

Volatility, Intermediaries and Exchange Rates

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Abstract

This paper studies how financial market volatility drives exchange rates through the risk management practice of financial intermediaries. We build a model in which the major participants in the international financial market are levered intermediaries subject to Value-at-Risk constraints. Higher portfolio volatility translates into tighter funding conditions and increased marginal value of wealth. Thus, foreign currency is expected to appreciate. Our model can resolve the Backus-Smith puzzle, the forward premium puzzle, and the exchange rate volatility puzzle quantitatively. Our empirical tests verify two implications of the model that measures of both financial market volatility and funding condition have predictive power on exchange rates.

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1 Introduction

Exchange rates are puzzling. They seem to be disconnected from economic fundamentals, especially relative consumption growth rate, which is in sharp contrast to the almost perfect correlation implied by most international macro models (Backus and Smith, 1993). High-interest-rate currencies do not tend to depreciate as the uncovered interest parity suggests, and sometimes they even appreciate (Hansen and Hodrick, 1980, Fama, 1984). As a result, excess returns of currency investment can be predicted by interest rate differentials. Finally, it is hard to obtain correct exchange rate volatility in either complete market arbitrage-free asset pricing models (Brandt et al., 2006) or incomplete market two-country international macro models (Chari et al., 2002).

In the recent three decades, there has been a great effort to try to resolve these exchange rate puzzles. This paper studies how intermediary funding condition fluctuations drive exchange rate dynamics. The fluctuations originate from time-varying financial market volatility faced by intermediaries, due to their value-at-risk constraints. The foreign exchange market is the largest financial market in the world, with a daily trading volume of more than 5 trillion dollars (Bank of International Settlement, 2013 triennial survey), among which most turnovers are implemented by financial institutions. As emphasized by the recent margin-based asset pricing literature (Brunnermeier and Pedersen, 2009, Garleanu and Pedersen, 2011, among others), levered financial institutions are subject to funding shocks, with potential micro foundations including Adrian and Shin (2014) and so on. It is natural for us to think about whether shocks originating from the financial sector will drive exchange rate dynamics, which is absent in either existing representative agent macroeconomic or arbitrage-free asset pricing models.

This paper builds a two-country, two-good general equilibrium exchange rate model. Throughout the paper, we refer to “US” as the home country, and “UK” as the foreign country. Both US and UK have a continuum of homogenous households and intermediaries. Financial markets are segmented, in which households only have access to a risk-free money market account in local intermediaries. Intermediaries combine money market deposits and their own net wealth to invest in a local risky asset, namely “equity”. They also have access to a single international bond. The international bond is denominated in US dollars (US composite good). Both intermediaries face a value-at-risk induced leverage constraint such that the size of the balance sheet cannot exceed a fraction of their market value (Gertler and Karadi, 2011 Dedola et al., 2013). The constraint varies with portfolio volatility of intermediaries. The higher volatility intermediaries face, the lower leverage they are allowed to take. Consequently, intermediaries value their net worth and deposits differently. In other words, intermediaries behave as a constrained arbitrageur in the market and earn a risk-adjusted excess return.

Volatility in the financial market drives asset prices in the economy by fluctuating funding con-

ditions faced by intermediaries. Suppose the two countries start from their initial state with no international bond positions. When there is a positive volatility shock in the US economy, local equity market volatility increases, and US intermediaries take less leverage. Intermediaries are impeded from investing in the risky asset regardless of the desirable investment opportunities, thus their valuation of net worth and deposit both increase. Intermediaries have incentive to borrow from abroad. We assume that foreign liabilities are not subject to the balance sheet constraint, due to the superior clearing technology for trades between sophisticated financial institutions. The marginal value of wealth for US intermediaries is higher than that of UK intermediaries, and the US dollar is expected to depreciate in the next period.

We show that the calibrated model can resolve the three exchange rate puzzles. In our model, the funding condition, and intermediary book leverage, enter into the pricing kernel. Expected exchange rate change and interest rate differential are linked through the funding condition channel: when US volatility gets larger, funding condition gets tighter in the US, so that its interest rate gets lower but US composite good is expected to depreciate. Our incomplete financial market setting is closer to a two-country international macro model, but with an additional volatility shock to generate higher exchange rate volatility than most models do.

We examine the empirical implications of our model. First, the growth rate of US total outstanding financial commercial paper has predictive power over the exchange rate of various currencies vis-a-vis the dollar. The larger amount of commercial paper predicts a lower foreign exchange rate in the next period. The predictability is preserved after controlling for several credit demand indicators. This finding is in line with Adrian et al. (2015). We also provide further evidence to link exchange rate to foreign exchange market volatility. In our model, domestic equity market volatility is the driving force of funding conditions, but the reality is far more complicated. Intermediaries have sophisticated balance sheets of various types of assets. Thus, it is hard to identify the exact portfolios held by intermediaries. However, all foreign exchange market participants bear foreign exchange risk, so exchange rate volatility seems to be a good candidate. Since US intermediaries are more globalized than intermediaries in other countries, foreign exchange volatility affects US intermediaries more than others. We find that average annual realized volatility of major currencies in the world has predictive power on exchange rate change for various major currencies. The higher global foreign exchange realized volatility predicts an appreciation of foreign currencies and a depreciation of the dollar.

The rest of the paper is organized as follows. In the remaining part of section 1 we briefly review the related literature. Section 2 lays out some institutional features of the foreign exchange market. Section 3 presents the model and section 4 shows how this model can qualitatively resolve the three exchange rate puzzles. In section 5 we report the quantitative performance of the model. Empirical implications are tested in section 6 and section 7 concludes our paper.

1.1 Related Literature

We review the two main strands of literature related to this paper: exchange rate literature and financial market frictions literature.

In the recent three decades, many studies have attempted to resolve these exchange rate puzzles. Following the consumption-based asset pricing literature, Verdelhan (2010) provides a habit-based model of exchange rates consistent with the anomalies above. Bansal and Shaliastovich (2013) explains bond market and foreign exchange market altogether in a long run risk setting with stochastic volatility. Colacito and Croce (2011), Colacito and Croce (2013) use a long-run risk framework to account for various international asset pricing anomalies, including the comovement of global equity returns, exchange rate volatility, disconnect between consumption growth and exchange rate change, and forward premium puzzle. Farhi and Gabaix (2016) gives a rare disaster explanation of exchange rate anomalies. There are also various attempts to explain these puzzles with incomplete financial market, including Corsetti et al. (2008) for the Backus Smith puzzle, Favilukis et al. (2015) for the forward premium puzzle, etc. However, Lustig and Verdelhan (2016) shows that standard international macro models with only financial market incompleteness cannot resolve the three puzzles simultaneously.

Bai and Ríos-Rull (2015) matches both business cycle moments and Backus-Smith correlation with a model of demand shock and search friction. Bacchetta and Van Wincoop (2010) resolves the forward premium puzzle with infrequent portfolio decisions. Burnside et al. (2011) explains the forward premium puzzle with investor overconfidence.

All papers mentioned above are arbitrage free, whether the financial market is complete or not. In our model, we have limits to arbitrage on intermediaries, so that the restrictions imposed by arbitrage-free models are no longer valid. Therefore, the key to understand risk premium in our model is the wedge between net worth and deposits of intermediaries.

The second strand of literature considers the role of financial market frictions in macro dynamics and asset prices, in both closed and open economies. The seminal work of Bernanke and Gertler (1989), Kiyotaki and Moore (1997), and Bernanke et al. (1999) build insightful yet tractable frameworks to study the macroeconomic effect of financial frictions. Mendoza (2010) shows that real shocks can be amplified by financial frictions, leading to sudden stops and financial crisis. Jermann and Quadrini (2012) emphasizes the importance of financial shocks in understanding both the macro economy and firms' capital structure. Gertler and Kiyotaki (2010) and Gertler and Karadi (2011) provide models suitable for analyzing the effect of unconventional policies. Li (2013) studies asset prices in this framework. As for the asset pricing literature, Brunnermeier and Pedersen (2009), Garleanu and Pedersen (2011) are examples of margin-based asset pricing models.

Financial frictions have been shown to be important in open economies. Gabaix and Maggiori (2015) builds a model in which imperfect financial markets create global liquidity and determine

exchange rates. Their model is stylized and flexible in addressing various open economy issues. Our model differs from theirs in that the role of financial frictions in their model is to impede consumption risk sharing across countries, while in our model the main driving force of exchange rate dynamics is the idiosyncratic risk associated with local intermediaries. Our model is calibrated to data and succeeds in explaining the exchange rate puzzles quantitatively. Our work is also related to Maggiori (2011), who develops a model featuring different risk-bearing capacities in different countries to explain the global imbalance and international monetary system. The extension of Gertler and Karadi (2011) into open economies includes Dedola et al. (2013), which studies the transmission of financial shocks. Kim (2015) further extends it into a two-good model and makes an attempt to explain the disconnect between consumption growth differential and exchange rate change. Our paper also attempts to explain the forward premium puzzle as well as the volatility puzzle.

2 Exchange Rates and Financial Institutions

We sketch the basic structure of the foreign exchange market in this section. There have been tremendous changes in many aspects of the foreign exchange market in the recent three decades, including the use of electronic trading systems, the increase of foreign exchange transactions between financial institutions, etc. We describe the common features of the market across time. For more details about the institution details of the foreign exchange market, see Osler (2008) and King et al. (2011).

The foreign exchange market is the largest financial market in the world, with daily trading volume exceeding five trillion dollars in 2013, according to the 2013 BIS triennial survey. The foreign exchange market is a two-tier market, including the inter-dealer market and dealer-customer market. Most of the inter-dealer transactions are making the market at very high frequencies. According to Bjønnes and Rime (2005), the half-life of inventory for dealers is between 1 to 30 minutes and dealers usually end the day with small amount of inventory. These transactions are not considerations of our model.

The second tier is the dealer-customer market, in which transactions take place between dealers and customers. Main categories of customers include financial customers, corporate customers, and retail customers. Retail customers account for a very small fraction; therefore we do not study their behavior in our paper. Financial customers can be divided into two groups: real money investors and levered investors. Real money investors include mutual funds, pensions funds, endowments, and so on, which do not take much leverage and adjust less frequently on their portfolios. Levered investors include non-dealer commercial banks, hedge funds and commodity trading advisors, and so on. They take high leverages and actively adjust their portfolios. Apart from these customers,

dealers also take speculative positions, with horizons from one day to three months (Sager and Taylor, 2006). Speculative positions are constrained for reasons such as risk management and avoidance of excess risk taking for each trader.

Corporate customers trade for real purposes, such as production, investment, and dividend payout. The size of corporate transactions is small relative to financial transactions. Table 1 shows the portion of transactions implemented by different entities from 1998 to 2013 at triennial frequency, reported by the BIS triennial survey. The portion of nonfinancial transactions account for no more than 20% of all turnovers, and it has been decreasing in the recent decades. Meanwhile, there are increasing turnovers associated with nondealer financial institutions, rising from 17% in 1998 to 53% in 2013. The 2013 version of the BIS triennial survey makes a detailed split of nondealer financial institutions into nonreporting banks (24%), institutional investors (11%), hedge funds and PTFs (11%), official sector (1%), and other institutions (6%). Nonreporting banks, institutional investors, hedge funds, and PTFs are the major participants. Furthermore, as reported by the Bureau of Economic Analysis, financial institutions excluding central bank acquired 78% of US foreign claims from 2012 to 2015.

Given these facts, it is important for us to understand the behavior of financial institutions, especially those levered speculative investors, to explain exchange rates.

3 The Model

There are two countries in the economy, US and UK, each endowed with a unit measure of households and a Lucas tree. Fruits from the two trees differ. In both countries, each household sends out a manager to operate the intermediary it owns. Households deposit in local intermediaries. Intermediaries combine deposits and their own net worth to invest in risky assets, including the local Lucas tree and an international bond. Intermediation is imperfect, since the intermediaries in each bank face a leverage constraint, whose tightness is determined by the portfolio volatility faced by the bank through value-at-risk constraint. At the end of each period, a fixed fraction of intermediaries exit the market and rebate back their net worth to their owners, while the same measure of new intermediaries is set up with some initial funds to keep the measure of intermediaries stationary. The structure of intermediaries is similar to Gertler and Kiyotaki (2010).

We describe the behavior of households and intermediaries in detail in the following subsections.

3.1 Households

Households in US and UK are endowed with a Lucas tree with different fruits, X for US and Y for UK. They follow cointegrated processes:

$$\begin{aligned} \log X_{t+1} - \log X_t &= \mu + \tau(\log Y_t - \log X_t) + \sigma_{X,t+1} \varepsilon_{X,t+1} \\ \log Y_{t+1} - \log Y_t &= \mu - \tau(\log Y_t - \log X_t) + \sigma_{Y,t+1} \varepsilon_{Y,t+1} \end{aligned} \quad (1)$$

Volatilities are stochastic, following:

$$\sigma_{X,t+1}^2 = (1 - \rho_\sigma) \bar{\sigma}^2 + \rho_\sigma \sigma_{Xt}^2 + \eta_{X,t+1}, \quad \sigma_{Y,t+1}^2 = (1 - \rho_\sigma) \bar{\sigma}^2 + \rho_\sigma \sigma_{Yt}^2 + \eta_{Y,t+1} \quad (2)$$

The two goods aggregate into a composite consumption for agents in both countries. The aggregator takes the form of constant elasticity of substitution:

$$C = [(1 - \alpha)C_X^{\frac{\sigma-1}{\sigma}} + \alpha C_Y^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}}, \quad C^* = [(1 - \alpha)C_Y^{*\frac{\sigma-1}{\sigma}} + \alpha C_X^{*\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}}$$

C_X, C_Y are consumption of X and Y for US households, while variables with an asterisk refer to the UK counterpart. Households in US and UK put different weights on X and Y with consumption home bias, captured by α , typically smaller than 0.5. σ is the price elasticity of substitution between X and Y. The composite good of US households is in dollars (as numeraire), while the composite good of UK households is in pounds. The price of pounds over dollars is defined to be the real exchange rate Q_t . An increase in Q means an appreciation of the UK pound and a depreciation of the US dollar.

In every period, given composite consumption of C, C^* and prices P_X, P_Y , households choose how much X and Y to consume. US households solve the intratemporal optimization problem:

$$\begin{aligned} &\min_{C_X, C_Y} P_X C_X + P_Y C_Y \\ &s.t. : C = [(1 - \alpha)C_X^{\frac{\sigma-1}{\sigma}} + \alpha C_Y^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}} \end{aligned}$$

The allocation between X and Y are solved as:

$$C_X = \frac{C \left(\frac{P_X}{P_Y} \frac{\alpha}{1-\alpha}\right)^{-\sigma}}{P_Y + P_X \left(\frac{P_X}{P_Y} \frac{\alpha}{1-\alpha}\right)^{-\sigma}}, \quad C_Y = \frac{C}{P_Y + P_X \left(\frac{P_X}{P_Y} \frac{\alpha}{1-\alpha}\right)^{-\sigma}} \quad (3)$$

Similarly, for UK households:

$$C_X^* = \frac{C^* \left(\frac{P_X}{P_Y} \frac{\alpha}{1-\alpha}\right)^{-\sigma} Q}{P_Y + P_X \left(\frac{P_X}{P_Y} \frac{\alpha}{1-\alpha}\right)^{-\sigma}}, C_Y^* = \frac{C^* Q}{P_Y + P_X \left(\frac{P_X}{P_Y} \frac{\alpha}{1-\alpha}\right)^{-\sigma}} \quad (4)$$

The prices UK households face in UK pound are $\frac{P_X}{Q}, \frac{P_Y}{Q}$.

All households have identical Constant Relative Risk Aversion (CRRA) preference over their composite goods with risk aversion γ . A fraction α_t of the Lucas tree goes to the households as nontradable income, while the remaining are capitalized in the equity market and paid out as dividends. Households are not allowed to hold equities directly. This assumption is justified by the fact that a large fraction of US households do not participate in the equity market (Vissing-Jørgensen, 2002) or frequently adjust their portfolios (Chien et al., 2012). Nontradable income can also be interpreted as capital income from infrequently adjusted portfolios.

Households solve a standard intertemporal optimization problem:

$$\max_{C_t, D_{t+1}} E \sum_{t=0}^{\infty} \frac{C_t^{1-\gamma} - 1}{1-\gamma}$$

$$s.t. : C_t + D_t = \alpha_t P_{X_t} X_t + R_{t-1} D_{t-1} + \Pi_t$$

D_t is the deposit by households into intermediaries at time t , while $D_{t-1} R_{t-1}$ is the repayment from intermediaries of principal and interest. Π_t is the net lump-sum payout from the intermediaries that exit the market, which will be specified later. Euler equations hold for households in both countries:

$$E_t \beta \left(\frac{C_{t+1}}{C_t}\right)^{-\gamma} R_t = 1, \quad E_t \beta \left(\frac{C_{t+1}^*}{C_t^*}\right)^{-\gamma} R_t^* = 1 \quad (5)$$

3.2 Intermediaries

Each intermediary is owned by a household, and faces a portfolio choice problem on how many deposits to take and how many equities and international bonds to purchase. We exclude the holding of foreign equities by intermediaries for two reasons. First, in most countries' portfolios, domestic equities account for a very large fraction (home equity bias, French and Poterba, 1991). Second, this assumption simplifies our analysis since we avoid indeterminacy of asset holdings at the deterministic steady state when assets are perfect substitutes (Devereux and Sutherland, 2011), while not losing the economic content of the model.

Intermediation is imperfect because managers of intermediaries are subject to agency frictions,

leading to a reduced-form leverage constraint on intermediaries in both countries: ¹

$$V_t \geq \theta_t(Z_t s_t + d_{It}), \quad V_t \geq \theta_t^*(Z_t^* s_t^* - \frac{d_{It}}{Q_t}) \quad (6)$$

V_t, V_t^* are the market value of an intermediary in US and UK. Z_t, Z_t^* are equity prices in both countries, s_t, s_t^* are the share of equities and d_{It} is the holding of the international bond by US intermediaries. Lower case letters refer to variables associated with a single intermediary, while their upper case counterparts refer to the aggregate variables. The international bond is denominated in US dollars, reflecting the exorbitant privilege of the US dollar since the breakdown of the Bretton-wood system (Eichengreen (2010)). International short positions are not subject to the leverage constraint, since intermediaries as foreign exchange speculators mark their position to the market with frequent position clearing. ² In other words, they have priority in seizing the proceeds of investment. θ_t and θ_t^* measures the tightness of leverage constraint faced by intermediaries, which are linked to the portfolio volatility of intermediaries. We call them “value-at-risk” (VaR) in our model, expressed as:

$$\theta_t = \sqrt{a^2 + c * var_t R_{t+1}^P}, \quad \theta_t^* = \sqrt{a^2 + c * var_t R_{t+1}^{P*}}$$

R_{t+1}^P is the portfolio return of US intermediaries, while the UK counterpart is R_{t+1}^{P*} , given as follows:

$$R_{t+1}^P = \frac{Z_t S_t}{Z_t s_t + d_{It}} R_{S,t+1} + \frac{d_{It}}{Z_t s_t + d_{It}} R_{It} \equiv \omega_t R_{S,t+1} + (1 - \omega_t) R_{It}$$

$$R_{t+1}^{P*} = \frac{Z_t^* s_t^*}{Z_t^* s_t^* + d_{It}^*} R_{S,t+1}^* + \frac{d_{It}^*}{Z_t^* s_t^* + d_{It}^*} \frac{Q_t R_{It}}{Q_{t+1}} \equiv \omega_t^* R_{S,t+1}^* + (1 - \omega_t^*) \frac{Q_t R_{It}}{Q_{t+1}}$$

ω_t, ω_t^* are the portfolio weight allocated to local equities by US and UK intermediaries. $R_{S,t+1}$ and $R_{S,t+1}^*$ are returns on investing in local equities, R_{It} is the return on the international bond in dollars. Only UK intermediaries face exchange rate risk. a and c are two constants. c governs how intermediaries’ funding conditions are affected by portfolio volatility, and a captures leverage restrictions caused by any other time-invariant frictions. ³

Since intermediaries face intermediation frictions, they have the incentives to accumulate net worth to get out of the constraints. Each intermediary has probability $1 - p$ to exit the market for exogenous reasons, so that intermediaries will not accumulate enough net worth to grow out of the

¹Ideally, our leverage constraint should be imposed on book leverage, but using book leverage will make the model nonstationary and impossible to solve. Therefore, we use market leverage as a proxy. For distinction between book leverage and market leverage, see Adrian and Shin (2014).

²Assuming a certain fraction of international liabilities being subject to constraint can be easily incorporated into our model. As long as the fraction is not too small, it will not change our result qualitatively.

³Technically, $a > 0$ will enable us to solve the model with perturbation methods.

leverage constraint. Upon exit, intermediaries rebate all their net worth to the households, and the managers return to their households. In the meantime, these households each will send out new managers and establish new intermediaries with some startup funds to initiate their operation. Each new intermediary is endowed with ξ fraction of the average net worth of current incumbents. The value function of a representative intermediary can be written recursively:

$$V(s_t, d_t, d_{It}) = \max_{s_{t+1}, d_{t+1}, d_{I,t+1}} E_t \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} [(1-p)N_{t+1} + pV(s_{t+1}, d_{t+1}, d_{I,t+1})]$$

$$s.t. : n_{t+1} = Z_{t+1}s_{t+1} + d_{I,t+1} - d_{t+1}$$

$$V_t \geq \theta_t (Z_t s_t + d_{It})$$

$V(s_t, d_t, d_{It})$ is the value of the intermediary at the end of period t , with the holding of domestic equity, international bond and deposit as state variables. $\beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma}$ is the stochastic discount factor of households. If the intermediary exits, it pays out its net worth n_{t+1} . If not, it continues to operate and choose the holding of assets and liabilities, with value function $V_{t+1}(s_{t+1}, d_{t+1}, d_{I,t+1})$. The first constraint is the balance sheet identity, with left-hand side the intermediary's net worth and right-hand side the intermediary's assets net of liabilities. The second constraint is the leverage constraint as discussed before. The dynamics of net worth for a single intermediary is given by:

$$n_{t+1} = R_{S,t+1}Z_t s_t - R_t d_t - R_{It} d_{It}$$

where $R_{S,t+1} = \frac{Z_{t+1} + (1-\alpha_t)P_{Xt}X_t}{Z_t}$ is the return to holding domestic equities. Following Gertler and Kiyotaki (2010), we guess the value function is linear in all three state variables, which will be verified later. Suppose it has the following form:

$$V_t = v_{St}Z_t s_t + v_{It}d_{It} - v_t d_t$$

Assigning λ_t and ψ_t to be the Lagrangian multipliers to the two restrictions, we can obtain the first order conditions:

$$1 - p + p v_{St} + \lambda_t - \psi_t \theta_t = 0$$

$$1 - p + p v_{It} + \lambda_t - \psi_t \theta_t = 0$$

$$1 - p + p v_t + \lambda_t = 0$$

From these three first order conditions, we have our first key result:

$$v_{St} = v_{It} \geq v_t \tag{7}$$

When the leverage constraint does not bind, all three of them are equal. This is the case where the marginal benefit of investing in both risky assets is the same as the marginal cost of taking deposits. When the leverage constraint binds, the marginal benefit of investing in risky assets are still identical, both larger than the marginal cost of taking deposits. Absent the constraint, intermediaries still have incentives to take more deposits, but they are constrained. The key determinant of whether the leverage constraint binds or not is the net worth of the intermediaries. If they have ample net worth, they will exhaust investment opportunities before they hit the constraint. In the remaining part of the paper, I will use the notation v_{S_t} to replace v_{I_t} whenever it shows up.

Next, we verify the linear value function. Plugging back the value functions into the Bellman equation, and using the evolution of net worth, we derive expressions for these time-varying coefficients on the state variables:

$$v_{S_t} = E_t \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} (1 - p + p\theta_{t+1}\phi_{t+1}) R_{S,t+1} = E_t \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} (1 - p + p\theta_t\phi_t) R_{I_t} \quad (8)$$

$$v_t = E_t \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} (1 - p + p\theta_{t+1}\phi_{t+1}) R_t \quad (9)$$

ϕ_t is the book leverage of US intermediaries, defined to be:

$$\phi_t \equiv \frac{Z_t S_t + D_{I_t}}{N_t}$$

UK intermediaries face the same problem. The only difference is with the international bond. US intermediaries do not face exchange rate risk in trading international bond, while UK intermediaries do. The pricing equation of the international bond for UK intermediaries is:

$$v_{S_t}^* = E_t \beta \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\gamma} (1 - p + p\theta_t^* \phi_t^*) R_{I_t} \frac{Q_{t+1}}{Q_t} \quad (10)$$

3.3 Aggregation

We already specify the problem as well as the optimality conditions of any single intermediary. The linearity of the model simplifies aggregation. Since we have a representative intermediary, each intermediary has the same optimality conditions and makes the same choice. We can directly replace individual variables n_t, s_t, d_t, d_{I_t} and their foreign counterparts $n_t^*, s_t^*, d_t^*, d_{I_t}^*$ with the aggregate variables $N_t, S_t, D_t, D_{I_t}, N_t^*, S_t^*, D_t^*, D_{I_t}^*$ in the flow of funds constraints, leverage constraints, and optimality conditions.

The net worth dynamics in aggregate is different from the one for a single intermediary, due to the

entry and exit. The aggregate dynamics is given by:

$$N_{t+1} = (1 - p + \xi)(R_{S,t+1}Z_t S_t - R_t D_t + R_{It} D_{It}) \quad (11)$$

$$N_{t+1}^* = (1 - p + \xi)(R_{S,t+1}^* Z_t^* S_t^* - R_t^* D_t^* + R_{It}^* D_{It}^* \frac{Q_t}{Q_{t+1}}) \quad (12)$$

3.4 Equilibrium

Lastly, we have market clearing conditions for good markets and asset markets.

$$C_{Xt} + C_{Xt}^* = X_t, \quad C_{Yt} + C_{Yt}^* = Y_t, \quad S_t = S_t^* = 1, \quad D_{It} + D_{It}^* Q_t = 0 \quad (13)$$

A competitive equilibrium consists of a sequence of allocations $\{C_t, C_t^*, D_t, D_t^*, N_t, N_t^*, S_t, S_t^*, D_{It}, D_{It}^*, \phi_t, \phi_t^*\}$, a sequence of prices $\{R_t, R_t^*, P_{Xt}, P_{Yt}, Z_t, Z_t^*, Q_t, R_{It}, R_{It}^P, R_{It}^{*P}\}$, a sequence of volatility $\{\theta_t, \theta_t^*, \text{var}_t R_{t+1}^P, \text{var}_t R_{t+1}^{*P}\}$, and a sequence of intermediary valuation $\{v_{St}, v_t, v_{St}^*, v_t^*\}$ such that:

- (i) Households in both countries solve their optimization problem;
- (ii) Intermediaries in both countries solve their constrained optimization problem;
- (iii) Good markets (X and Y) clear;
- (iv) Asset markets (Deposit, Equity, and International bond) clear.

3.5 Asset Prices

In this model, intermediaries play the central role in pricing all the assets. The asset pricing equations can be written as:

$$E_t \Omega_{t,t+1} R_{S,t+1} = E_t \Omega_{t,t+1} R_{It} = v_{St} \quad (14)$$

$$E_t \Omega_{t,t+1} R_t = v_t \quad (15)$$

where:

$$\Omega_{t,t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} (1 - p + p \theta_{t+1} \phi_{t+1})$$

Due to limits of arbitrage, the stochastic discount factor that prices equities and the international bond $\frac{\Omega_{t,t+1}}{v_{St}}$ is different from the one that prices deposits $\frac{\Omega_{t,t+1}}{v_t}$. The difference depends on the wedge between the marginal benefit of investment and the marginal cost of taking deposits, which essentially relies on the tightness of the leverage constraint.

The stochastic discount factor has three components: consumption growth, the product of leverage ϕ_t and VaR θ_t , and the marginal value of net worth or the marginal cost of taking deposits. Intermediaries assign higher value to their net worth at times when they can take a larger leverage. If

we assume the leverage constraint binds and rewrite equation (6), we have:

$$V_t = \theta_t \phi_t N_t$$

Thus, $\theta_t \phi_t$ measures the conversion rate of one unit of net worth to market value of the intermediary.

4 Exchange Rate Puzzles

4.1 Backus-Smith Puzzle

Denote the US stochastic discount factor (SDF) to be $M_{t,t+1}$, and the UK SDF $M_{t,t+1}^*$. Consider the return of US risk-free bond R_t , the following two equations hold:

$$E_t M_{t,t+1} R_t = E_t M_{t,t+1}^* R_t \frac{Q_t}{Q_{t+1}} = 1$$

Q_t is the price of UK goods in terms of US goods, consistent with the notation in section 3. If the financial market is complete, then the equation holds state by state. Therefore:

$$\Delta q_{t+1} = m_{t,t+1}^* - m_{t,t+1}$$

Lower-case letters are natural logarithms of variables. If we assume a constant relative risk aversion utility function, following the convention of business cycle analysis, then we obtain:

$$\Delta q_{t+1} = \gamma(\Delta c_{t+1} - \Delta c_{t+1}^*)$$

Exchange rate change is proportional to consumption growth differential. Even when the financial market is incomplete, such as in the models of Heathcote and Perri (2002) and Chari et al. (2002), the correlation between Δq_{t+1} and $\Delta c_{t+1} - \Delta c_{t+1}^*$ is close to 1. This is inconsistent with the weak correlation between US and a number of developed economies (For example, the correlation is -0.21 between US and UK nominal exchange rate change and nominal consumption growth rate differential). This puzzle is named after Backus and Smith (1993).

In our model, we have the following Euler equations for intermediaries in both countries:

$$E_t \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \frac{(1-p + p\theta_{t+1}\phi_{t+1})}{v_{St}} = E_t \beta \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\gamma} \frac{(1-p + p\theta_{t+1}^*\phi_{t+1}^*)}{v_{St}^*} \frac{Q_{t+1}}{Q_t}$$

Following the logic in standard international macro models, in which the correlation between ex-

change rate change and relative log stochastic discount factors are close to 1, we have:

$$\text{corr}(\Delta q_{t+1}, -\gamma(\Delta c_{t+1} - \Delta c_{t+1}^*) + \log\left(\frac{1-p+p\theta_{t+1}\phi_{t+1}}{1-p+p\theta_{t+1}^*\phi_{t+1}^*}\right) + \log\frac{v_{St}}{v_{St}^*}) \approx 1$$

Exchange rate change is correlated to consumption growth differential plus two extra terms: one capturing the relative financial conditions and leverage, the other measuring the relative marginal value of the investment. The latter two terms dominate so that consumption growth differential seems to be disconnected with exchange rate change.

The response of consumption and exchange rate to endowment and volatility shocks also helps us understand the disconnect.⁴ Upon an endowment shock in the US, US consumption increases relatively, while the US dollar depreciates. When the US experiences a positive volatility shock, US consumption increases relatively as well, but the US dollar appreciates. The two forces at play offset with each other and generate the disconnect phenomenon.

4.2 Forward Premium Puzzle

Uncovered Interest Rate Parity suggests that if US has a higher interest rate than UK, we would expect the US dollar to depreciate in the next period, so that investing in US and UK deliver similar payoffs. However, this parity condition is rejected by data. We regress a US investor's currency excess return of UK pounds on interest rate differential between UK and US Treasury bills, and obtain a regression coefficient of 1.4, being significantly different from 0. For many other countries, the coefficients are all larger than 1. This result shows that the currency with the higher interest rate tends to further appreciate. In other words, currencies are mostly at a forward premium. Thus the puzzle is called the "forward premium puzzle".

In our model, volatility shocks mainly explain the failure of uncovered interest rate parity. When the US experiences a positive volatility shock, the US interest rate is lower and its leverage constraint gets tighter. The wedge between investing and borrowing becomes larger. Expected exchange rate change in the next period will make investing in home equity and borrowing from abroad equivalent. When US intermediaries have a larger wedge, the US dollar is expected to depreciate.

We can also understand the forward premium puzzle from the intermediaries' perspective. From the Euler equations for international bond for both intermediaries:

$$E_t \Delta q_{t+1} \approx E_t [(\log \Omega_{t+1}^* - \log v_{St}^*) - (\log \Omega_{t+1} - \log v_{St})]$$

⁴In Section 5, we will discuss the impulse response functions to both endowment and volatility shocks in detail. IRFs are shown in Figure 1.

If we ignore the higher than first order moments, the expected exchange rate can be reduced to:

$$E_t \Delta q_{t+1} \approx (v_{St} - v_t + r_t) - (v_{St}^* - v_t^* + r_t^*)$$

when the US experiences a positive volatility shock, $r_t < r_t^*$. Since US intermediaries are more constrained in taking leverage, the wedge is larger for US, $v_{St} - v_t > v_{St}^* - v_t^*$. If the wedges do not exist, we have uncovered interest rate parity. However, in our model, the wedge dominates interest rate difference in driving exchange rates.

In this model, there are no such investors facing a pure currency speculative opportunity as in the UIP regression. Intermediaries invest in the international bond at rate R_{It} , not the deposit rate R_t or R_t^* . In reality, most of the currency trading occurs not for speculating on Treasury bills, but instead on foreign long-term bonds, equities, or more sophisticated global financial products. Our model can possibly explain the uncovered long-term bond parity condition (Lustig et al., 2015) and uncovered equity parity condition (Curcuro et al., 2014). More work needs to be done to validate this possible explanation.

4.3 Exchange Rate Volatility Puzzle

Most international macro models cannot generate volatile exchange rates as in the data. On the other hand, Brandt et al. (2006) shows that compared to standard arbitrage-free asset pricing models with sufficiently volatile stochastic discount factors (SDF), exchange rates are too smooth.

Our model features an incomplete financial market, being closer to the international macro literature. We will show in the next section that exchange rate volatility in our model is more volatile than that in most international macro models due to two reasons. First, the leverage constraint of intermediaries amplifies the fundamental volatilities into financial market volatility; second, volatility shocks make the tightness of leverage constraint time-varying, to generate even more volatile exchange rates.

4.4 Volatility and Exchange Rates

The main driving force of exchange rates is the idiosyncratic volatility in two countries, which translates into different value-at-risk faced by intermediaries and thus different leverage. There is abundant literature about the relationship between volatility and exchange rates. Bekaert (1996) and Bansal (1997) show that in a complete market setting with affine linear stochastic discount factors, stochastic volatility is necessary to violate UIP. Bansal and Shaliastovich (2013) also attribute time variation in currency premia to volatility fluctuations.

Our model is different from theirs. The channel volatility affects exchange rates in our model is

through affecting the behavior of intermediaries, inducing time-varying leverage constraint. Time-varying quantity of risk also exists, but is very weak. Our model is a standard general equilibrium model with CRRA preference, which will lead to fairly small second order terms, as is well known since Mehra and Prescott (1985). Therefore, we are proposing a new mechanism to link volatility to exchange rates, in complementary with the vast existing literature.

5 Quantitative Results

5.1 Calibration

We calibrate the model at quarterly frequency. Benchmark parameter values are reported in Table 2. Three parameters commonly used in macro models are chosen ad hoc. Time discount factor, labor income share, and risk aversion are set to be 0.995, 0.67, and 2, respectively. Following Colacito and Croce (2013), we have the degree of consumption home bias α to be as small as 0.03, and we impose a weak cointegration relationship between the two endowment processes with the error correction parameter τ to be 0.0005. The elasticity of substitution between the two goods is 0.9, following estimates of various studies, including Stockman and Tesar (1995) and Heathcote and Perri (2002).

We set up a growth economy to capture the effect of low-frequency component on asset prices, following the convention of macro asset pricing literature, but we assume the average growth rate to be 0 in order to match the low interest rate level. The tension between consumption growth and risk-free rate is a long-standing puzzle (risk-free rate puzzle, Weil, 1989). This paper does not attempt to provide any new insight on the resolution of the risk-free rate puzzle. In our model, only second order moments of consumption and output growth matter for results, instead of their level. Volatility and cross-country correlation of endowment match the data counterpart in the US (US-UK for correlation) from 1973 to 2015.

The stochastic volatility processes are the main driving forces of our model. Volatility is a persistent variable, so we calibrate its persistence to be 0.98. The mean of endowment growth volatility is calibrated to the data counterpart from 1973 to 2015, and the volatility of volatility shock is assumed to be half of the mean of endowment growth volatility. The two parameters determining the relationship between VaR and volatility, a, c are to match the mean and volatility of intermediary leverage. We follow the definition by Krishnamurthy and Vissing-Jorgensen (2015) of the “financial sector” of all institutions supplying short-term debt. ⁵Quarterly assets and liabilities data for

⁵These institutions include US-Chartered Depository Institutions, Foreign Banking Offices in US, Banks in US-Affiliated Areas, Credit Unions, Money Market Mutual Funds, Issuers of Asset-Backed Securities, Finance Companies, Mortgage Real Estate Investment Trusts, Security Brokers and Dealers, Holding Companies and Funding Corporations.

each type of financial institution are from Flow of Funds, published by the Federal Reserve Board. Payout rate $1 - p$ and initial funds for new intermediaries ξ are set to be 0.87 and 0.03, to make the constraint binding in most cases and keep the net payout rate at 10% of net worth of the existing intermediaries.

We make two ad hoc normalizations in the benchmark case. We assume the fluctuations of both shocks are independent across countries, and volatility shocks and endowment shocks are orthogonal to each other. With zero correlated endowment process, our model produces cross-country correlation of output and consumption growth similar to the data, due to the correlation of goods price. In our model, it is the idiosyncratic volatility that moves the relative tightness of leverage constraints, which in turn leads to cross-border borrowing and lending. Fluctuations in the common component of volatility do not affect the incentive for intermediaries to borrow or lend internationally, so they are abstracted from the model.

5.2 Impulse Response Functions

Figures 1 and 2 report the impulse responses of different US and UK variables to a one-standard-deviation US positive endowment shock and volatility shock.

When US has a one standard deviation positive endowment shock, the dividend payment of the Lucas tree increases for US investors and consumption growth increases in the US. The price of the US tree increases and the net worth of US intermediaries are strengthened. As a result, US intermediaries can borrow more, which further pushes up the price of the tree. The amplification mechanism explains the relative larger asset price change with respect to the change in the dividend. The marginal value of investing in the tree and the marginal cost of borrowing both decline, as does the wedge between the two. This can be reflected in the return on the international bond. In this scenario US intermediaries are lending to the UK intermediaries. The shock in the US is transmitted to UK with higher consumption growth rate in UK as well as a higher price of UK goods. The price of the UK tree also increases, so that all intermediary variables in UK move in the same direction as in the US. The synchronization of the intermediary balance sheet has been studied in Dedola et al. (2013). Due to more supply of the US good X, the price of X decreases and the US dollar depreciates. The leverage of intermediaries decreases, because the strengthening of net worth dominates the expansion of balance sheet in determining leverage. Interest rate changes in the US and UK in this case are intuitively ambiguous. The higher endowment creates more supply of deposit, while the loosening of leverage constraint generates more demand. The direction of interest rate movement depends on which force dominates. Under our parameterization, the US interest rate increases, and the UK interest rate decreases.

The more interesting channel in our model can be seen in the impulse responses to a one stan-

standard deviation volatility shock. The volatility shock is amplified through the same feedback loop between net worth, borrowing and asset price illustrated previously. The greater volatility in the financial market will tighten intermediaries' leverage constraint, which forces them to sell part of their asset to satisfy the constraint. The same feedback loop makes the price of the US tree decline further. Since the US intermediaries borrow less, US households' consumption increases, and US interest rate decreases. The marginal benefit of investing in the Lucas tree as well as the marginal cost of borrowing both increase, and so does their difference, reflected in the increase of international bond return. US intermediaries are willing to borrow from UK intermediaries so that some of resources are transferred from UK to US. The price of the UK tree also decreases and all variables of UK intermediaries move in the same direction as US intermediaries. The US dollar is expected to depreciate.

5.3 Quantitative Results

Table 3 presents the quantitative results of the model.

Panel A lists country-specific moments in the model, as well as US data counterparts of these moments. Output volatility, leverage mean, leverage standard deviation, and risk-free rate in the US are targets for calibrating the mean and volatility of the two exogenous processes. Financial sector dividend yield is the moment used to calibrate the exit probability or payout ratio. The quarterly risk-free deposit rate is about 0.4% in the model, higher than 0.23% in the data from 1973 to 2015. However, if we exclude the period after the financial crisis, in which the real interest rate is known to be negative, the average interest rate will be as high as about 0.5%. Therefore, we target the interest rate to be 0.4%. Quarterly equity return in the model is 1.6%, close to 1.4% in the data. The model does not generate enough volatility in equity return. The standard deviation of equity return in the model is only 1.6%, about 20% of 8.5% in the data.

Panel B shows the correlation and autocorrelation moments. Though the correlation between two endowment shocks is zero, the correlations between output growth and consumption growth across the two countries are close to their data counterpart. This is because of the correlation of their prices. In our model, consumption growth is more correlated than output growth, being inconsistent with the data (Backus et al., 1992).

Panel C shows that our model can resolve the three exchange rate puzzles quantitatively. Exchange rate volatility is 3.8% per quarter, close to 5.2% in the data, being higher than most international macro models. Consumption growth differential is disconnected with exchange rate change, due to the augmented Euler equation shown in section 4.1. Finally, the UIP coefficient is larger than 1. Though there is a bit of overshooting in UIP coefficient, the model can explain why low-interest-rate currencies tend to further depreciate instead of appreciating.

6 Empirical Implications

Our model sheds light on the determination of exchange rate by the funding condition fluctuations originated from time-varying financial market volatility. We implement two empirical tests on our implications. First, we also show that the year-over-year growth rate of US aggregate financial commercial paper has predictive power in explaining bilateral exchange rates between the dollar and major foreign currencies. Aggregate US financial commercial paper serves as a measure of funding conditions in the US. Further, we control for different indicators of credit demand and find the predictive power remains. Second, we find that global realized exchange rate volatility in the past 12 months also has predictive power in bilateral exchange rates. The finding supports our model that financial market volatility matters in exchange rate determination.

6.1 Data

6.1.1 Exchange Rates

We have 12 countries in our sample, including Australia, Belgium, Canada, Denmark, France, Germany, Italy, Japan, New Zealand, Switzerland, Sweden, and the UK. We calculate the log difference in nominal exchange rates in each currency with respect to US for both monthly and quarterly frequency, from 1991 to 2015.

6.1.2 Measuring Financial Conditions

Commercial papers are one of the major forms of external funding used by financial institutions in the US, as illustrated by Adrian and Shin (2010). We measure US financial conditions by both (one-sided log detrended) level and growth rate of US outstanding commercial paper for financial business (commercial paper for short), published by Flow of Funds. Our data span from January 1991 to December 2015 at monthly frequency. The measurement is in line with Adrian et al. (2015). Further, we control for several variables that represent investment opportunities, including investment-capital ratio, stock dividend yield, stock market return, and output growth. The control variables are from National Income and Product Accounts and CRSP.

6.2 Predictive Regression with US Commercial Paper

In Table 4, we report results for univariate predictive regression of bilateral exchange rates on year-over-year US financial commercial paper growth.⁶ Standard errors are calculated using Hansen and

⁶If we use monthly, quarter-over-quarter growth rate or one-sided detrended US financial commercial paper, the result is qualitatively identical. These results are available upon request.

Hodrick (1980). US financial commercial paper as a measure of US funding conditions, contains predictive information of bilateral exchange rates of US against all major currencies at monthly, quarterly and annual frequencies. Higher commercial paper (easier funding conditions) predicts a depreciation of foreign currencies in the next period, which is consistent with our model prediction. For robustness, we control for four variables that are regarded as indicators of credit demand, including investment-capital ratio, dividend yield, stock market return, and GDP growth in the US, to eliminate concerns that aggregate commercial paper growth is caused by higher demand of credit. Table 5 shows the results for monthly predictive regressions.⁷

6.3 Predictive Regression with Global Foreign Exchange Volatility

Our model attributes the funding condition fluctuations to time-varying financial market volatility. The ideal measure is the volatility of intermediary portfolio volatility. However, we have no idea which assets intermediaries actually hold, and we have to find a proxy. For all intermediaries involving in FX trade, they face exchange rate risk. Therefore, the volatility of exchange rate risk is a candidate for the proxy. As US intermediaries are more active participants in the FX market, as reported by BIS, they are more exposed to exchange rate risk. Global exchange rate volatility is calculated as the simple average of realized volatility for each currency pair with US dollar in the past 12 month.⁸ Table 6 reports results for predictive regressions of bilateral exchange rate and global exchange rate volatility at monthly, quarterly, and annual frequencies. An increase in global FX volatility predicts an appreciation of foreign currencies in the next period. The empirical finding is consistent with our model implications.

7 Conclusion

This paper builds a two-country endowment economy model with financial intermediaries to study the effect of financial intermediary behaviors on exchange rate dynamics. Intermediaries are subject to fluctuating leverage constraints induced by time-varying financial market volatility. We show that the fluctuations in funding conditions can potentially resolve three exchange rate puzzles: the Backus-Smith puzzle, the forward premium puzzle, and the volatility puzzle. We also find empirical evidence consistent with our model.

⁷For sake of space, we do not report the regression with controls for quarterly and annual regressions. Results are robust, and available upon request.

⁸If we take the first principal component, we can get similar results.

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Table 1: Foreign Exchange Turnovers by Counterparties

Units are in percentage point. Data source: BIS triennial survey for specific years.

	1998	2001	2004	2007	2010	2013
Reporting dealers	63	59	53	43	38.9	39
Nonfinancial customers	20	13	13	17	13.4	9
Other financial institutions	17	28	33	40	47.7	53

Table 2: Calibrated parameters

Variable	Notation	Value	Target
Discount factor	β	0.995	Standard
Home bias	α	0.03	Colacito-Croce 2013
Nontradable share	α_l	0.67	Standard
Elasticity	σ	0.9	Heathcote-Perri 2002
Risk aversion	γ	2	Standard
Mean X	μ_x	0	Risk Free Rate
Mean volatility	$\bar{\sigma}$	0.006	Output volatility
Volatility persistence	ρ_σ	0.98	Standard
Error Correction	τ	0.0005	Colacito-Croce 2013
X,Y correlation	ρ_{XY}	0	Output correlation
Volatility correlation	ρ_{η_x, η_y}	0	Normalized
Exit rate	p	0.87	Payout rate
Initial intermediary fund	ξ	0.03	Payout rate
VaR constant	a	0.36	Mean of leverage
VaR slope	c	150	Volatility of leverage

Table 3: Quantitative results

Panel A: Country specific moments			
	Home	Foreign	Data(US)
Output growth std	0.0046	0.0057	0.0052
Consumption growth std	0.0042	0.0061	0.0051
Leverage mean	9.35	9.28	9.24
Leverage std	1.46	2.85	1.60
Risk free rate	0.005	0.005	0.0023
Equity return	0.016	0.016	0.014
Equity return std	0.016	0.023	0.085
Panel B: (Auto)correlation moments			
Output growth		0.37	0.34
Consumption growth		0.48	0.30
Panel C: Exchange rate moments			
	Model	Data(US/UK)	
FX rate change sd	0.038	0.052	
UIP coefficient	3.64	1.40	
Backus Smith correlation	0.11	-0.21	

Table 4: Predictive regression of exchange rates on US financial commercial paper

We report results for the predictive regression of bilateral exchange rate on US aggregate financial commercial paper year-over-year growth rate at monthly, quarterly and annual frequency. Data covers from 1991 to 2015. The t-statistics are reported in the parentheses, based on heteroscedasticity and autocorrelation consistent standard errors. * significant at 10% confidence level, ** significant at 5% confidence level.

	AUD	BEF	CAD	CHF	DEU	FRF	GBP	ITY	JPN	NZD	NOK	SWE
Monthly	-0.05**	-0.02	-0.01	-0.02	-0.02	-0.02	-0.05**	-0.03*	-0.02	-0.02	-0.02	-0.01
	(-3.25)	(-1.54)	(-1.05)	(-1.50)	(-1.27)	(-1.56)	(-2.91)	(-1.84)	(-1.50)	(-1.56)	(-1.30)	(-1.00)
R^2	0.04	0.01	0.00	0.01	0.00	0.01	0.04	0.01	0.00	0.01	0.00	0.00
Quarterly	-0.13**	-0.06*	-0.05*	-0.06	-0.05	-0.06	-0.14**	-0.09**	-0.07**	-0.06	-0.05	-0.04
	(-3.10)	(-1.64)	(-1.70)	(-1.58)	(-1.33)	(-1.64)	(-3.05)	(-2.30)	(-2.17)	(-1.63)	(-1.28)	(-1.15)
R^2	0.08	0.02	0.02	0.02	0.01	0.02	0.10	0.03	0.03	0.02	0.01	0.01
Annual	-0.36**	-0.14	-0.16**	-0.13	-0.09	-0.14	-0.44**	-0.24**	-0.21**	-0.14	-0.10	-0.05
	(-2.97)	(-1.24)	(-2.02)	(-1.17)	(-0.82)	(-1.23)	(-3.62)	(-2.46)	(-2.55)	(-1.22)	(-0.62)	(-0.68)
R^2	0.15	0.03	0.07	0.03	0.01	0.03	0.20	0.06	0.08	0.03	0.01	0.00

Table 5: Predictive regression of exchange rates on US financial commercial paper with controls
 We report results for the predictive regression of bilateral exchange rate on US aggregate financial commercial paper year-over-year growth rate at monthly frequency. We add additional controls of investment capital ratio, dividend yield, US stock return and US GDP growth into the predictive regression. Control variables data are from Amit Goyal's website. For the sake of space, we only include the results for monthly regressions. Data covers 1991 to 2015. The t-statistics are reported in the parentheses, based on heteroscedasticity and autocorrelation consistent standard errors. * significant at 10% confidence level, ** significant at 5% confidence level.

	AUD	BEF	CAD	CHF	DEU	FRF	GBP	ITY	JPN	NZD	NOK	SWE
CP	-0.05** (-3.20)	-0.02 (-1.48)	-0.02 (-1.16)	-0.02 (-1.46)	-0.02 (-1.20)	-0.02 (-1.51)	-0.05** (-3.01)	-0.03* (-1.81)	-0.02 (-1.47)	-0.02 (-1.50)	-0.02 (-1.34)	-0.01 (-1.22)
I/K	-0.04 (-0.55)	-0.06 (-1.25)	0.02 (0.53)	-0.06 (-1.13)	-0.06 (-1.24)	-0.06 (-1.22)	0.01 (0.20)	-0.04 (-0.74)	-0.07 (-1.24)	-0.06 (-1.27)	-0.02 (-0.47)	0.08** (1.98)
R^2	0.04	0.01	0.00	0.01	0.01	0.01	0.04	0.01	0.01	0.01	0.00	0.01
CP	-0.05** (-3.29)	-0.02 (-1.38)	-0.02 (-1.42)	-0.02 (-1.37)	-0.02 (-1.61)	-0.02 (-1.41)	-0.05** (-2.95)	-0.04** (-2.06)	-0.02 (-1.43)	-0.02 (-1.40)	-0.02 (-1.24)	-0.02 (-1.46)
DP	0.00 (-0.17)	0.00 (0.25)	0.00 (-1.02)	0.00 (0.22)	-0.01 (-0.74)	0.00 (0.25)	0.00 (0.13)	-0.01 (-0.68)	0.00 (0.09)	0.00 (0.25)	0.00 (0.18)	-0.01 (-1.06)
R^2	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.00	0.00	0.00	0.00
CP	-0.05** (-3.21)	-0.02 (-1.41)	-0.01 (-1.07)	-0.02 (-1.39)	-0.02 (-1.14)	-0.02 (-1.44)	-0.05** (-2.94)	-0.03* (-1.80)	-0.02 (-1.40)	-0.02 (-1.43)	-0.02 (-1.28)	-0.01 (-1.16)
Ret	-0.03 (-0.49)	-0.07 (-1.36)	0.02 (0.42)	-0.06 (-1.24)	-0.07 (-1.38)	-0.07 (-1.32)	0.00 (0.02)	-0.04 (-0.77)	-0.06 (-1.20)	-0.07 (-1.37)	-0.03 (-0.52)	0.07* (1.72)
R^2	0.04	0.01	0.00	0.01	0.01	0.01	0.04	0.01	0.01	0.01	0.00	0.01
CP	-0.06** (-3.32)	-0.02 (-1.59)	-0.02 (-1.29)	-0.02 (-1.52)	-0.01 (-1.00)	-0.02 (-1.58)	-0.06** (-3.25)	-0.04** (-2.18)	-0.02 (-1.53)	-0.02 (-1.58)	-0.03* (-1.90)	-0.02 (-1.61)
ΔGDP	0.09 (0.45)	0.04 (0.24)	0.05 (0.42)	0.03 (0.16)	-0.06 (-0.32)	0.03 (0.17)	0.11 (0.49)	0.12 (0.71)	0.01 (0.08)	0.03 (0.18)	0.17 (1.20)	0.15 (1.35)
R^2	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.00

Table 6: Predictive Regression of Exchange Rate with Global Realized FX Volatility

We report results for the predictive regression of bilateral exchange rate on global FX volatility. Data covers from 1980 to 2015. We use daily exchange rate data to calculate the realized volatility of exchange rate change in the past 12 months in each currency pair reported in the table, and take the simple average as measure of global FX volatility. Predictive horizons include 1 month, 1 quarter and 1 year ahead. The t-statistics are reported in the parentheses, based on heteroscedasticity and autocorrelation consistent standard errors. * significant at 10% confidence level, ** significant at 5% confidence level.

	AUD	BEF	CAD	CHF	DEU	FRF	GBP	ITY	JPN	NZD	NOK	SWE
Monthly	0.02** (1.99)	0.02* (1.90)	0.01 (1.17)	0.02** (2.11)	0.02** (2.00)	0.02** (1.95)	0.01 (1.04)	0.02** (2.16)	0.02** (2.19)	0.02* (1.93)	0.02** (2.34)	0.02* (1.90)
R^2	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01
Quarterly	0.06** (2.11)	0.04* (1.82)	0.03 (1.61)	0.05** (2.19)	0.05* (1.94)	0.05* (1.90)	0.02 (1.04)	0.05** (2.12)	0.04* (1.72)	0.07** (2.26)	0.05** (2.30)	0.05** (2.01)
R^2	0.03	0.02	0.02	0.03	0.02	0.02	0.01	0.03	0.02	0.05	0.03	0.02
Annual	0.25** (4.25)	0.18* (1.69)	0.13** (3.37)	0.19** (2.54)	0.17 (1.62)	0.17* (1.71)	0.11** (1.97)	0.18* (1.76)	0.17** (2.21)	0.32** (5.97)	0.22** (3.53)	0.21** (3.76)
R^2	0.16	0.07	0.12	0.10	0.07	0.07	0.04	0.07	0.07	0.20	0.14	0.09

Figure 1: Impulse Response Functions to a Positive US Endowment Shock

Figure 1 reports the impulse responses to a positive one-standard-deviation US endowment shock. Variables include interest rate (R), equity price (Z), equity return (R_S), consumption growth (Δc), marginal value of investment for intermediaries (ν_s), marginal cost of taking deposit for intermediaries (ν) and leverage (ϕ). Impulse responses of both US and UK variables are shown in the same figure. Also, the responses of exchange rate (Q) and US position on international bond (D_I , being positive means US is borrowing from UK) are reported.

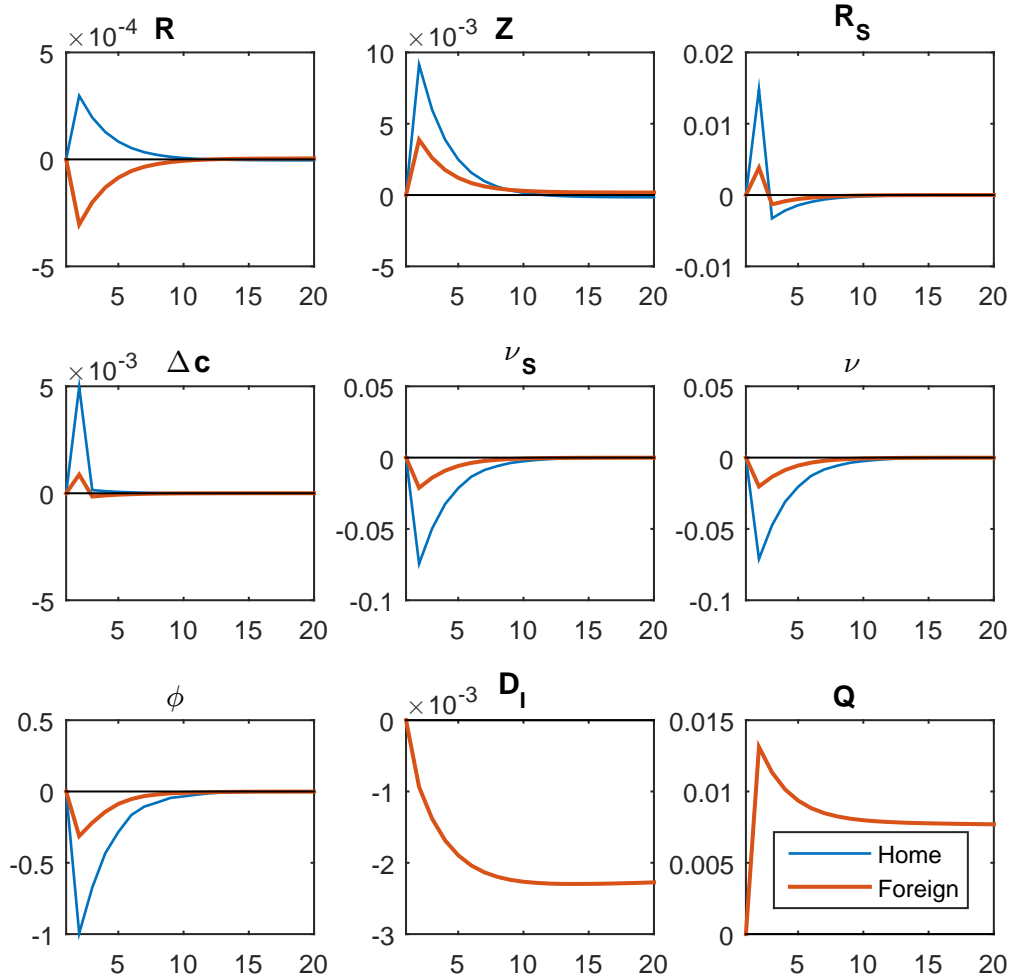


Figure 2: Impulse Response Functions to a Positive US Volatility Shock

Figure 1 reports the impulse responses to a positive one-standard-deviation US volatility shock. Variables include interest rate (R), equity price (Z), equity return (R_S), consumption growth (Δc), marginal value of investment for intermediaries (ν_S), marginal cost of taking deposit for intermediaries (ν) and leverage (ϕ). Impulse responses of both US and UK variables are shown in the same figure. Also, the responses of exchange rate (Q) and US position on international bond (D_I , being positive means US is borrowing from UK) are reported.

