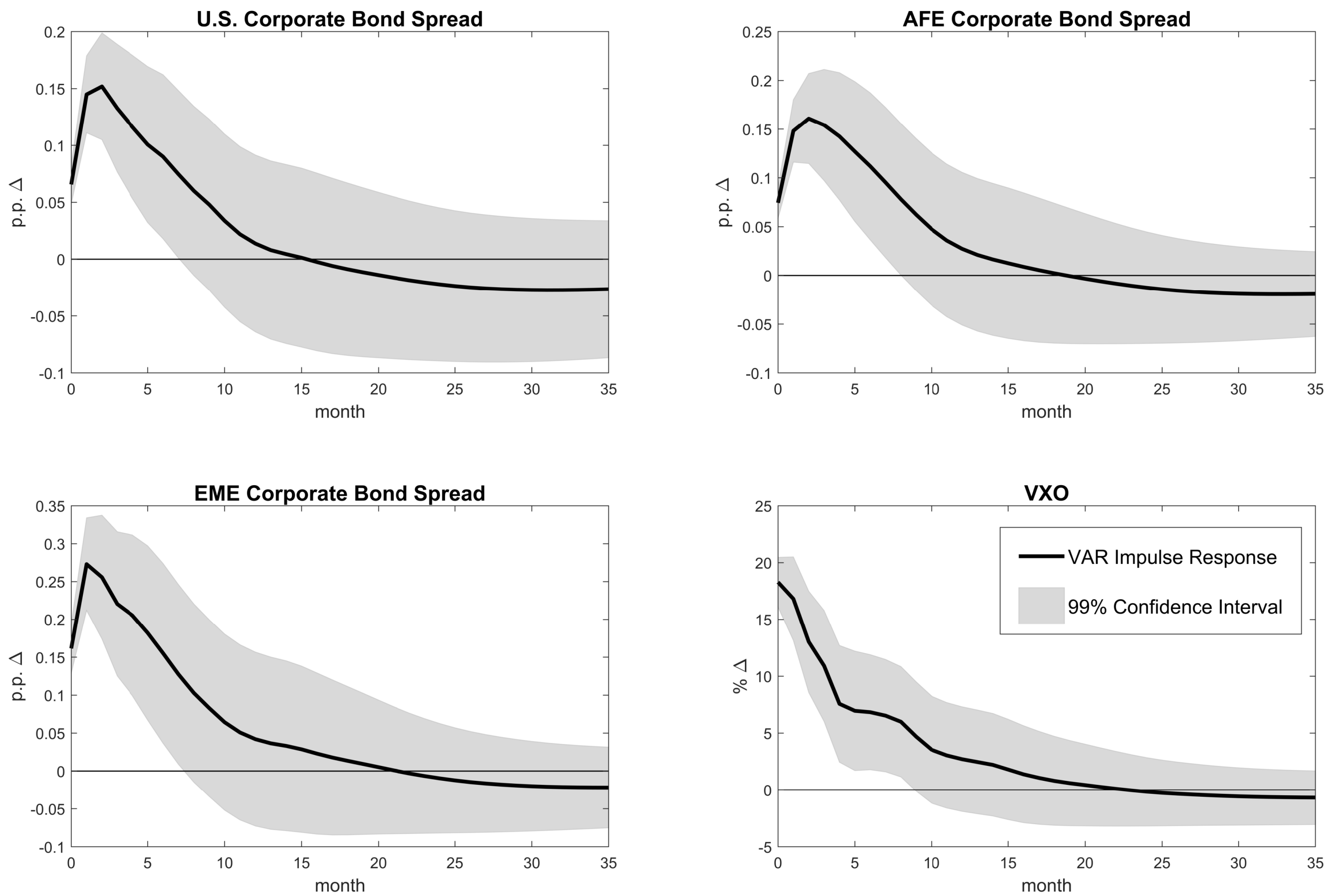


Figure 16: VAR-predicted effects of uncertainty shock on dollar exchange rates